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"Biological and Water Quality Effects of Artificial Destratification of Lake of the Arbuckles"

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By

Dale W. Toetz

School of Biological Sciences

Oklahoma State University

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INTRODUCTION

Thermal stratification of lakes and reservoirs often results in depletion of oxygen (DO) in the hypolimnion and clinograde distributions of DO (Hutchinson, 1957). Oxygen depletion in the hypolimnion creates reducing conditions and anaerobic bacterial respiration. Manganese and iron go into solution and reduced forms of nitrogen and sulphur accumulate, i.e. ammonia (NH_4^+) and sulfide ($S^=$), respectively. Organic matter increases and pH decreases (Huchinson, 1957). Such changes often make hypolimnetic water unfit for municipal and industrial purposes and increase the cost of water treatment. For example, water treatment plants in the United States routinely attempt to chlorinate with enough gas that a residual of 1 mg Cl_2/l remains in water. When reduced substances are relatively high in concentration, more chlorine must be used. Hypolimnetic depletion of DO may also lead to undesirable tastes and odors of the water and fish mortality.

Artificial mixing of lakes has been attempted to improve water quality of water taken from the hypolimnion. The strategy is to treat water quality problems in the lake or reservoir and thus prevent downstream water problems and assure the usefulness of the entire water column at all times.

Hooper et al (1953) first attempted artificial destratification of a Michigan lake with limited success, but recent attempts have been more successful (Fast, 1968 and 1971; Riddick, 1957; and Bernhardt, 1967). Lakes have been destratified by mechanical pumping (Hooper et al, 1953; Flick, 1968; Irwin et al, 1966; Steichen, 1974), or by the use of compressed air (aeration) (Riddick, 1957; Meyer, 1962; Ford, 1963; Fast, 1966 and 1968; and

Laverty and Nielson, 1970). Toetz et al (1972) give a recent review of the literature on the subject of artificial destratification and its biological effects.

Although many lakes have been destratified, none have been larger than 320 acres. Moreover, the relative efficiency of most systems is energetically about 1% efficient, so the use of these systems on large lakes would be expensive. Destratification has been attempted on larger reservoirs (Leach 1968; and Bernardt, 1967), but only resulted in decreasing the amount of water in the hypolimnion.

Dr. James Garton, Oklahoma State University, developed an axial pump mixing device that was used successfully to destratify Ham's Lake, a 40 hectare lake near Stillwater, Oklahoma. The Garton device has the advantage of an efficiency about 4-5 times that of conventional systems. It was anticipated that the Garton Pump could be scaled-up and used to keep a larger lake continually destratified.

During the spring of 1973, the Bureau of Reclamation met with representatives of the Oklahoma Water Resources Research Institute and described water quality problems with Arbuckle Lake, Oklahoma, which has a surface area of 2349 acres and is 27 m deep. The lake stratifies early in May and by late June about 42% of the volume contains less than 2 mg/l DO. Severe water quality problems thus develop that interfere with water treatment. Representatives of the Bureau of Reclamation described to us the essential features of a compressed air "gun" that would be used during 1973 to destratify a portion of the lake near the outlet to solve some water quality problems in situ. However, they also felt that Arbuckle Lake would be a good place to test a scaled-up version of the Garton pump.

This research project was initiated to assess the impact of the "gun" that the Bureau of Reclamation operated in 1973 and the impact of the Garton pump, (installed and operated during 1974 and 1975) on water quality and to a lesser extent on the standing crop of plant pigments and seston.

There are three basic ways to assess such impacts. One can compare parameter values between years when the lake was perturbed to (an) other year(s) previously when the lake was not perturbed. This method is preferable as it can account for year to year natural fluctuations. Alternatively, one could compare parameter values before and after artifical mixing began in the same year. In large reservoirs one could compare an area affected by the perturbation to an area not so affected. The latter methods have the obvious disadvantage of not providing true control data. It is possible to separate a body of water mechanically and perturb only one part, using the other as a control, but this is only possible with ponds or small lakes.

The major objective of this research was to compare parameters of water chemistry reported by Duffer and Harlin (1971), when the lake was stratified in 1968, to the same parameters during years when destratification was attempted (1973, 1974, and 1975). It will be shown below that the 1973 and 1974 data sets could also be used as base-line data, i.e. the lake was not destratified during those years as well. Another objective was to describe the impact of artifical mixing on the biomass of seston. Further, since the vertical distribution of many water quality parameters changes markedly after destratification (Toetz, et al, 1972), such changes by themselves can be used as proof that the mixing device functioned as anticipated. For example, the vertical distribution of DO, phosphate (PO_4^{+3}), NH_4^+ and $S^=$ should become orthograde upon destratification and the near-bottom concentration of Mn^{++} should decrease (Toetz, et al, 1972). It was thought that changes in the vertical distribution of DO, PO_4^{+3}, NH_4^+, and $S^=$ at the deepestpoint in Arbuckle would demonstrate the efficacy of the mixing device. Further, a decrease in the concentration of Mn^{++} and an increase in DO near the bottom at a station, which was a considerable distance from the mixing device, would demonstrate the horizontal extent of artifical mixing.

As mentioned above, the Garton pump was used successfully to destratify Ham's Lake during 1973. Steichen (1974) described changes in several aspects of water chemistry and the composition of the algal flora after mixing began in 1973. Although base-line data were not available from a comparable period of the year when the lake was not perturbed, it was desirable to make measurements in 1974 and 1975 when the lake was mixed in an effort to describe long term effects of mixing. For example, does the same successional change always occur in the algal flora upon lake destratification in successive years? Will the concentration of algal nutrients change? How does mixing affect fish distribution in small lakes?

ARBUCKLE LAKE

Description of Lake

Arbuckle Lake is located in Murray County, Oklahoma. The dam impounds Rock Creek immediately below the confluence of Buckhorn and Guy Sandy Creeks. The lake was built by the Bureau of Reclamation in 1966 to provide a supply of municipal and industrial water to Ardmore, Davis, Sulphur, and Wynnewood. Arbuckle Lake has a surface area of about 950 hectares and a maximum depth of 27.5 m at the dam (Duffer and Harlin, 1971). Duffer and Harlin (1971) collected physical, chemical, and biological data on Arbuckle Lake during 1968, which show the lake to be strongly stratified in the summer, and the hypolimnion to be anoxic from June through October. Arbuckle Lake is a warm monomictic lake with August temperatures ranging from 30° C in the epilimnion to 18° C in the hypolimnion.

Sampling Stations

Four sampling stations were established, located in approximately the same position as Duffer and Harlin's stations of 1968 (Figure 1), and numbered 1, 5, 6, and 7. The numbers 5, 6, and 7 correspond to numbers of the stations Duffer and Harlin used in 1968. During 1975 the Oklahoma Water Resources Research Institute (OWRRI) established stations in the lake. The OWRRI stations 1, 5 and 6, described elsewhere,correspond to our stations 7, 6, and 5, respectively. Station 7 was located in the forebay at 24 m. Station 5 was located about 2.25 km from the dam in the Rock Creek arm at 11 m. Station 6 was located 1.75 km from the dam in Buckhorn Creek at 15 m. Station 1 was located at the platform of the aero-hydraulic gun during 1973.

