A LIMNOLOGICAL REVIEW AS RELATED TO THE FOX CHAIN OF LAKES

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THE FOX CHAIN OF LAKES

WATER QUALITY SECTION
ILLINOIS STATE WATER SURVEY

FEBRUARY 15, 1966

by Ralph L. Evans

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PREFACE

Although the original request for technical assistance concerned algal growth in the Fox River, which threatened a planned and approved developmental program for that stream, it seemed that very little could be accomplished toward desired corrective measures until conditions on Fox Chain of Lakes were reviewed and a plan developed for enhancing the quality of that system's waters. On this premise the preparation of this report was undertaken. Consequently any program developed must have as its ultimate objective the improvement of water in the Fox River basin quality from the Wisconsin - Illinois Line to Ottawa, Illinois.

OF 11 recommendations

RECOMMENDATIONS

1. Arrangements should be made to insure the proper application of copper sulfate to Lake Marie, including the Grass-Marie Channel, and Petite Lake (total area 650 acres) during the 1966 bloom season. Preparations should be completed in time to permit application by May 1, 1966.

   a. Suggested responsibility for arrangement:
      Division of Waterways

   b. Suggested responsibility for supervision:
      Department of Conservation
      Natural History Survey

2. All lakes should be monitored during the period May 1 to October 1 at weekly intervals for (1) algal densities and type (2) temperature and (3) pH.

   a. Suggested responsibility for collection:
      Division of Waterways
      Lake County Health Department

   b. Suggested responsibility for identification:
      State Water Survey
      Lake County Health Department

3. Several stations on the Fox River, downstream of the Chain during the period May 1 to October 1, should be monitored at bi-weekly intervals for (1) algal densities and type and (2) temperature.

   a. Suggested responsibility for collection:
      Sanitary Water Board

   b. Suggested responsibility for identification:
      Sanitary Water Board

4. Arrangements should be made for a conference during 1966 in the vicinity of the Chain with appropriate officials of the State of Wisconsin for an exchange of views regarding improving water quality on the Fox River basin as well as exploring coordinated hydraulic schemes pertinent to overall basin development.

Suggested contact agencies:
Sanitary Water Board
Division of Waterways

5. Preliminary observations should be made during 1966 of current movements with the Chain with the expectation of using any recorded information for a more intensified investigation during 1967.

Suggested agencies: All

A study should be undertaken (of at least 2 year duration) to permit an estimate of total incoming nutrients compared with outflowing nutrients.

Suggested study agencies:
Natural History Survey
State Water Survey

7. A study should be undertaken to determine (1) nutrient accumulation in the winter months and (2) concentration of nutrients in the bottom muck, including organic content.

Suggested study agencies:
State Water Survey
Natural History Survey

8. Consideration should be given by all agencies for the inclusion in the budget of an appropriate agency or agencies sufficient funds earmarked specifically for chemical control and coordinated studies on the Fox Chain of Lakes. A request for such funds should be submitted to the legislature for the next biennium if not sooner. The preparations required for determining the amount and desired pre-legislative contacts should commence immediately.

9. An investigation should be undertaken to assess the use of other chemicals and/or biological agents for controlling blue-green algae. Field tests for evaluating the effectiveness of 2,3 DNQ as well as cost would appear to be desirable as an initial undertaking.

Suggested study agencies:
Natural History Survey
Department of Conservation

10. All recorded observations on the Chain including algal counts, temperature, pH, current movement, chemical dosage, as well as progress reports on studies should be submitted to a central agency for use in preparing an annual report of progress as well as formulating suggested procedures for the following year's activities on the Chain.

Suggested central agency:
State Water Survey

11. An individual in one of the agencies should be designated as having the responsibility for the release of newsworthy items and progress reports to the news media involving the coordinated activities of the agencies.

(13)

SUMMARY

1. Only 21% of the Fox Chain of Lakes drainage area lies within Illinois.
2. The Chain's water surface area is approximately 6400 acres and it has a mean depth of 8 feet at the normal pool elevation 736.5 m.s.l.
3. In Illinois there are 7 sewage treatment plants, serving about 28,325 persons, located on the Chain's Watershed; in Wisconsin there are 12 sewage treatment plants, serving about 61,000 persons, on the watershed.
4. The water quality of the lakes are chemically and bacteriologically satisfactory and support a desirable fish population in terms of numbers, sizes and species distribution.
5. Nuisance algal blooms have been a source of recorded complaints for at least 30 years. Apprehension has been expressed regarding the curtailment of bathing, boating, water skiing, fishing, lowering of property values, cancellation of resort trade and the impairment of the picturesque beauty of the lake waters.
6. Studies designed to determine the interrelationship of the many factors contributing to the ecological system of the Fox Chain of Lakes are non-existent.
7. The Lake County Health Department, Illinois Department of Conservation, Illinois Department of Public Health and U. S. Public Health Service have, since 1958, made

studies pertinent to the productivity of the lake system.

8. A 14-month nutrient study by the Lake County Health Department indicated a phosphorous load to the lake system of 569,100 pounds per year. Approximately 75% of the load originated in Wisconsin.

9. Of that phosphorous load originating in Illinois about 32% was of sewage origin and the remainder from land drainage. Within Illinois it was estimated that 45% of the total load was from McHenry County and the remainder from Lake County.

10. Per capita contributions in sewage effluents on the Chain's watershed were estimated to be 1.6 and 6.3 pounds per year of phosphorous and nitrogen respectively.

11. A search of the literature has not revealed a single instance where the aging process of a major lake, hastened by unatural inducement, has been successfully reversed or indeed retarded.

12. The principal trouble makers associated with nuisance blooms of blue-green algae are Microcystis, Aphanizomenon and Anabaena. These plankton are identical to those that have plagued the Madison lakes for years.

13. Any lake showing concentrations in excess of 0.01 mg/l

of inorganic phosphorous and 0.3 mg/l of inorganic nitrogen at the time of spring turnover can be expected to produce algal blooms of such density as to cause a nuisance. The values approximate 0.02 and 0.9 lbs per acre-foot of phosphorous and nitrogen, respectively.

14. Phosphorous loadings to Marie and Platzke Lakes were estimated to exceed the minimum phosphorous requirements for nuisance blooms by 20+ times.

15. The lack of data on current movements within the lake system precludes an intelligent appraisal of nutrient distribution.

16. External sources of nutrients include precipitation, land runoff, groundwater and numerous conduits. An annual rainfall of 30 inches is estimated to contribute 5.5 pounds of nitrogen per acre. Nitrogen from land drainage varies from 3800 to 5200 lbs/year/sq.mi. Phosphorous, from land drainage, is estimated to be 225-255 lbs/year/sq.mi. Ducks can contribute 2.8 pounds of nitrogen and 5.6 pounds of phosphorous per acre of water surface. Treated sewage effluents indicate an average annual per capita contribution of 2.0 lbs of phosphorous and 6.0 lbs of nitrogen.

17. The tremendous deposits of nutrient matter occurring annually in bottom muds serve to furnish fertilizing

minerals for the overlaying waters for years to come.

18. Based upon Wisconsin studies it is estimated that sufficient nutrient may be retained in the bottom muck of the Fox Chain of Lakes to sustain nuisance algal blooms for a period of 30 years, without any additional replenishment of nutrient matter, during that time.

19. The total amount of nutrients leaving a lake compared to that entering would be a measure of nutrient accumulation within the lake system.

20. Assuming complete development of the Chain's shoreline and a complete breakdown of 1/3 the household sewage disposal system the estimated nutrient load would be about 2% of the total load applied to the system.

21. Shoreline dwellers on the Chain appear to be an insignificant source of nutrients at this time.

22. A plan has been developed for diverting treated sewage effluents, in Lake County, downstream of the lake system. The estimated cost, not including lateral sewers, over a 30 year period is $23,550,000 for a 1980 design population. Twenty thousand customers would be expected.

23. Methods have been developed to chemically remove phosphorous from treated sewage effluents but capital cost, chemical cost, sludge volume and lack of proof that such treatment will be effectual have deterred plant scale construction.

24. At anticipated efficiencies of chemical treatment or other demonstrated methods it is probable that sufficient nutrients will remain in effluents to sustain blooms.

25. Chemical control measures employing algicides have been successfully used for years in minimizing the nuisance effect of algal blooms.

26. Extensive field and laboratory studies have shown that the proper application of copper sulfate has not adversely affected fishing or fish yields nor accumulated in bottom muds in concentration that would harm bottom dwelling organisms.

27. The cost per acre for chemicals and distribution using a liquid spray with boat is about $2.00. Helicopters have been found to be more economical for an 850 acre reservoir.

28. A promising chemical, 2, 3 dichloronapthoquinone (2,3DNQ), was found to be specific for blue-green algae at a concentration range of 30 - 55 ppb.

29. A blue-green virus has been isolated which was the first definite evidence that viruses may infect and destroy fresh water algae. It was not effective for those blue-greens common to the Chain.

30. Current movement in Grass Lake, because of its shallowness, is believed to be considerably influenced by wind

direction.

31. Among the recommendations that have been proposed for eliminating nuisance algal blooms on the Fox Chain of Lakes are the following:

a. A master plan for the proper collection, treatment and ultimate disposal of domestic and industrial wastes.

b. Eliminate septic tanks.

c. Locate waste water outfalls to bypass the lakes.

d. Restrict the operation of high-speed motor boats.

e. Remove bottom feeding fish and restocking with desirable species.

f. Prohibit future construction of long, narrow embayments.

g. Dredge out the organic material and use for diking the bordering marshlands.

h. Regulate flow by upstream storage.

i. Stock lakes with plankton feeding fish.

j. Establish rooted aquatic plants.

k. Eliminate all nutrients.

A LIMNOLOGICAL REVIEW

AS RELATED TO

THE FOX CHAIN OF LAKES

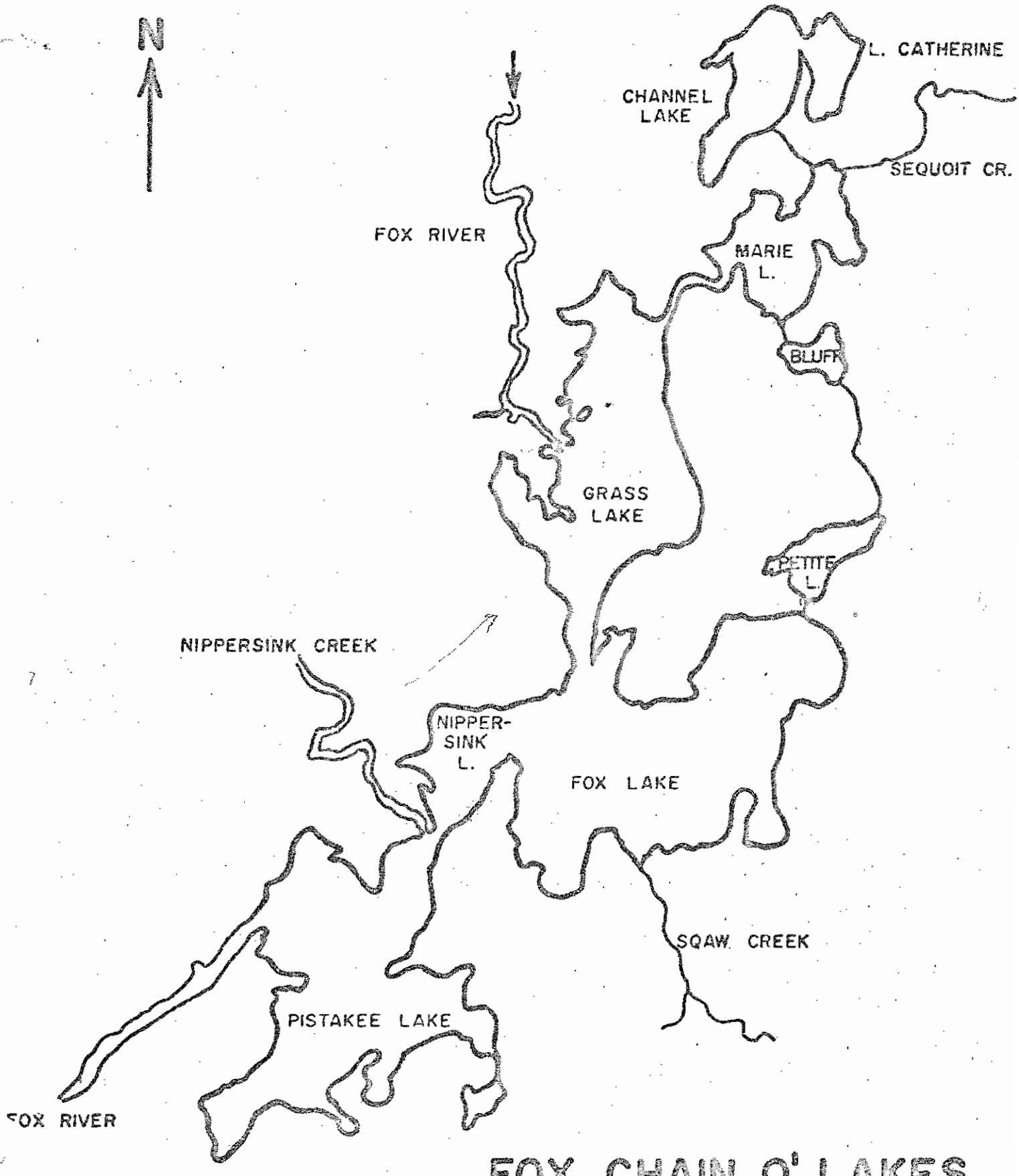
GENERAL

There are 9 major internally connected lakes in the Fox Chain of Lakes system. These are depicted in Figure 1. The surface water level in the system is maintained and influenced by the McHenry Dam under the operation of the Illinois Division of Waterways (1). Flow through the Chain contributes the major portion of flow in the Fox River from McHenry to Ottawa, Illinois. The major tributary to the lake system is the Fox River which originates in Wisconsin. Other tributaries of importance are the creeks Sequoit, Nippersink and Squaw. The quantity of flow from the creeks is not significant during the period May to October.

The Fox River has a drainage area in Wisconsin of 940 square miles (2). The drainage area of the Fox Chain of Lakes as measured at Johnsburg, Illinois, is 1184 square miles (3). Approximately 21% of the Chain of Lakes drainage area lies within Illinois.