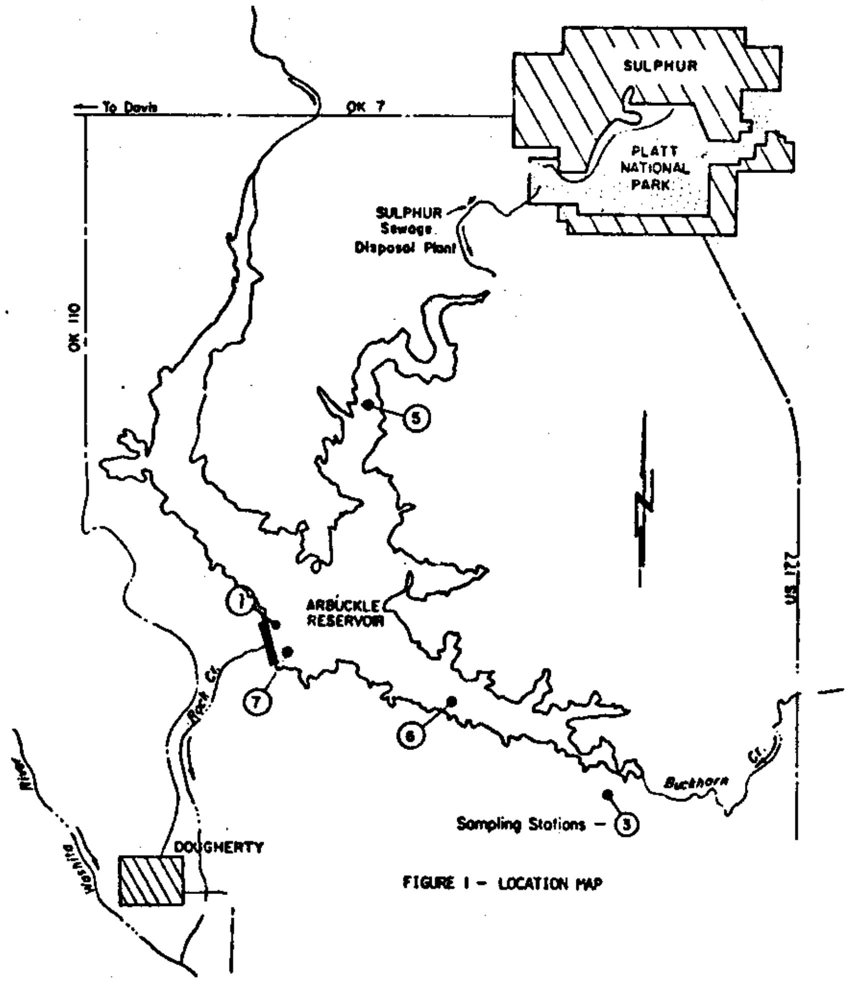

Figure 1. Location map of Arbuckle Lake showing sampling stations used in 1973. Stations 5, 6, and 7 were used by Duffer and Harlin in 1968.

Sampling 1973

Samples were collected at station 5, 6, and 7 at approximately two week intervals from May 1 through September 7, 1973. Station 1 was sampled on June 20, July 10 and 25, and August 7 and 23, 1973. Temperature and the concentration of DO were measured at one meter intervals at all four sampling stations. Triplicate water samples for iron and manganese were taken from near the bottom and transparency measurements were made at stations 5, 6, and 7. Water was collected using a 2 l Van Dorn water sampler at depths of 0, 4, 8, 12, 16, 20, and 24 m at station 7 for chemical analysis. The water was placed in 4 l polypropylene bottles and taken to a portable laboratory located at Arbuckle Lake. Water to be used for $S^{=}$ determinations was placed in 125 ml glass stoppered bottles or graduated cylinders, taking care not to aerate the sample and returned to Stillwater on ice for analysis. Two composite samples of the entire water column were obtained at stations 5, 6, and 7 by pooling like aliquots of water taken with a Kemmerer bottle (or pump) at meter intervals. Two subsamples were taken from each composite for pigment analysis and two subsamples of 100 ml were taken from each composite sample and preserved with 10% Lugol's solution.

Sampling 1974 and 1975

Samples were taken during March, May and June, twice during July and once during August, 1974. Essentially the same sampling methods were used in 1973, 1974 and 1975.

During 1975, sampling was accomplished about every other week with supplemental sampling in early June just after the Garton pump began operation. Although sampling to monitor the impact of this device on a lake should be conducted at other seasons as well (with perhaps the same or greater frequency), observations during pump operation were thought to be most critical.

During 1975 field season, samples were taken at one meter for pigment analysis at stations 5, 6, and 7 and OWRRI station 3 in the Guy Sandy arm of the lake. Duplicate subsamples were taken and the results are used below as an estimate of pigment in the lake at one meter. These further data were used to monitor the lake water for a bloom of algae that might occur immediately after destratification.

Laboratory Methods

Temperature was measured at one meter intervals with a thermistor telethermometer. The concentration of DO was similarly measured with a galvanic oxygen probe and meter or the Alsteberg Modification of the Winkler method (A.P.H.A., 1965). Transparency was measured with a 20 cm Secchi disc. Alkalinity, BOD and pH were measured on unfiltered lake water, using the procedures in A.P.H.A., 1965, and a Beckman and/or Corning pH meter, respectively.

Water samples were taken with a Kemmerer bottle or (at Arbuckle during 1975) by pumping. Water for chemical analysis was filtered through Reeve Angel (RAF) or Gelman Glass fiber filters at Arbuckle and 0.45 u Millipore filters at Ham's Lake. Methods of storage are given in Table 1 for samples that were not immediately analyzed upon return to Stillwater. Usually samples were analyzed for NH_4^+, $S^=$, and PO_4^{+3} upon returning to Stillwater and for nitrate (NO_3^-) and nitrite (NO_2^-), no more than a few days later. Pigments were always measured within 18 to 24 hours after extraction began. Samples were transported in ice water.

Muffled Reeve Angel (RAF) filters were used to retain seston for determination of particulate carbon (PC), particulate nitrogen (PN) and the concentration of plant pigments. The filtrate of water samples filtered through RAF filters for the determination of PC or PN was used to estimate the concentration of dissolved organic carbon (DOC) and dissolved organic nitrogen (DON). In this paper, DOC represents the difference between the concentration of total carbon and the concentration of inorganic carbon in the filtrate. DON is the concentration of nitrogen in the filtrate determined by a micro-kjeldahl method, and the concentration of NH_4^+. Kjeldahl nitrogen (KN) was determined during 1973 and 1974 as DON + PN.

Table 1. Methods used to preserve samples and storage procedures, when employed. Conc.= concentrated.

Parameter	Preservative	Stored At	Storage Container
NO_3^-	none	5° C	polyethylene
NO_2^-	none	5° C	" "
NH_4^+	none	5° C	" "
PO_4^{+3}	none	5° C	polypropylene
PN	desiccation	room temperature	glass or aluminum foil
PC	desiccation	room temperature	glass or aluminum foil
KN	40 mg $HgCl_2$/l	5° C	glass
DON	2 ml conc. H_2SO_4	room temperature	glass
DOC	2-3 ml conc. H_2SO_4	room temperature	glass
Mn^{++}, Fe^{++}, Ca^{++}, Mg^{++}, Na^+, SO_4^{-2}, Cl^-	2-3 ml conc. HNO_3	room temperature	polyethylene
Pigments	90% acetone	5° C in ice chest or refrigerator	glass

Methods for the analysis of NH_4^+ followed Solórzano (1969). Strickland and Parsons (1968) was used for the following analyses: NO_3^-, NO_2^-, reactive phosphate $(PO_4)^{+3}$, PC, $S^=$, and PN during 1974. During 1973 PN analyses were accomplished on a Coleman Nitrogen Analyzer II.

During 1973 samples for $S^=$ were taken in graduated cylinders or reagent bottles with tightly fitting glass stoppers and reagents were added at Stillwater about a day later. Laboratory investigation showed only 5 to 10% $S^=$ was lost in transit. During 1974 and 1975 reagents were added in the field.

Anlayses for sulfate $(SO_4)^{-2}$ followed A.P.H.A. (1965). Chloride $(Cl)^-$ was determined using a specific ion electrode marketed by Orion Research. A Varian Techtron Atomic Absorption Spectrophotometer was used to analyze for the following metals: iron (Fe^{++}), manganese (Mn^{++}), calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^+), and potassium (K^+). Methods for plant pigments follow Strickland and Parsons (1968) using equations of Parsons and Strickland (1965). Extraction with 90% acetone lasted 18-24 hours. Algae enumeration followed methods of McNabb (1960).

Destratification Methods Used in 1973

The aero-hydraulic gun (Figure 2) was located near the water intake structure in the dam in about 20 m of water. It consisted of several sections of vertical pipe (61 cm diameter) suspended from a platform. The total length of the pipe was 16 m. Located at the bottom of the pipe was an air trap which intermittently released large air bubbles. Compressed air was supplied from a shore-based compressor to the trap. When the trap or chamber located below the pipe was full, it would release a large bubble of air. This bubble fit snugly in the pipe and would act as a piston which forced water from above the bubble to the surface. This pumping action is designed to mix the strata of water. As the water from the bottom reached the surface it would gain heat and dissolved oxygen and therefore break up stratification. The expected volume of water to be pumped was 14, 177 m^3 daily (U.S. Department of Interior, Pers. Comm., 1973). The aerator was operated and maintained by the Bureau of Reclamation. It ran continuously from July 10 until October 1, 1973, except for short service shutdowns.