Stream flow records through the Chain for the period 1915-24 and 1926-60 as extrapolated from flow records at the U.S.G.S. gaging station at Algonquin for the "boating season", May to October, are contained in Table 1. A minimum flow range of 85-150 cfs is maintained through the McHenry Dam system. Flow recording stations exist at the crossing of Ill. Rt. 173 and

FIGURE 1



FOX CHAIN O' LAKES

(FROM ILLINOIS DEPT. OF CONSERV.)

downstream of McHenry Dam, on the Fox River, upstream and downstream of the Chain respectively. Stage recorder stations are maintained on Nippersink, Fox and Channel Lakes. A non-recording discharge gage station, of short term record, is located on Nippersink Creek.

Table 1

Flow Return Period	cfs	MGD	Acre-ft/day
Once in 10 years	104	67	204
Once in 5 years	140	91	278
Once in 2 years	304	196	596

The water surface area of the Chain at normal pool (736.5' m.s.l.) is approximately 6400 acres with a mean depth of 8 feet. Grass Lake, Fox Lake and Pistakee Lake make up about 75% of the total surface area. During the mean flow of the Fox River the estimated residence time in the Chain during May - October is ~~estimated to be~~ 87 days; this, assuming that flow is equally distributed through the system. Information regarding basic morphometric characteristics of the lake chain, based upon available data, is set forth in Table 2. In addition to lake shoreline there is about 30 miles of "dredged channel" shoreline developed to accomodate the desire for lake frontage property.

There are 7 municipal sewage treatment plants, located in Illinois, with effluents discharging within the Fox Chain of Lakes drainage basin. Six of these have discharges to streams flowing into the Chain; one discharges directly to the lake system. The cities being served and other pertinent data re-

garding treatment facilities are included in Table 3.

*Table 2

Name	**Surface Area Acres	Max. Depth Feet	Mean Depth Feet	Volume Acre-Ft	Shoreline Miles
Channel	352	42	21	7400	3.6
Catherine	155	45	26	4050	2.0
Marie	480	35	15	7200	6.0
Bluff	86	31	18	1500	1.6
Petite	167	22	12	2000	2.0
Grass	1360	5	3	4080	8.5
Fox	1700	22	7	11900	10.2
Nippersink	420	7	4	1680	1.9
Pistakee	1700	31	7	11900	11.8
Total	6420	-	8	51760	47.6

* W. L. Elevation 736.5

** Determinations from maps furnished by Division of Waterways

Table 3

Municipality	(4)Pop.('64)	(5)Design P.E.	*Treatment	**% Removal
Antioch	2270	5000	TF - AS	85-90
Fox Lake	3700	10000	TF	30-85
Hebron	700	1080	TF	80-85
Lake Villa	900	1000	L	85-90
Richmond	855	1350	TF	80-85
Round Lake S.D.	11000	18600	TF - P	88-94
Woodstock	8900	19650	TF - AS	85-90
	28325	56680		

* TF - Trickling Filter
AS - Activated Sludge
L - Oxidation Pond
P - Polishing Ponds

** Est. capability for 5-day BOD removal

In addition there are 12 municipal sewage treatment plants, located within Wisconsin, with effluents being discharge into the Fox River basin upstream of the Chain. The plants serve approximately 61,000 persons (6).

WATER QUALITY

The Fox Chain of Lakes can be classified as "hard water drainage lakes," rich in the bicarbonates of calcium and magnesium. Such waters are typical of lakes of glaciated origin in Wisconsin and Michigan (7). The waters are reasonably shallow and summer temperatures exceed 80°F. The bottom of the lakes can be characterized as organically enriched muck. The concentration of some of the principal constituents affecting the water chemistry of the lake system is summarized in Table 4.

* Table 4

Period	Inorganic N	Soluble P	Hardness	Alkalinity
July '63 (7)	0.32	0.13	-	-
Aug. '63 (7)	0.67	0.25	-	-
Aug. '65 (8)	4.10	0.26	280	212
No. of Samples	30	29	8	8

* Mean Values in mg/l

The pH range of the lake waters is 8.3 - 9.0. During May to October, dissolved oxygen measurements, at daylight hours, generally exceed saturation.

Median values of coliform determinations, during a 2-year study (1959 - 1961) of the lake waters, did not exceed the 2400/100 ml index considered as justification by the Lake County Health Department for recommending that bathing be discontinued. Only one station, at Grass Lake near the confluence of the Fox River, exceeded 200/100 ml. None of the lake waters was found to be substandard from a bacteriological standpoint (8). An earlier investigation in 1954 revealed that 43% of all lake samples con-

tained coliform bacteria counts as high as 32,000/100 ml (9). Offenders at that time, were notified to cease improper discharge of inadequately treated sewage.

An investigation in 1963 to provide factual evidence regarding the fish population the lake system found that desirable numbers and sizes of many species of game and panfish were present and the growth and condition of the fishes were favorable (10).

Nuisance algal blooms have been a source of recorded complaints on the Chain for at least the past 30 years (11). Such protests have at one time or another expressed apprehension regarding the curtailment of bathing, boating, water skiing and fishing activities, the lowering of property values, cancellation of resort trade and the impairment of the picturesque beauty of the lake waters. Luxuriant and prolonged algal blooms with associated pigmentation of the waters, periodic fish kills and offensive odors have been observed during many investigations (8) (9) (10) (11) (12) (13). The predominant nuisance phytoplankton consisted entirely of the blue-green type, Cyanophycean. The nuisance bloomers have been principally Microcystis Aeruginosa and Aphanizomenon flos-aquae.

PREVIOUS INVESTIGATIONS

Studies designed to determine the interrelationship of the many factors contributing to the ecological system of the Fox Chain of Lakes, so far as can be determined, are non-existent. It would appear that in every instance with the exception of one, investigations were limited to a 2 - 3 day period or predicated upon complaints or had as an objective some other single facet associated with the waters such as fish population, or bacterial densities. Most of the water chemistry data, temperature and dissolved oxygen measurements have been incidental to the main purposes of the investigations. An examination of bottom deposits for nutrient material or organic content has not been undertaken nor does there appear to be any detailed information assembled with regard to probable current flow within the Chain. With the exception of the 14-month study (12) performed by Lake County Health Department regarding a nutrient budget for the Chain there does not appear to have been a long-term study with the objective in mind of determining specifically the principal factors existing which stimulate and sustain annually, nuisance algal blooms or the proportinate influence of each factor. Such lack of minimal information has not precluded the recommending of far - reaching and costly remedial measures. Those investigations most pertinent to the productivity of the lake system from the standpoint of biomass have been made since, 1958. A brief resume' of the four at hand and one in preparation follows.

A. 1959-1961 Lakes and Streams Survey (8)

The report summarizes observations by the Lake County Health Department in an effort to evaluate the quality of lake and stream water in the county as such quality might affect public health. Based solely on bacterial densities it was concluded that "At present the streams rather than the inland lakes, are the source of concern." Further, "While Lake County bathing beaches are reasonably free from bacteria, they are not free of algae blooms..... The Chain O'Lakes was not extensively evaluated (in 1959) because little data had been collected from these lakes at that time." and "A special study was conducted on eight selected lakes, i.e. Cedar Lake, Long Lake, Third Lake, Loch Lomond, Bangs Lake, Slocum Lake, Lake Zurich, Diamond Lake, on a year round basis. The study concluded that although adding effluent which has been properly purified and chlorinated to lakes probably is not a danger to the health of the public it often accelerates the natural aging process, eutrophication. The results of these studies have been substantiated by work done by the Fishery Division of the Illinois Department of Conservation."