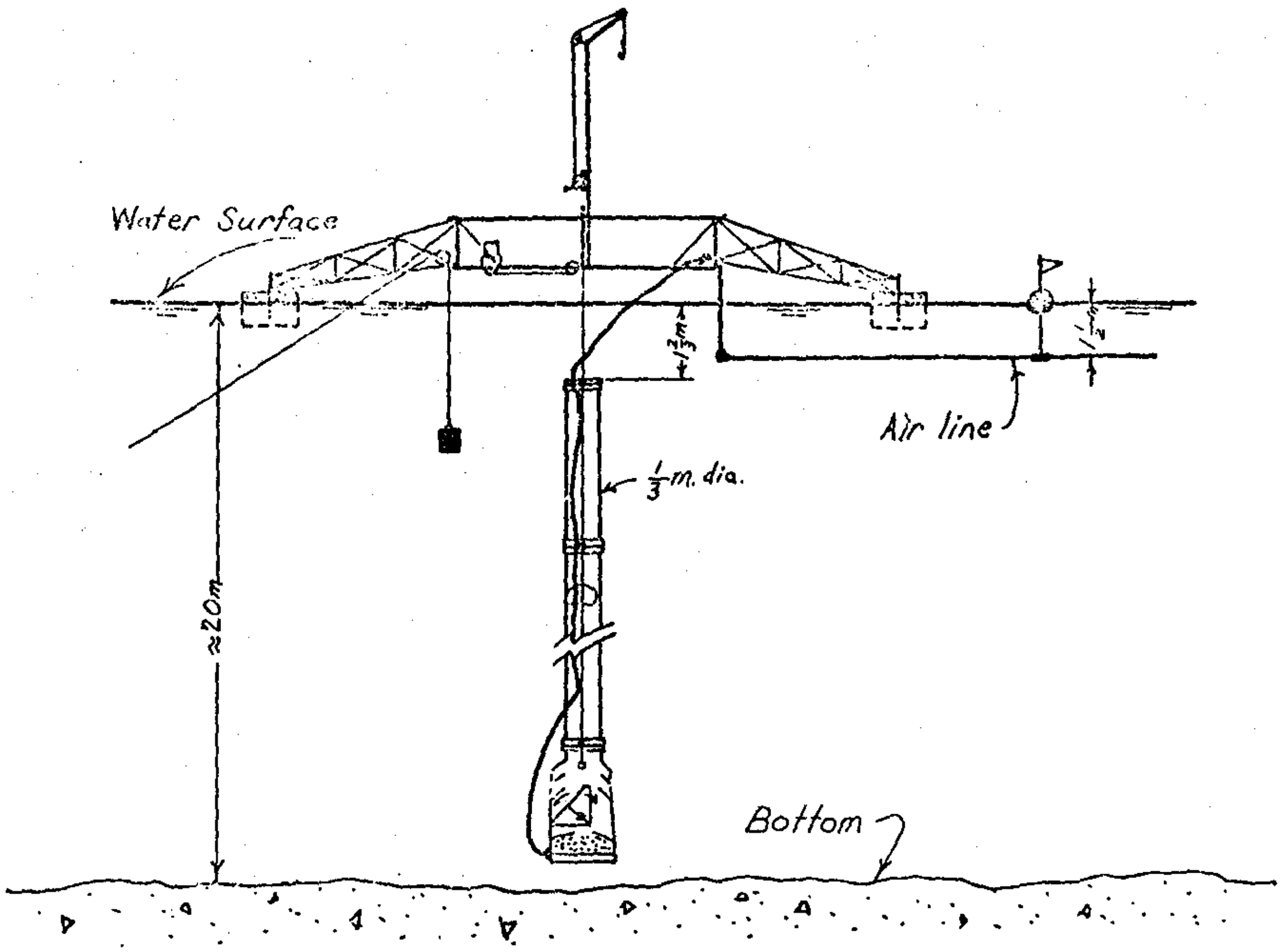

Figure 2. Side view of air "gun" used on Arbuckle Lake during 1973.

Garton Pump 1974 and 1975

The Garton pump (Figure 3) was used in both years. However, the design of the pump was slightly different in 1975. Details are found elsewhere. Table 2 contains data on length and frequency of operation. It can be seen that destratification was attempted in July and August in 1974 and between June and September, 1975, except for brief periods of service or malfunction. Mechanical problems in 1974 prevented less than full scale operation in Arbuckle Lake.

The Garton pump is an axial flow type pump constructed by suspending propellors from a raft. It was driven with an electric or gasoline motor (Figure 3). In contrast to other destratification devices, surface water is moved downward instead of upward, creating general turbulence throughout the whole basin.

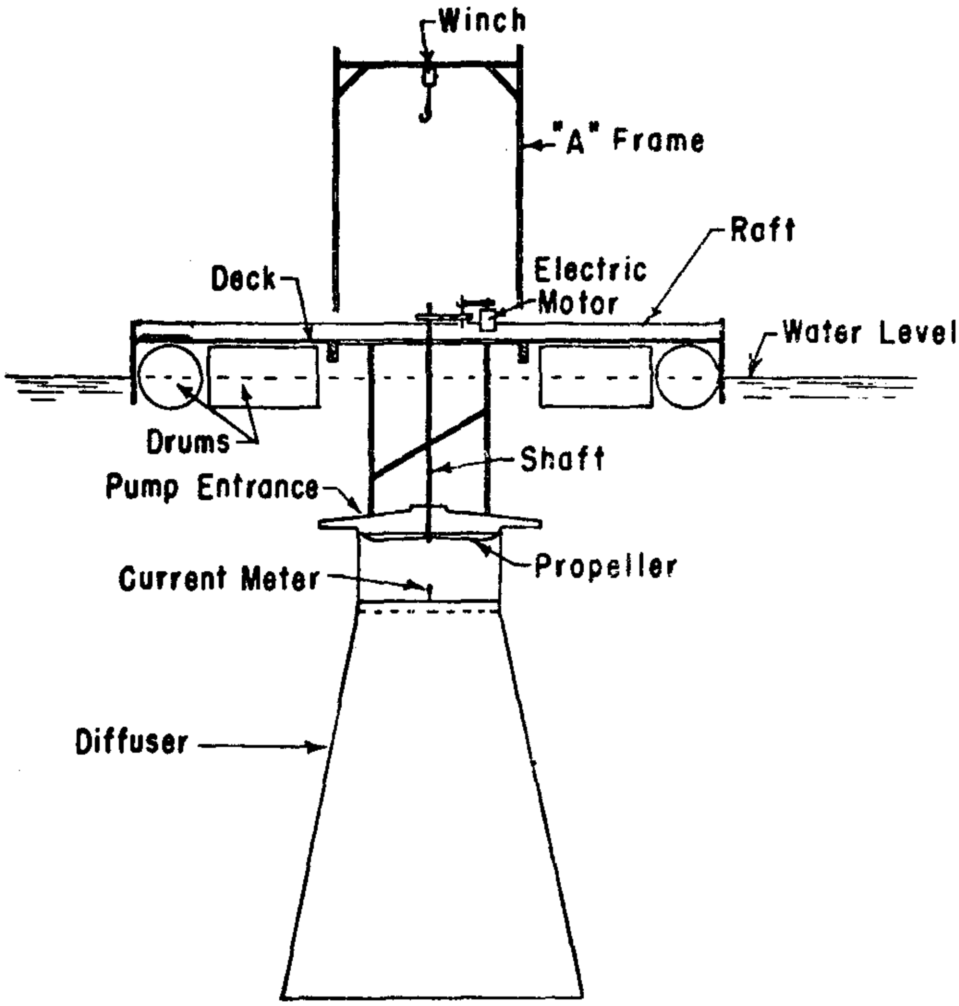

Figure 3. Side view of the Garton pump used at Ham's Lake during 1973.

Table 2. Length and frequency of operation of the Garton pump at Arbuckle Lake and Ham's Lake during 1974 and 1975.

Lake	Year	Beginning Date	Ending Date
Arbuckle	1974	July 17	Sept. 1
	1975	June 2	Sept. 13
Ham's	1974	May 13	Sept. 26
	1975	June 19	Oct. 10

RESEARCH PROJECT ACCOMPLISHMENTS -- ARBUCKLE - 1973

Limnology

The objectives of this research were (1) to describe the effects of lake aeration by the aero-hydraulics gun on water chemistry of Arbuckle Lake and (2) to describe the effects of aeration on the abundance and taxa of algae and the mass of chlorophyll a.

Background data existed in the literature on water chemistry in 1968, when the lake was not stratified (Duffer and Harlin, 1971). We monitored changes in biological and chemical parameters they measured at the same stations that they used during 1968. See above for details. In addition, after the Bureau of Reclamation had installed their aeration device an additional sampling station (1) was established about fifty meters from this device toward the dam. Temperature and oxygen were measured at meter intervals at station 1 during the time the device was operated.

The profile of dissolved temperature and oxygen at both stations 1 and 7 was essentially the same (Figures 4 and 5). Figure 5 shows slightly more dissolved oxygen in the epilimnion at station 7 than at station 1. The aeration device, therefore had little effect on the vertical profile of temperature and oxygen in Lake Arbuckle. Further, no effect was exerted on temperature and oxygen profiles at stations far removed from the aerator. I conclude that data obtained from stations 5, 6 and 7 represent data obtained during a summer when the lake was stratified.

The data obtained on other aspects of water chemistry during 1973 generally reflect the effects of lake stratification on the vertical distribution of most of the chemical species normally measured in lakes. These data will be

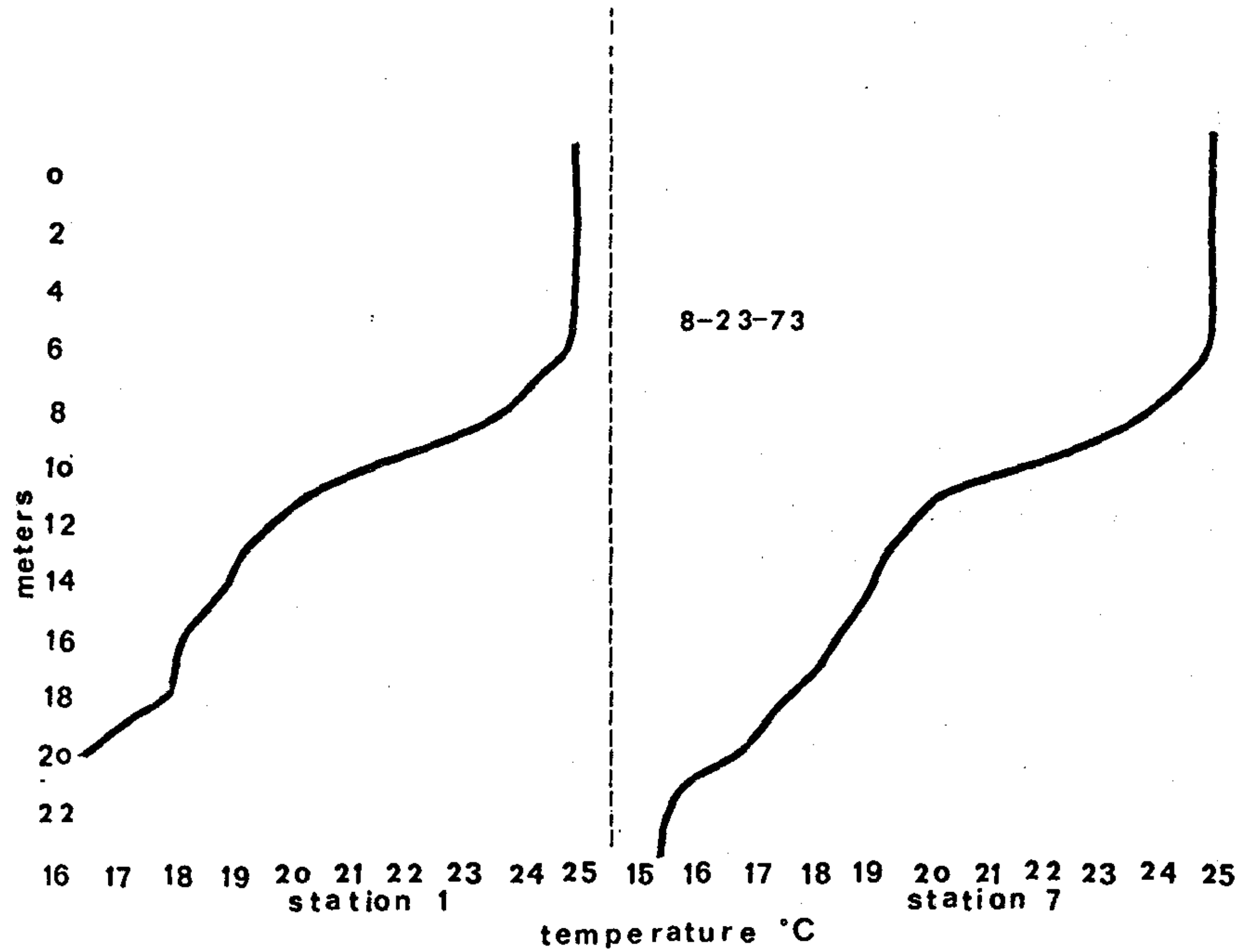

Figure 4. Vertical profile of temperature at stations 1 and 7, respectively, on August 23, 1973.

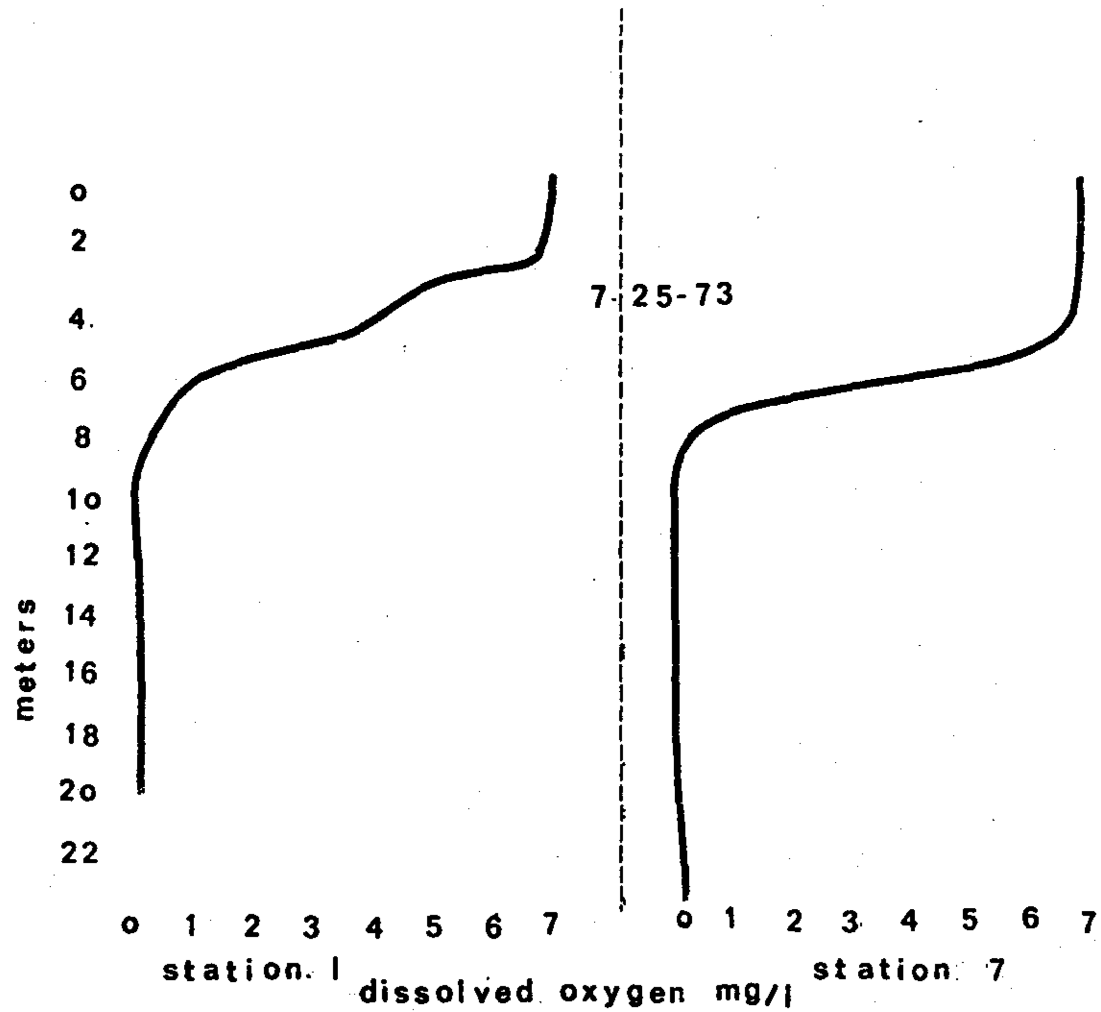

Figure 5. Vertical profile of dissolved oxygen at stations 1 and 7, respectively, on July 25, 1973.

presented and discussed below in the section on the comparative limnology of Arbuckle Lake. Basically, the data of 1973 and 1974 show that Arbuckle Lake stratified normally and its limnology was little changed since 1968.

Productivity and Turnover

A pilot study was conducted to learn if any differences existed between newly upwelled water and water from the euphotic zone of the undisturbed lake in terms of nutrients, biomass, algae, productivity, and turnover.

Early on the morning of August 7, 1973, water samples were taken at a depth of one meter at Station 7 and at Station 1 near the overflow boil of the aerator. Nutrients, biomass and algal density were determined as above. Productivity and turnover were determined by the ^{15}N method, described by Toetz, et al. (1973). In this method the uptake of nitrate is observed at serially increasing concentrations of the nutrient (substrate). The uptake can be described by the Michaelis-Menten model:

$$v = V_{max} S/K_s + S,$$

where v is the nitrate uptake rate, V_{max} is the maximum rate of uptake, S is the concentration of nitrate and K_s is the half saturation constant, and equivalent to S where $v = V_{max}/2$.