B. July - August 1963 Fox Chain of Lakes - Algal Problems (9)

The report summarizes a 2-day sampling program under the direction of the U. S. Public Health Service and sets forth some chemical and biological data. Pertinent historical

information was obtained from the files of the Illinois Sanitary Water Board and the U. S. Public Health Service. The probable causes of the algal problem existing at that time in the lake system was stated to be (1) shallow depths of the lakes (2) influx of nutrients (3) extensive canalization of low areas of the lakes (4) septic tank drainage at the lakes' edge (5) climatic conditions including low stream flows and (6) the recirculation of nutrients from the bottom muds. Aphanizomenon flos-aquae comprised the bloom. The conclusions reached were:

1. "The several lakes of the Fox Chain are biologically overproductive as manifested by algal blooms of such density and quality as to cause nuisance conditions and concomitant devaluation as aesthetic and recreational resources."
2. "The algal condition in 1963 was caused by a combination of low flow in the Fox River and fertilization from three principal sources: (a) treated sewage from the villages of Antioch, Fox Lake and Round Lake; (b) infiltration of septic tank absorption field in unsewered residential areas; and (c) agricultural runoff in the drainage basin and from the nutrient-rich waters of the Fox River."
3. "According to Dr. Baker, no serious health hazard existed. However, the water quality was so poor as to be undesirable for bathing and aesthetic enjoyment."

4. "A program to remedy the problem should be initiated immediately. Such a program must involve the best-informed technical talent available and will require the full cooperation of local residents as well as the assistance of federal and state agencies having capabilities in this field."

The remedial measures proposed consisted of a combination of actions some of which could be taken immediately and others on a long-term basis. These, as stated, were as follows:

"A wide area master sewage plan should be developed as soon as possible. This master plan should provide for the proper collection, treatment and ultimate disposal of domestic and industrial waste waters, and it should encompass all of the area of the Fox River watershed that is within the Chicago Metropolitan Area, rapidly becoming urbanised. The plan should identify strategic points at which waste waters can be discharged with minimum detriment to the stream, and analysis should be made of the impact of waste loads on the system, for both present and projected future loads. This does not mean that a single sewerage system must be built for the whole area. It does mean, however, that coordinated planning should be done for the whole area. Piecemeal planning by individual municipalities, or even by single counties, will not produce an adequate plan, as the water does not respect political boundaries. In addition, piecemeal planning will

not receive the widespread acceptance essential to promulgation.

Reduction in present nutrient contributions will be required if the waters of the Chain of Lakes and the Fox River are to be improved. This can be accomplished by the elimination of septic tanks in built-up areas, especially those draining to the lakes; by construction of intercepting sewer systems; and by changing locations of waste water outfall points to bypass the lakes and discharge to flowing streams. Concentrations of nutrients might also be reduced by placing restrictions on the operation of high-speed motor boats that may cause resuspension of nutrients from the bottom sediments. Bottom-feeding fish, such as carp and catfish, may also cause resuspension of bottom sediments. The possibility of removal of bottom-feeders, and restocking with more desirable species, should be investigated. Future construction of long, narrow embayments where stagnant water conditions develop should be prohibited.

Institution of the foregoing measures as soon as practicable should result in considerable alleviation of the presently unsatisfactory conditions. Further progress toward restoration of the subject waters will require several long-range approaches. If determined feasible from an engineering viewpoint, the organic sediments in the lakes should be dredged and the spoil used for filling or diking off the bordering marshlands. The possibilities for flow

regulation by upstream storage that would augment low flows in the Fox River, and for further reduction in nutrient concentrations in waste waters by additional treatment, should be investigated. The latter will require research to develop economically feasible techniqes. The possibility should be explored of using biological controls such as stocking the lakes with plankton feeding fish or establishing rooted aquatic plants that will successfully compete with the algae for nutrients and light. No efficient method of biological control are known at this time."

C. 1963 - Fishery Investigation (10)

The report's principal objectives have been previously stated together with conclusions regarding the fish population in the Chain. In addition some limited data regarding water chemistry is presented in the report along with the observation concerning "the apparent depletion of abundance of submergent vegetation --- over recent years;" thus concluding that "the present scarcity of submergent vegetation and the expanding problem of planktonic algae dramatizes the significance of the biological changes which are taking place." Conclusions other than those pertaining to the fish population consisted primarily of the following:

"The main cause for concern at this time would be the future water quality. The increasing severity of plank-

tonic blue-green algae blooms during the warm months indicates environmental conditions which approach stagnation in some lakes of the Chain causing fish mortality in areas as a result of algae drift and decomposition. Low water flow caused by prolonged drought was a contributing factor to algae abundance in 1963. Because blue-green algae blooms are usually related to the influence of extra nutrients such as from sewage treatment plants and septic systems it is recommended that a central sewage collection be expanded in the residential areas around these lakes and that sewage treatment plants' effluents be diverted away from the watershed leading into these lakes."

The report in conclusion stated.

"A regular program of water sample collections should be set up for the Chain, which would include chemical and biological analyses of the water. Permanent sampling stations and standardized sampling procedure should be a part of such a program. All public agencies concerned with the Fox Chain of Lakes area, be it conservation, health, boat safety, waterways or recreational planning should coordinate and share their programs and information one with another."

D. <u>April 1964 - Bottom Organisms</u> (14)

The study was part of a general appraisal of bottom fauna existing in the Fox River basin within Illinois. The report identifies sampling points and presents a list of those

organisms collected. The investigator stated, "It is possible from a study of the inter-relationship of the species of bottom-dwelling organisms and their individual responses to a pollutional load to devise a system of stream classifications. Such a system acknowledges the degree to which an environment is capable of maintaining a state of balanced aquatic production."
For the purposes of classification the terms balanced, unbalanced, semi-polluted and polluted have been incorporated. Nine locations on the lakes of the Chain and their tributaries were sampled. The stations and their classifications are as follows:

1.	Fox Lake	Polluted
2.	Pistakee Bay	Semi-Polluted
3.	Squaw Creek	Unbalanced
4.	Fox-Petite Channel	Semi-Polluted
5.	Fox-Grass Channel	Polluted
6.	Sequoit Cr. - u.s. Antioch	Semi-Polluted
7.	Nippersink Creek	Unbalanced
8.	Fox River at Rt. 173	Semi-Polluted
9.	Fox River at Wis-Ill. Line	Unbalanced

The bottom fauna observed consisted principally of:

Tendipes La
Sponges
Annelids
Fairy Shrimp
Nematodes
Flat worms

E. July 1963 - September 1964 - Nutrient Study (12)

The study was undertaken by the Lake County Health Department for the purpose of determining the significant sources of nutrients as related to tributaries of the Chain and the

quantity of nutrient inflow from each tributary. For the purposes of the study nutrients were considered to be phosphorous (PO_4) and nitrogen (N). A report is in preparation and comments set forth herein are based upon a review of the data made available by the Lake County Health Department.