Productivity is estimated by V_{max} or by v measured at ambient levels of substrate. K_s gives insight into the adaptive capacity of populations to take up nitrate. Low values of K_s for a population indicate a highly adaptive capability to compete for nutrients. Turnover time can be estimated by assuming ambient S does not change, i.e., the system is at steady state. If v can be estimated for the ambient value of S, then the turnover time is equal to S/v. For example, if S = 100 micromoles per liter and v is 5 micromoles per liter per hour, then the turnover time is 20 hours.

The results of this experiment showed little difference in nutrients, biomass and algal density (Table 3). Nitrate and nitrite were undetectable in both samples. Ammonia was absent at Station 1 but present at Station 7. Chlorophyll a biomass was not significantly different between the samples, even though differences appear large. Differences between stations existed for particulate nitrogen, but the absolute difference is still only about 10% of the estimate. In no case was an algal species present in large numbers (1000 organisms/ml) in one sample but not in the other (Table 4).

Unfortunately, there was insufficient label to estimate v at near ambient levels of S. Hence, only V_{max} was estimated and the respective values for Stations 1 and 7 were 4.0 $\pm$ 2.4 and 5.8 $\pm$ 6.5 micrograms nitrate nitrogen taken up per liter per hour.

In this case then, there was little difference between nutrients, biomass, algal density, and productivity in newly upwelled water and water taken from a nearby undisturbed area of the lake. The study further demonstrated that the biomass, nutrient and algal parameters were almost identical, thus allowing one to use the sample from the water mass as a control in productivity studies. The reason the method is apparently useful is that the aeration device takes water from within a rather shallow

Table 3. Concentration of nitrate, nitrite, ammonia, particulate nitrogen and chlorophyll *a* at one meter at Stations 1 and 7. Station 1 is in the upwelling region. Concentrations as micrograms per liter.

	NO_3-N	NO_2-N	NH_4-N	Particulate Nitrogen	Chlorophyll *a*
Station 1	-0-	-0-	-0-	110.5 $\pm$ 3.4	2.0 $\pm$ 10.1
Station 7	-0-	-0-	14	97.7 $\pm$ 5.8	3.0 $\pm$ 6.5

Table 4. Density of algae in water samples taken at one meter at Station 1 and 7, respectively, on August 7, 1973. Density as cells or filaments per ml. A plus sign indicates the organism was observed in scanning and a minus sign means the species was not observed.

Algae	Station 1 Subsample		Station 7 Subsample	
	A	B	A	B
Melosira distans	1,270	1,270	761	1,270
Melosira granulata	-	-	+	251
Cyclotella	3,551	1,772	2,031	3,042
Navicula	1,521	1,521	3,042	1,521
Synedra	2,532	2,030	3,042	2,030
Nitzschia	251	+	+	+
Cymbella	+	251	-	-
Anabaena	+	+	+	251
Oscillatoria	+	+	+	+
Pediastrum	251	+	251	251
Euglenoids	760	3,042	761	2,791
Amphora	-	-	251	+
Scenedesmus	-	-	+	+

depth of the epilimnion and that the epilimnion is rather deep and uniformly mixed. This conclusion is no doubt unique to this lake and the type of aeration device employed, however. It is quite clear that if the observations are to be repeated, more effort needs to be made in obtaining truly representative samples of the different water masses.

RESEARCH PROJECT ACCOMPLISHMENTS -- ARBUCKLE - 1974

Two objectives of this research were (1) to describe the effects of the Garton pump on water chemistry of Arbuckle Lake and (2) effects of the Garton pump on the abundance of taxa and algae and the mass of chlorophyll a. The additional objectives that were described in the proposal for FY 1974 were not pursued, i.e. the objectives to describe the effect of continuous mixing on phytoplankton productivity and on the sediments. Completion of these objectives was not feasible because of a manpower shortage, and because I had the opportunity to enlarge the number of observations at Ham's Lake where Dr. Garton had successfully used his pump. Therefore, during 1974 I made extensive limnological observations on Ham's Lake during July and August to provide more data for parameters, i.e., NH_4^+, NO_3^-, NO_2^-, PO_4^{+3}, dissolved organic matter, chlorophyll a, etc. Samples were also taken for enumeration of algae to learn the most reliable method to sample the algal flora. Results for Ham's Lake are described below in the section on Ham's Lake.

The procedures for the 1974 work on Arbuckle Lake were basically the same as those used in 1973. Background data on water chemistry was available for 1968 and 1973, when the lake stratified normally. We set out to compare the 1974 data to the background data, using the same stations and methods as those employed in 1973. In addition, after the Garton pump was installed, additional sampling stations were established next to the pumping device, and about 30, 60, and 200 m away. Temperature and oxygen were measured at meter intervals at the mixing device (Station 1) and elsewhere during the time the pump was operated.

By early August the Garton pump had disturbed the water column within about 200 m of the pump (Figures 6 and 7). There was a clear increase in oxygen below the region of the thermocline at 10 m, but the thermal profiles reveal little disturbance of the water column. However, during the period when we made measurements, these changes had extended only partially to sampling station 7, and not at all to stations 5 or 6, respectively.

If the vertical profiles of temperature and dissolved oxygen are compared between 1968, 1973 and 1974, the conclusion is reached that the lake as a whole stratified normally and that the effects of the Garton pump operated in 1973 were relatively local. For example, the profiles of temperature at station 7 are nearly alike (Figure 8) in the three years at comparable dates. A similar conclusion can be made for dissolved oxygen at station 7 (Figure 9). Thus, the Garton pump had a local effect and no such changes were observed elsewhere in the lake. We concluded that data obtained from stations 5, 6 and 7 essentially represent data obtained during a summer when the lake was not destratified.

The data obtained on water chemistry during 1974 generally reflect the effects of lake stratification on the vertical distribution of most of the chemical species normally measured in lakes. These data are discussed below in a comparison between years.

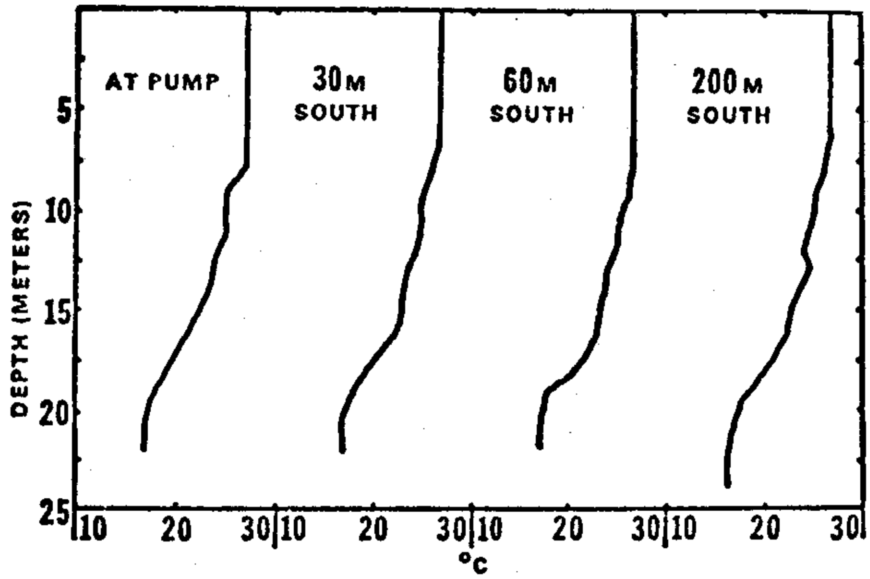

Figure 6. The vertical distribution of temperature in the vicinity of the Garton Pump during 1974.

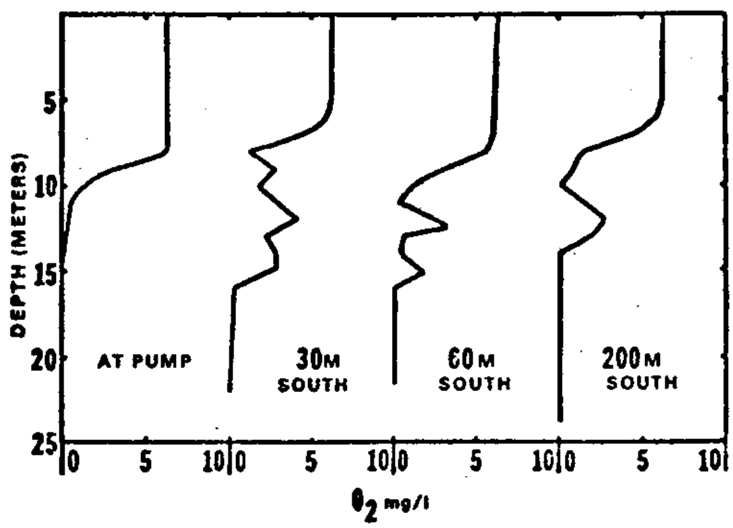

Figure 7. The vertical distribution of dissolved oxygen in the vicinity of the Garton pump during 1974.

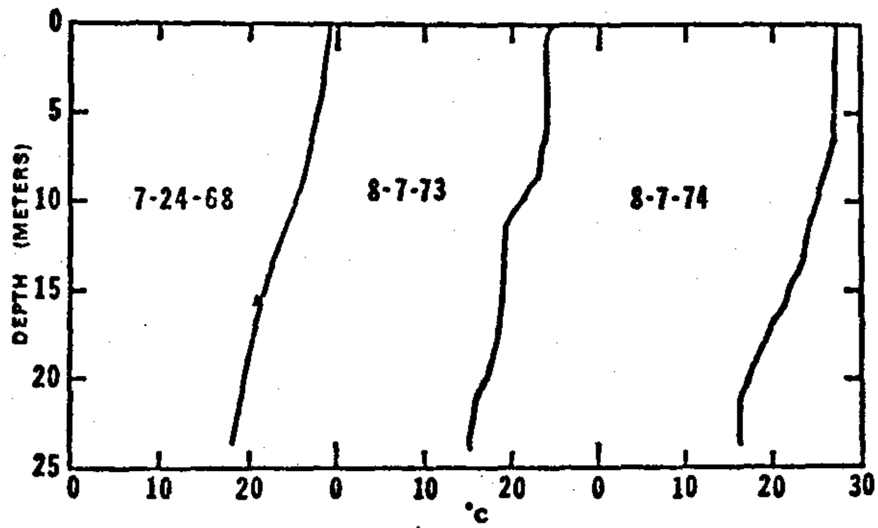

Figure 8. The vertical distribution of temperature at station 7 during midsummer in 1968, 1973 and 1974.

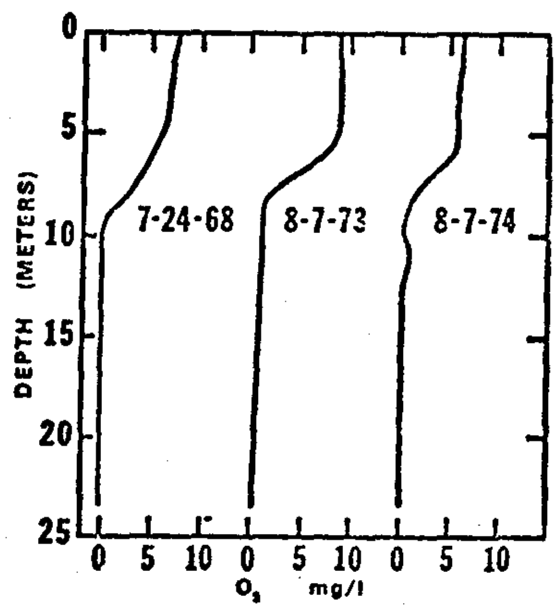

Figure 9. The vertical distribution of dissolved oxygen at station 7 during midsummer in 1968, 1973 and 1974.

RESEARCH PROJECT ACCOMPLISHMENTS -- ARBUCKLE - 1975

The 1975 research objectives were identical to those of 1974. The Garton pump began operation on 2 June. The pump operated until 13 September, although it was periodically shut down (Table 2).

Destratification was not achieved during 1975 and the vertical profiles of DO and temperature during 1968, 1974 and 1975 were basically the same (Figure 10). However, by 25 July 1975, the difference in water temperature between the surface and 24 m at station 7 was 6 C, whereas in previous years it was 14 C (1974) and 11 C (1968). Therefore, the Garton pump increased the heat budget of the lake.

Other data on water chemistry show that the lake was stratified during the summer of 1975 and chemical species such as sulfide, ammonia, BOD, and DOC had clinograde profiles at station 7 (Figure 11). These data are discussed below.

Increasing the heat budget during 1975 had no effect on the biomass of algae, the standing quantity of chlorophyll *a*, since the range of concentrations determined during 1975 was similar to the range of concentrations determined during 1973 and 1974 (Figure 12), when the heat budget was not increased. The concentrations reported in Figure 12 are for the entire water column and this is the reason concentrations are lower at station 7 where the lake is 24 m deep than at station 5 or 6 where the lake is 11 and 15 m deep. Concentrations of chlorophyll *a* in the euphotic zone (1 m) during 1975 ranged from 5.3-14.6 mg $(m)^{-3}$ indicating a mesotrophic status for Arbuckle Lake. Further, there was a tendency for concentrations to decrease during the course of the summer (Table 5). The dominant algal species in Arbuckle Lake during the summer are desmids, diatoms, phytoflagellates, and bluegreen algae (Table 6). The most abundant desmid was *Pediastrum simplex*; *Melosira distans* the most abundant diatom. Bluegreen

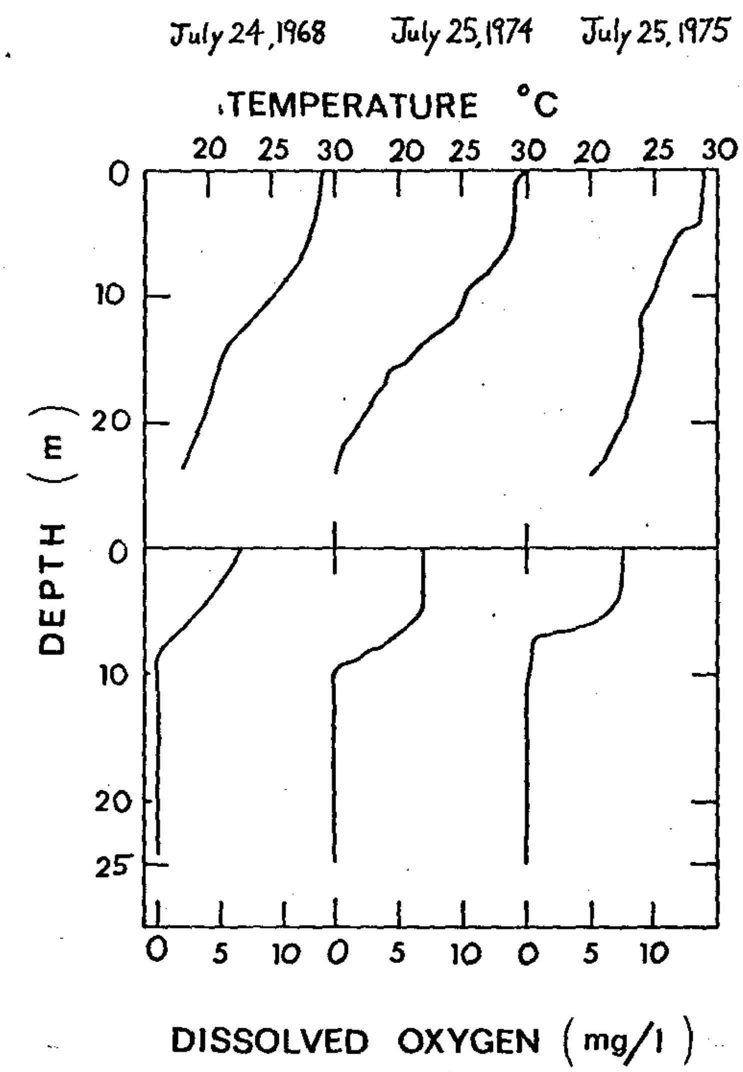

Figure 10. Vertical distribution of temperature and dissolved oxygen at Station 7 at Arbuckle Lake during 1968, 1974 and 1975.