In addition to phosphorous and nitrogen determinations, temperature, wind direction, secchi readings, pH and algal counts were recorded. Some effort was made to study current movements by the release of dye.

Preliminary estimates indicate the phosphorous (PO_4) load to the lake system, and the tributaries involved, to be as follows:

Fox River	430,000 pounds per year
Sequoit Cr.	40,000 pounds per year
Squaw Cr.	36,100 pounds per year
Nippersink Cr.	63,000 pounds per year
	569,100 pounds per year

Of the approximately 285 tons of phosphorous applied to the Chain annually from tributary inflow about 75% originates from the drainage area in Wisconsin; of that originating within Illinois boundaries 32% is of sewage origin and the remainder from land drainage. From the viewpoint of county contributions, within Illinois, it is estimated that 45% of the total phosphorous load emanates from McHenry County (mainly land drainage) and 55% from Lake County.

A summary is presented in Table 5.

Table 5

Source	Wisconsin	Lake County	McHenry County
Sewage	92,000	30,100	14,500
Land Drainage	338,000	46,000	48,500
	*430,000	*76,100	*63,000

* Annual Poundage of Phosphorous

From determinations made on the Fox River near Johnsburg, 33% of the phosphorous applied to the lake system was either retained in the lake system or lost by algal flow-through.

Land use in the Chain's basin is considered to be 15% urban and the remaining 85% agriculture or open space; phosphorous contributions approximate 24% and 76% from each use respectively.

Composite samples of sewage effluents from treatment facilities serving the municipalities of Fox Lake, Round Lake Sanitary District and Antioch indicated a per capita per year contribution of 1.6 lbs and 6.3 lbs. of phosphorous (PO_4) and total nitrogen (N) respectively. The treatment facilities serving Lake Villa, because of location, was not considered significant for the purposes of the study.

Nitrogen computations were not available however in applying the ratio N:P of analytical results, the amount of total inorganic nitrogen tributary to the lake systems

appears to be:

Fox River	400,000 pounds per year
Sequoit Cr.	105,000 pounds per year
Squaw Cr.	86,000 pounds per year
Nippersink Cr.	174,000 pounds per year
	765,000 pounds per year

The former engineering director of the Lake County Health Department and director of the study expressed the opinion that the complete removal of sewage effluent discharges into the tributaries or the lakes proper would not significantly alter the continuing algal blooms environment now existing in the Chain. He was of the opinion that land drainage alone contributed quantities of phosphorous and nitrogen considerably in excess of the minimum required to sustain algal blooms in the Fox Chain of Lakes.

Certain lakes in the Chain area were reported by Lake County staff members to be in "clear" condition throughout the year even though they are completely surrounded by dwellings. These include Cedar, Deep, Loon, Wooster, Silver, Duck, Fish and Bang's Lakes. The water chemistry of these lakes was reported to be similar to the Chain.

DISCUSSION

Of the numerous investigations and long term studies of productivity in lakes the undertakings at the Madison lakes in Wisconsin, appear to be the most pertinent to conditions existing in the Fox Chain of Lakes (15, 16, 17). The origin,

water chemistry, mineral content and temperature ranges are quite similar and the types of algae, creating nuisance conditions, are identical. In spite of the major changes that have been instituted at Madison, with regard to the diversion of treated sewage effluents from the lake system, annual nuisance blooms persist. Such blooms continue to occur on Lake Mendota where drainage, primarily, has always been from non-urban areas and Lake Monona from where municipal sewage effluents were diverted 30 years ago.

A search of the literature, though not exhaustive, has not revealed a single instance where the aging process of a major lake, hastened by unatural inducement, has been successfully reversed or indeed retarded as measured by productivity. Bartch has stated with regard to lakes "During the course of history they change continually ----- and it is at the algal bloom stage that people are concerned of the immediate unpleasantness of algae that interfered with water resource enjoyment and not because this is a milestone in the progressive extinction of the lake" (17A).

Since the ideal objective, that of improving water quality, would involve reversing or retarding the aging process of the Chain's lake system it would seem desirable to review some information pertaining to the productivity of the system or similar ones as well as the work of others regarding algae, nutrients, sewage and control measures.

A. Phytoplankton

The number of algal cells per ml constituting a bloom has been arbitrarily set at 500 (18). Whether or not a "nuisance bloom" exist is dependent upon the predominant genera; the blue-green type are generally the trouble makers (12) (15) (16). It is not uncommon to have cell counts in excess of 500 per ml in the Chain during the period May to October, consisting predominantly of BGA. Investigators have reported "blooms", under ice cover (15). These algae like any other chlorophyll-bearing plant depend upon a supply of carbon dioxide from which they convert to carbohydrate matter in the presence of sunlight. In the absence of free CO_2, the bicarbonates (HCO_3) yield sufficient CO_2 for photosynthetic needs (19). An equilibrium exists in water between the carbonate, bicarbonate and hydroxyl ions; thus any CO_2 uptake from bicarbonate will increase the hydroxyl concentrations and correspondingly the pH. An increase in pH is usually associated with a bloom.

Many of the blue-greens are capable of nitrogen fixation. This means they can supply any deficiency of nitrogen from the atmosphere as long as other nutrients are available. Sawyer, in laboratory studies, concluded that phosphorous plays a key role in nitrogen fixation and that in the absence of phosphorous nitrogen fixation would not occur (178). Aphanizomenon was the test organism in Sawyer's work.

For the two principal nutritional elements to be readily available for ultilization by blue-green algae they must be in the form of soluble inorganic phosphorous and nitrogen (15) (17C) (20). Benoit however has suggested that since BGA grow best in waters with high organic matter the algae do grow by ultilizing organic phosphate (21). Benoit emphasizes there is no shortage of organic phosphate in natural waters and refers to a calculation by Hutchinson that as high as 60% of the total phosphorous in some Wisconsin lakes may be in organic form. Blue-green algae cells were found to be about 7% nitrogen and 0.7% phosphorous on a dry weight basis; a ratio of 10 N:P. It was determined that the minimum cell content for Microcystis necessary for maximum growth (critical level) was, on a dry weight basis 4% nitrogen and 0.12% phosphorous; a ratio of about 33:1 (23). The minimum N:P ratio for laboratory cultures was about 60:1. These ratios not only demonstrate the luxury uptake of the two principal nutrients nitrogen and phosphorous but do suggest the potential of nutrient accumulation within lake systems by the settlement of algae to the lake bottom. There is no information of this nature for blooms on the Chain.