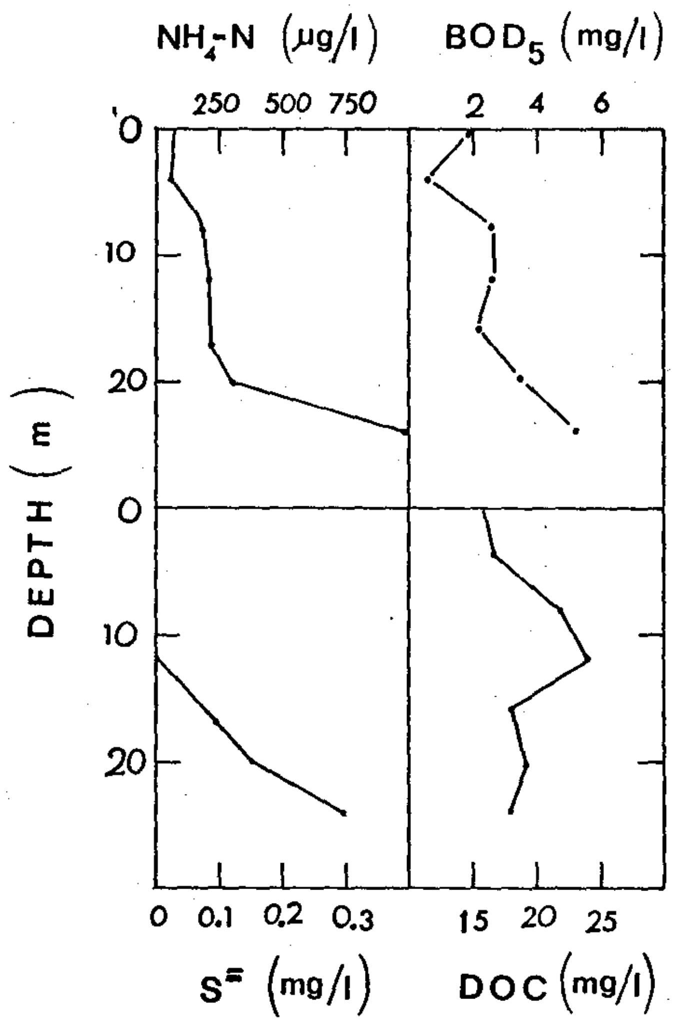

Figure 11. Vertical distribution of ammonia, sulfide, dissolved organic carbon (DOC) and 5 day BOD at station 1 at Arbuckle lake on 25 July, 1975.

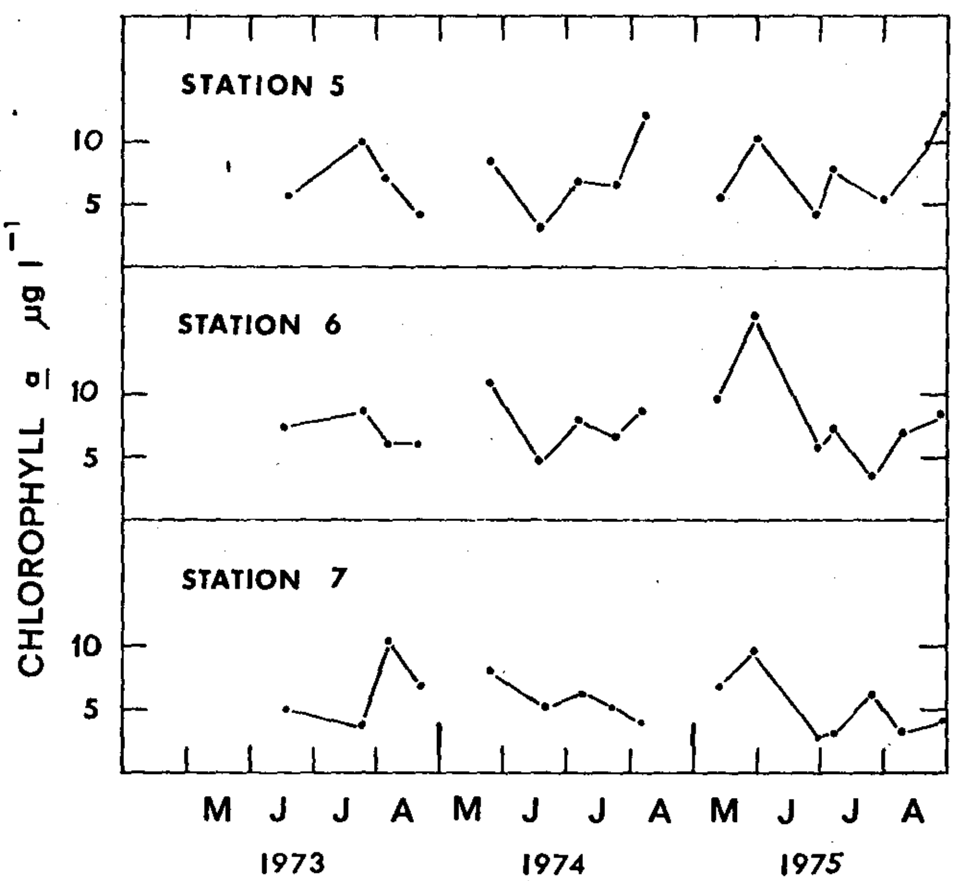

Figure 12. Mean concentration of chlorophyll a in the water column at three stations at Arbuckle Lake.

Table 5 . Mean concentration as micrograms per liter of chlorophyll *a* at one meter at Arbuckle Lake during 1975.

Date	Mean	Lower Confidence Limit	Upper Confidence Limit
5/13	8.0	6.9	9.1
5/29	14.6	10.5	18.7
6/2	9.4	4.7	14.1
6/10	12.7	4.4	21.0
6/25	7.7	4.1	11.2
7/8	6.6	5.5	7.7
7/25	7.4	4.2	10.5
8/7	5.3	4.6	6.0
8/30	9.8	8.0	11.5

algae were relatively more abundant during late summer. The algal flora in 1975 was similar in composition to the composition of the flora in 1974.

Table 6 . Density of algae as numbers per ml in Arbuckle Lake during 1974.

	Date			
CHLOROPHYTA	5/23	6/21	7/9	7/25
Ankistrodesmus sp.	17.7	5.4	--	0.2
Closterium sp.	0.2	0.5	--	4.3
Coelastrum microporum	7.6	0.9	0.7	+
Cosmarium sp.		0.3	0.2	1.1
Kirchneriella sp.		--	--	+
Pediastrum simplex	132.4	64.1	58.4	19.0
Scenedesmus sp.	1.3	--	0.5	--
Staurastrum sp.		0.3	0.3	1.4
Tetraedon sp.		--	--	--
CHRYSOPHYTA				
Asterionella formosa	--	--	--	0.2
Caloneis amphisbaena	--	--	--	+
Caloneis bacillum	--	--	--	+
Caloneis sp.	--	--	--	0.2
Cocconeis placentula	--	0.3	--	--
Cyclotella meneghiniana	--	0.5		0.6
Cymbella tumida	--	--	--	--
Cymbella turgida	--	--	--	--
Cymbella ventricosa	0.1	--	--	0.2
Diatoma vulgare	--	--	0.2	--
Diploneis smithii	0.1	--	0.2	0.6
Epithemia sorex	--	--	0.2	--
Fragilaria crotenensis	--	0.3	--	+
Fragilaria sp.	--	0.3	--	+
Gomphonema augustatum	1.0	--	0.2	0.2
Gomphonema olivaceum	1.7	0.2	0.2	0.9

	5/23	6/21	7/9	7/25
Gyrosigma spencerii	--	--	--	--
Mallomonas sp.	--	--	--	1.8
Melosira distans	8.0	52.0	66.2	30.6
Melosira granulata	--	0.5	0.9	1.1
Melosira varians	--	--	--	--
Navicula elginensis	--	0.3	--	--
Navicula lacustris	0.7	0.8	--	2.8
Navicula seminulum	--	--	--	--
Navicula sp.	0.2	0.2	--	--
Nitzschia acicularis	--	--	--	--
Nitzschia dissipata	+	--	0.3	3.9
Nitzschia filiformis	0.1	--	--	--
Nitzschia parvula	--	--	0.2	--
Nitzschia sigmoidea	+	--	--	0.2
Nitzschia tryblionella	+	--	--	--
Rhoicosphenia curvata	+	--	--	--
Stephanodiscus astrae	7.7	3.4	0.8	--
Surirella brightwellii	--	--	--	--
Synedra sp.	--	--	8.7	67.2
Synedra ulna	--	--	0.2	6.2
CYANOPHYTA				
Anabaena sp.	0.4	+	0.2	5.6
Aphanizomenon flos-aquae	--	--	--	--
Merismopedia sp.	--	--	--	--
Oscillatoria sp.	0.2	--	3.2	37.9

	5/23	6/21	7/9	7/25
EUGLENOPHYTA				
Euglena sp.	--	3.5	3.7	21.3
Phacus sp.	--	--	--	1.0
PYRROPHYTA				
Ceratium hirundinella	0.3	6.9	1.0	1.8
Glenodinium pulvisculus	--	--	--	0.3

COMPARATIVE LIMNOLOGY -- ARBUCKLE - 1968-1975

This discussion is limited to data collected during the summer months, when water quality problems are most acute. Figure 11 shows the vertical distribution of four water quality parameters that affect Cl_2 demand, directly or indirectly. The salient feature of these profiles is that highest concentrations are reached at 24 m. The region of the lake below 20 m is isolated from the rest of the lake between early May and late October so reducing conditions at 24 m are common.