B. Nutrients

Inorganic nitrogen and phosphorous were found to be the critical factors in plankton productivity in Madison lakes (15). Lackey speculated that nitrogen was the limiting

factor in regard to the amount of growth and phosphorous acted largely as a governor upon the rate at which growth occurred (17). Sawyer has concluded that any lake showing concentrations in excess of 0.01 mg/l of inorganic phosphorous and 0.3 mg/l of inorganic nitrogen at the time of spring turnover could be expected to produce algal blooms of such density as to cause a nuisance (24). These values are often referred to by other investigators and there does not appear to be any contradictory evidence. They approximate 0.027 and 0.8 lbs per acre-foot of phosphorous and nitrogen respectively. On the basis of nutrient studies on the Chain the least amount of phosphorous calculated as applied annually to the lakes Marie and Pistakee is 5.5 and 5.3 lbs per acre-foot respectively. This is about 200 times the minimum phosphorous requirement; minimum nitrogen requirements are exceeded about 18 times for the two lakes. Lack of information regarding currents and nutrient uptake precludes an intelligent appraisal for the loads on all lakes in the Chain. External sources of nutrients are made up largely from (1) precipitation (2) land runoff (3) ground water and (4) man-made conduits. Mackenthun stated that the nitrogen applied from a 30 inch rainfall per year would be about 5.5 pounds per acre (16). Engelbrecht et al estimated a mean total phosphorous contribution from land drainage on the Kaskaskia River basin of 225 lbs/year/sq.mi. (25). Sawyer reported total phosphorous from land drain-

age of 255 lbs/year/sq.mi. and nitrogen ranging from 3800 to 5200 lbs/year/sq.mi. (20). The nutrient study of the Chain suggested a phosphorous contribution from land drainage of 365 lbs/year/sq.mi.

Ruttner stated that in contrast to nitrogen, phosphate is held avidly to the soil and is not so easily leached out by rainwater as are nitrates (27). In general the application of common fertilizers does not cause significant fertilization of streams because they are supplied during the growing season and tilled in the soil. There is some possibility of nitrogen enrichment because nitrates are not bound by the soil (26). Storm water at Madison has been found to carry about 0.56 mg/l total phosphorous and 0.44 mg/l inorganic nitrogen (16). The annual contribution to Lake Chautaqua in Illinois from the wild duck population was 12.8 pounds of total nitrogen and 5.6 pounds of total phosphorous per acre of water surface (28). A study by Sylvester is summarized in Table 6 in which the mean concentration of nutrients are listed (17E).

Table 6

Source	Total P(mg/l)	Nitrates (mg/l)
Streams from forested areas	0.07	0.13
Return flow drains Sub-surface irrigation	0.22	2.69
Return flow drains Surface irrigation	0.25	1.25
Multiple Use River	0.14	0.32
Urban Street Drain	0.15	0.42
Urban Streams	0.12	1.36

Sewage is generally considered the major source of lake

fertilization, not solely because of its nutrient content, but also because the nutrients, phosphorous and nitrogen are in a readily available form for algal assimilation; to wit: inorganic soluble form.

A summary of several studies for which the annual contribution per capita of phosphorous and nitrogen have been determined is included in Tables 7 and 8.

Table 7 - Phosphorous

Year	Reference	Concentration	Source
1943	15	1.2 lbs	sewage, treated
1947	29	0.6 - 1.5 lbs	sewage, treated
1950	24	1.6 lbs	detergents and water softening
1955	25	1.9 lbs	household detergents
1957	16	2.8 - 3.7 lbs	sewage, treated
1957	30	1.1 - 13.8 lbs	sewage, treated
1957	25	1.75 - 4.15 lbs	sewage, treated
1960	32	1.1 lbs	sewage, treated
1962	31	3.1 lbs	sewage, treated
1963	12	1.6 lbs	sewage, treated
1964	*26	2.9 - 5.1 lbs	sewage, treated
--	17A	0.3 - 3.9 lbs	sewage, treated

* estimated that 50% originated from detergents.

Table 8 - Nitrogen

Year	Reference	Concentration	Source
1957	16	8.5 lbs	sewage, treated
1960	32	4.1 lbs	sewage, treated
1962	31	7.9 lbs	sewage, treated
--	17A	6.1 - 15.2 lbs	sewage, treated
1963	12	6.3 lbs	sewage, treated

From a review of the data in Tables 7 and 8 the values determined by the Lake County Health Department in their nutrient study of the Chain appear to be in line with independent studies by others.

On the basis of a maximum allowable load of .027 lbs. of

phosphorous per acre-foot the total phosphorous load (in the Chain) would be limited to about 1392 lbs/per year equivalent to treated sewage from 870 persons or a drainage area of about 4 sq. mi. From the viewpoint of 0.8 lbs of nitrogen per acre-foot as a maximum loading a similar analyses indicates a limitation of approximately 41,500 lbs/per year equivalent to treated wastes from 6600 persons or drainage (using Sawyers estimates) from 9.2 sq.mi. of land. This is admittedly an over-simplification of a complex chain of reactions including uptake rates, flow-through losses, settlement etc, but it does demonstrate a futility that may be encountered in a program designed for nutrient control.

Thus far only external sources of nutrients have been reviewed; probably as important or nearly so are the nutrients bound internally within a lake system. Sawyer concluded that from the tremendous amount of deposited unstable nitrogenous matter occurring in Madison lakes the deposits would serve to furnish fertilizing minerals for the overlaying waters for several years to come (15). The component parts of the bottom deposits are dead plankton bodies and decay from rooted vegetation. Especially in shallow lakes where there is no "hypolimnic trap" a rapid regeneration and efficient circulation of regenerated nutrients could be expected. Lauff points out that the general relationship between mean depth and productivity have been studied and an excellent correlation exists be-

tween average lake depth and unit area production of plankton thus providing evidence of the efficient circulation of nutrients in shallow bodies of water (17F).

The magnitude of nutrient enrichment in the bottom muck of the Chain has not been determined. The results of studies of the Madison lakes for the chemical composition of bottom muds are summarized in Table 9 (16).

Table 9

Lake	* N(mg/g)	* P(mg/g)
Mendota	7.30	1.2
Monona	7.10	1.07
Waubesa	9.08	1.07
Kegonsa	9.06	1.21

* Dry Weight.

If the nitrogen and phosphorous content in the bottom muck of the Chain is similar to that found within the Madison lakes, the reservoir of nutrient material is substantial. Assuming 100% regeneration and 100% uptake daily for a growing season of 6 months, with no replenishment of nutrient material to the Chain, it is estimated that sufficient nitrogen would be available to sustain a bloom for 7 years and enough phosphorous for a period of 30 years - all from bottom deposits - assuming conditions similar to that established for the Madison situation.

The total amount of nitrogen and phosphorous (organic and inorganic) leaving a lake compared to that entering should

give valuable information with regard to the rate of nutrient deposition and subsequent accumulation in the bottom muds. There has been some expression of concern regarding the discharge of nutrient material (sewage) from malfunctioning household systems on the shoreline of the Chain. Assuming the 78 miles of shoreline, including water front canals, are completely developed with 60' lots and 3.5 persons per lot and further that 1/3 of the systems are completely inoperative the annual phosphorous contribution would be about 2% of the total phosphorous load applied to the Chain waters. Shoreline dwellers at this time appear to be an insignificant source of nutrients.

C. Sewage Treatment

The objectives of conventional sewage treatment are the removal of biochemical oxygen demand, suspended solids and microorganisms. Achieving these objectives makes the effluent totally acceptable for discharge to surface waters so far as health and most water reuse considerations are concerned. Such treatment however provides neglible removal of algal nutrients. Conventional treatment will not prepare sewage adequately for discharge to waters physically suitable for algal growth.

A plan has been developed for collecting all sewage in the drainage area of the Chain within Lake County and discharging the treated effluent in the Fox River below the Chain (33).

The estimated cost for a 1980 designed population is $7,450,000. This is the basic cost and does not include lateral sewers or annual operating cost. Excluding lateral sewer cost but including bond retirement, annual operating cost and sinking fund the cost over a 30 year period is estimated to be $23,550,000.

It has been demonstrated that phosphorous, in all forms, can be removed from sewage by chemical coagulation (34). The method has been known for at least 20 years but the capital cost, chemical cost, volume of sludge and lack of proof that such treatment will be effectual has been a deterrent in constructing units on a plant scale. The treatment is about 90% efficient as applied to the per capita contribution on the Chain in Lake County. A 90% reduction of phosphorous between a sewage plant effluent and a lake, in one instance, did not prevent nuisance algal blooms in the lake (17G). Effectiveness of phosphorous removal up to 80% has been demonstrated, at laboratory scale, employing the activated sludge process (20). A futuristic waste water treatment process using this method for removing phosphorous has been diagrammatically developed.

Sewage effluent was diverted from a lake in one instance by using spray irrigation techniques at an application rate of 85,000 to 170,000 gpd/acre; the rate killed off vegetation and trees. A more reasonable rate for normal

vegetation growth would be about 10,000 gpd/acre (17G). The treated effluent was chlorinated prior to spraying. Waste stabilization ponds are capable of reducing applied phosphorous and nitrogen about 90% - 95%. At the normal design loading for such ponds in Illinois the soluble inorganic phosphorous (PO_4) loading, assuming raw sewage, is estimated to be 480 lbs per year per acre-foot of pond (35). In spite of the high nutrient loading, shallow depths, high temperature and adequate mineralization the predominant algae in waste stabilization ponds in Illinois are of the green type such as: Chlorella, Oocystis and Ankistrodesmus. Since the flow to the ponds is principally raw sewage, it would seem conditions would be created ideally for blue-green algal blooms.

D. CONTROL

The use of algicides is usually considered a "temporary measure" in spite of the fact that over 2 million pounds of copper sulfate ($CuSO_4.5H_2O$) was used on Lake Monona over a period of at least 26 years. Algicides are used annually on lakes serving as public water supplies to the extent that its cost has become a routine budgetary item. Copper sulfate was first used in Europe in 1890 and introduced to this country in 1904 (36). Its use was started on the Madison lakes in 1918 (15). Among the more common algae that have required control by the chemical are Aphanizomenon, Microcystis and Anabaena (19).

From experience in Wisconsin, dosages of the algicide are based on the alkalinity of the water as follows (37):

(a) Alkalinity less than 40 mg/l requires 0.9 lbs per acre-foot

(b) Alkalinity greater than 40 mg/l requires 5.4 lbs per surface-acre

For conditions as stated in (b) the mean concentration of $CuSO_4$ is 1 mg/l on the assumption that the effective depth range is 2 feet; for condition (a) the mean concentration is 0.3 mg/l. The copper ion is readily precipitated as $Cu(OH)_2$ or as basic copper carbonate $Cu_2(OH_2)CO_3$ in alkaline waters (19). For this reason its toxicity decreases rapidly as the pH of waters exceed 7.5.

Extensive field and laboratory studies have shown fish not killed at concentrations required for algal control and that fishing and fish yields have not deteriorated in lakes treated over a long period of time. After 26 years of treatment on Lake Monona copper accumulations in bottom muds were considerably less in concentration than amounts determined to have adverse affect on the bottom dwelling organisms (37).

The ability to know when to treat and how to obtain uniform distribution of the algicide is essential for proper control. Monie has had success in correlating treatment applications with certain temperatures and suggest that blooms are cyclic because of stimulated activity at these critical temperatures (38). The cost of $CuSO_4.5H_2O$ is

(1966)

estimated to be $386.00 per ton (39). Cost per acre for chemicals and distribution, using a liquid spray with boat, is about $2.00 (37). DeCosta found the use of helicopters to be more effective and economical than the use of boats (40). An 850 acre reservoir was treated in 4 hours where 2 boats and 4 men would have taken 2 days. Helicopter cost was $140.00 per hour flight time. Mackenthun estimated that 300-350 lbs ~~per acre~~ of the algicide can be distributed per hour with a liquid spray (37). This amount to a coverage of 60 acres per hour.

Fitzgerald et al investigated about 300 different chemicals to determine their toxicity to blue-green algae as compared with that of copper sulfate. The most promising chemical tested was 2, 3 dichloronapthoquinone. It was specific for blue-green algae and was found non-toxic to fish, snails and high aquatic plants in excess of saturation. Later studies, including field test on a highly fertile 27 acre lake, demonstrated the chemical's effectiveness in controlling excessive growths of blue-green algae (42). The treatment had no observable harmful effects on green algae, higher aquatic plants, fish or zooplankton. The dosage range used was 30 - 55 ppb.

Several other compounds have been demonstrated as effective algicide. They include:

(a) activated silver
(b) quatenary ammonium
(c) quinones
(d) rosin amines
(e) urea derivatives
(f) anti biotics
(g) organic zinc

As far as is known none of these, with the exception of quinones, have been used on lakes and reservoirs because of cost considerations or other limitations.

Safferman et al undertook an investigation that eventually lead to the isolation of blue-green virus (43). This was the first definite evidence that viruses may infect and destroy fresh-water algae. The biological algicide increased in concentration during treatment.

E. CURRENTS

The pattern of current flow through the lake chain has not been established. For the purpose of investigating alternatives for improving circulation in the lake waters it would be desirable to define the predominant direction, frequency and quantity of flow from Grass Lake during the period May to October. Dye test on a limited scale indicated flow from Grass Lake to Lake Marie (12). Temperature measurements during one day showed waters of the Lake Marie "Chain" to be about 5°F and Fox Lake to be about 3°F higher than the waters of Grass or Nippersink Lakes (13). This suggested flow from Grass Lake to Lake Marie also. Wind direction was not noted during measurements but the predominant wind direction during the warm months is from the southwest. Because of the shallowness of Grass Lake wind direction is considered to be a major influence on it's flow patterns.

CONCLUSION

It has been reported by the Illinois Department of Conservation that in 1915, 4000 boats existed in the Fox Lake waters. Fifty years later Lake County officials have estimated that 33000 boats are harbored on the Chain. They have further noted that an estimated 2 million gallons of gas is used annually by boaters on the lakes. This suggests activity. The Northeastern Metropolitan Planning Commission reportedly stated, "there is no area in the six counties with greater potential for meeting the varied recreation needs of the metropolitan area than the Chain of Lakes".

That the State of Illinois has a prime economic interest in the area there should be no doubt. It would seem that this interest might be so valued as to be desirous of preservation thus requiring a program of high priority designed to provide a water quality consistent with the needs of the sportsman, swimmer, boater or sightseer as well as the individual depending upon active use of the waters for his livelihood.

In consideration of the proficient ultilization of such minute quantities of nutrients by blue-green algae any attempt to reduce nutrients, under existing conditions, with the expectation of reducing nuisance blooms is not practical; nor does it seem reasonable to suggest to the people in Lake or McHenry counties that the elimination of sewage effluents to the Chain will solve the problem. There should be no restraint however in giving considered judgment to the prospects of eliminating

phosphorous from sewage effluents. Since the problem-causative agent is a blue-green algae, capable of nitrogen fixation, little could be gained by eliminating nitrate nutrients.

The use of algicides may be considered expensive but the expense for suggested alternatives, assuming equal effectiveness, is even more staggering. There are inherent dangers in the use of chemicals for controlling environmental conditions. However, with prudence and proper monitoring, algal problems have been successfully suppressed without adversely affecting innocuous organisms existing in an already unbalanced environment.

After at least 30 years of complaints and many investigations it is time, it would seem, to develop a program which would provide relief to the users of the lake waters while undertaking, concurrently, some specialized studies what would provide (1) insight toward selective algal control procedures and (2) techniques for rendering existing and potential nutrients incapable as algal stimuli.

REFERENCES

(1) "Regulation of Fox River - Fox Chain of Lakes Lake and McHenry County" - Illinois Department of Public Works and Buildings - Division of Waterways 1965

(2) "Stream Flow Data of Illinois" - Illinois Department of Public Works and Buildings - Division of Waterways (pp 653) 1937

(3) "Survey Report of the Development of the Fox River for Recreational Navigation" - Illinois Department of Public Works and Buildings - Division of Waterways (pp 75 - 86) 1962

(4) "Official List of Counties and Incorporated Municipalities of Illinois - 1964" - Secretary of State - State of Illinois

(5) "Data Book - Waste Water Treatment Works" - Sanitary Water Board - State of Illinois 1965

(6) Fox River Watershed Planning Program Prospectus Southeastern Wisconsin Regional Planning Commission Old Courthouse, Waukeska, Wisconsin (Oct 1964)

(7) Prescott, G. W., "Algae of the Western Great Lakes Area" Wm. C. Brown Comp. Dubuque, Iowa (1962)

(8) "Lakes and Streams Survey" - Lake County Health Department, Waukegan, Illinois May 1962

(9) "Memorandum Report - Fox Chain of Lakes, Illinois - Algal Problem - July - August, 1963" - USPHS Region V, Chicago

(10) "1963 Fox Chain O'Lakes Fishery Investigations" - Division of Fisheries - Illinois Department of Conservation

(11) Files of Illinois Sanitary Water Board - Springfield, Illinois

(12) Nutrient Study - Fox Chain of Lakes (1963 - 1964) Lake County Health Dept. - Waukegan, Illinois

(13) "Fox Chain of Lakes Investigation Report" - Water Quality Section - State Water Survey - Peoria, Illinois (1965)

(14) "Survey of Fox River in Illinois - April-June-July 1964" Illinois Department of Public Health - Springfield, Illinois

(15) Lackey, J. B. & Sawyer, C. N., "Plankton Productivity in Certain Southeastern Wisconsin Lakes as Related to Fertilization" SWJ 17:573 (May 1945)

(16) Mackenthun, Kenneth M., "A Review of Algae, Lake Weeds and Nutrients" JWPCF 34:1077 (Oct 1962)

(17) Transactions of the 1960 Seminar - "Algae and Metropolitan Wastes" - U. S. Department of Health Education and Welfare. SEC, Robert A Taft - Cinn. Ohio (pp10 - 17)

(17A) Bartch, A. F. (pp6-7)
(17B) Sawyer, C. N. (pp100-103)
(17C) Governors Committee (pp15-17)
(17D) Phinney, H. & Peek, C., (pp22-27)
(17E) Sylvester, R. O. (pp 80-87)
(17F) Lauff, G. H. (pp96-99)
(17G) Larson, W. C. (pp125-129)

(18) Nitrogen and Phosphorous in Water - An annotated Selected Bibliography of Their Biological Effects - U. S.EH.S. - U. S. D. H. E. W. (pp49) 1965

(19) Sawyer, C. N., "Causes, Effects and Control of Aquatic Growth" JWPCF 34:279 (March 1962)

(20) Levin & Shapiro - "Metabolic Uptake of Phosphorous by Waste Water Organisms" JWPCF 37:800 (June 1965)

(21) Benoit, R. J., "Relation of Phosphorous Content to Algae Blooms" SIW 27:1267 (November 1955)

(22) Gerloff, G. and Skoog, F., "Cell Content of Nitrogen and Phosphorous as Measure of Their Availability for Growth of Microcystis Aeruginosa" Ecology 35:348 (1954)

(23) Gerloff, G. and Skoog, F., "Nitrogen as a Limiting Factor for the Growth of Microcystis Aeruginosa in Southern Wisconsin Lakes" Ecology 38:556 (1957)

(24) Sawyer, C. N., "Some New Aspects of Phosphate in Relation to Lake Fertilization" SIW 24:768 (July 1952)

(25) Engelbrecht, R. S. and Morgan, J. J., "Studies on the Occurrence and Degradation of Condensed Phosphates in Surface Waters" SIW 31:458 (April 1959)

(26) Sawyer, C. N., "Problems of Phosphorous in Water Supplies" JAWWA 57:1431 (November 1965)

(27) Ruttner, F., "Fundamentals of Limnology" - University of Toronto Press, Toronto, Ont. (1953)

(28) Paloumpis, A. A. and Starrett, W. C., "An Ecological Study of Benthic Organisms in Three Illinois River Flood Plain Lakes" Amer. Midland Naturist 64:406 (1960)

(29) Rudolfs, W., "Phosphates in Sewage and Sludge Treatment" SWJ 19:43 (January 1947)

(30) Dietz, J. C. and Harmeson, R. H., "Phosphate Compounds Occurring in Illinois Surface Waters" Proc. 12th Indiana Waste Conference - Purdue University 94:285 (1958)

(31) Personal Communication - Greater Peoria Sanitary District (1965)

(32) Mackenthun, K. M. etal, "A Study of Diverting the Effluent from Sewage Treatment Upon the Receiving Stream" Wisconsin Acad. Sci. Arts, Letters 49:51 (1960)

(33) A Comprehensive Report on Existing Sanitary Conditions and Proposed Facilities for Water Pollution Control and Abatement for Lake County - Consoer, Townsend and Assoc., Consulting Engineers (February 1962)

(34) Lea, W. L. etal, "Removal of Phosphate from Treated Sewage" SIW 26:261 (1954)

(35) "Common Ions Additions to Sewage" - Study in Progress - Water Quality Section, Illinois State Water Survey

(36) Hale, F. E., "Use of Copper Sulfate in Control of Microscopic Organisms" Phelps Dodge Refining Corp., N. Y. (1954)

(37) Mackenthun, K. M., "What You Should Know About Algae Control" Public Works 9:14 (September 1960)

(38) Mor..., W. D., "Al... Control with Copper Sulfate" Water and Sewage ... 3:912 (September 19..)

(39) Personal Communication ... McKesson and Robbins Inc., Peoria, Illinois (19..)

(40) DeCosta, J. D. and ..., G. L., "Algal Problems and Their Control at ..." JAWWA 56:1201 (Sept. 19..)

(41) Fitzgerald, G. P., Ge..., ... and Skoog, F., "... Sites of Chlorella with ... Toxicity to Blue-Green Algae" SIW 24:613 (May 195.)

(42) Fitzgerald, G. P. and Skoog, F., "Control of Blue-Green Algae Blooms with 2, 3 - Dichloronaphthoquinone" SIW 26:1016 (Sept. 1954)

(43) Safferman and Morris, "Control of Algae with Viruses" J.AWWA 56:1217 (September 1964)