The epilimnion exists between 7-10 m, the exact depth shifting from day to day,depending upon how deep wind-driven currents erode the hypolimnion. Another thermocline exists below 20 m, which effectively remains in place from May to October.

Further analysis focuses on the region 8-20 m, because this region is frequently anoxic and contains reducing compounds. The volume of this region can be improved through artificial aeration. Hereafter, the region between 8 and 20 m will be called hypolimnion I (H-I).

Frequently, reducing compounds are highest in concentration at 20 m, at the bottom of H-I. Since outlet depth is at 6.4 m (21 ft.), which is in the epilimnion, it is difficult to see why water quality problems develop. The concentrations of reducing compounds are far lower at 8 m than 20 m. However, both BOD and DOC are frequently very high at the bottom of the epilimnion or the top of H-I (Figure 11) and organic matter in this region may exert a higher than expected Cl_2 demand. The reason for the relatively high concentration of DOC at the top of H-I is probably due to decomposition of organic matter "raining" down from the epilimnion.

It may be that lowering of the epilimnion in Arbuckle Lake would be more useful than aerating the entire H-I because the region of organic matter accumulation would be shifted downward, away from the outlet depth.

Water quality in H-I is compared between years in Table 7. Comparison is made between two dates late in July and August 1968, 1973 and 1975. Data taken at 8, 12, 16 and 20 m in 1973 and 1975 are compared with data taken by Duffer and Harlin (1971) at 9.1, 13.7, 18 and 22.8 m, during 1968. BOD data are compared for data taken during late June in 1968 and 1975.

I conclude from the above data that the water quality in H-I has not appreciably changed since 1968. Some parameters, such as pH, are remarkably constant from year to year. Plant nutrients such as PO_4^{+3} and NH_4^+ show considerable variation, but considering their high rates of turnover, the variability shown in Table 7 is not surprising. Alkalinity and $S^=$ apparently decreased over the years, but such changes may be the result of differences in methods of making measurements. Table 8 shows that Secchi disc transparency and dissolved oxygen at 10 m have remained relatively constant between 1968 and 1975. Temperature at 10 m shows considerable year to year variation, depending perhaps on the heat budget for the year. Concentrations of conservative elements such as Na, Ca and K did not change. In summary, there is no evidence to suggest that the water chemistry of Arbuckle Lake during the summer has changed between 1968 and 1975.

Table 7. Concentration or value and 95% confidence intervals for selected water quality parameters during July and August between 8 and 20 m in Arbuckle Lake at Station 7.

Parameter	Year	Units	Mean	95% Confidence Limits
NH_4-N	1968	micrograms/l	283	72-546
"	1973	"	61	22-124
"	1975	"	171	112-228
Alkalinity	1968	milligrams/l	170	161-179
"	1973	"	150	142-156
"	1975	"	128	125-132
pH	1968	-------	7.28	7.04-7.52
"	1973	-------	7.55	7.41-7.69
"	1975	-------	7.30	7.26-7.34
Sulfide-S	1968	milligrams/l	0.27	0.06-0.46
"	1973	"	0.02	0.01-0.02
"	1975	"	0.06	0.01-0.11
Manganese	1968	milligrams/l	0.53	0.05-1.01
"	1973	"	0.40	0.21-0.59
"	1975	"		
Phosphate-P	1968	micrograms/l	117	15-219
"	1973	"	13	3-23
"	1975	"	9	3-15
BOD_5	1968	milligrams/l	2.10	0.98-3.22
"	1975	"	2.82	2.42-3.21

Table 8. Concentration of important water quality parameters at 10 m and depth of the Secchi disc in Arbuckle Lake during June, July and August.

Parameter	Year	Units	Mean	95% Confidence Interval
Dissolved oxygen	1973	mg/l	0.66	0-2.45
	1974	"	0.56	0-2.32
	1975	"	0.53	0-2.36
Temperature	1973*	°C	20.5	16.5-24.5
	1974	"	26.1	25.5-27.0
	1975	"	24.8	23.3-26.3
Secchi disc	1973	m	1.80	1.17-2.43
	1974	m	1.50	1.28-2.72
	1975	m	1.60	0.97-2.23

*1973 data are systematically too low by 2° C.

HAM'S LAKE

Description of Lake

Ham's Lake is a flood detention reservoir located about five miles west of Stillwater, Oklahoma. It was built by the Soil Conservation Service. It has a surface area of 40 hectares and a volume of 115 hectare-meters when spillway elevation is 287.0 meters above sea level (Steichen, 1974). The greatest depth is about 9.5 meters. Although it is a relatively shallow lake, it is often thermally stratified. The epilimnion is 4 m deep and a thermocline extends from 4 m to the bottom. There is no true hypolimnion. When stratified, the surface water is often supersaturated with dissolved oxygen. Below 4 m DO is often zero (Steichen, 1974).

Ham's lake was used for a caged catfish farming operation during 1971 and 1972. During this time large quantities of organic matter were added to the lake in the form of uneaten feed and catfish waste. The catfish farming operation was terminated by a catastrophic fish kill during August, 1972. Steichen (1974) reports that the lake suddenly turned over during cool, cloudy weather and that DO decreased to very near zero and ammonia and hydrogen sulfide were mixed throughout the water column. About 200,000 catfish died, even those directly next to two aerators. Apparently no wild catfish died.

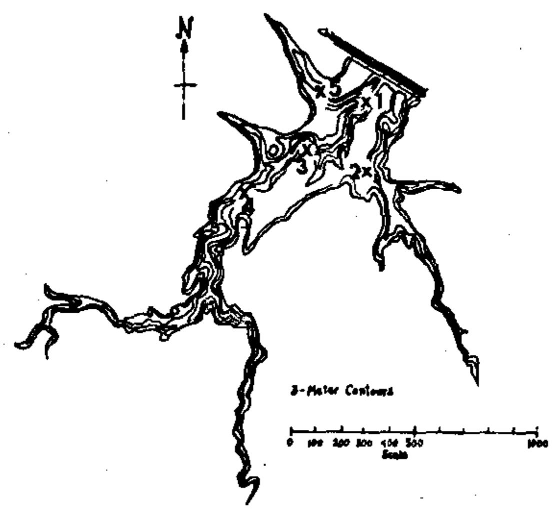

Figure 13. Contour map of Ham's Lake showing sampling stations used during 1975. Linear scale is in meters.

Sampling Stations

Five sampling stations were established (Figure 13). Samples for chemical parameters were taken at station 1, which was at a depth of maximum depth near the dam.

Sampling 1974

Samples for chemical analyses and pigments were taken at the surface, 5 m and 9 m at station 1 twice during July and once during August. At these times data on temperature and DO were obtained at one meter intervals using a telethermometer thermistor and galvanic oxygen probe and meter. Algae samples at each station were obtained by lowering a rubber hose 3 m below the surface, constricting the top end and emptying the contents into a bucket. Aliquots of the same volume taken at each station were pooled to obtain composite samples for the lake. This sampling program was not an effort to describe the flora during 1974, but an attempt to learn the way to sample the lake reliably for the 1975 field season.

Limnological Sampling 1975

Samples were obtained routinely between May and September at 3-day intervals. Chemical parameters were obtained at Station 1 at the surface, 4 m and 8 m. Every three days PO_4^{+3}, alkalinity and pH were measured; other chemical parameters, which were also measured at Arbuckle Lake, were sampled about every other week.

Samples for pigments were taken at each station with the rubber hose technique described above; duplicate subsamples were obtained. Secchi disc depth was also obtained at each station as well as a sample of algae. Algae samples were obtained and handled as in 1974.

Temperature and DO were also obtained as above, at one meter intervals, however, supplemental DO data using the Winkler method were obtained to check the accuracy of the probe and meter. Lake level was measured with a permanent pole gauge. Laboratory methods used for Arbuckle samples were also used at Ham's Lake with some differences (described above). During 1975 measurements of volatilization rate for ammonia were not accomplished because the methodology on hand was not sufficiently precise.

Laboratory Methods

Laboratory mehtods used at Ham's Lake were identical to those used at Arbuckle Lake during 1974 - 1975 described on pages 9-11 above.

Destratification Methods

The Garton pump is described above on page 14. Operation dates of the Garton pump (Figure 3) is in 1974 and 1975 is given in Table 2, page 16.

RESEARCH PROJECT ACCOMPLISHMENTS -- HAM'S LAKE -- 1974

The objectives of this research were (1) to describe the effects of lake mixing on water chemistry of Ham's Lake and (2) to describe the effects of aeration on the abundance and taxa of algae and the mass of chlorophyll *a*.

Background data existed in the literature on water chemistry before and after the outset of artifical mixing (Steichen, 1974) but only for pH, alkalinity and algal density. We monitored additional biological and chemical parameters at the station in the deepest part of the basin that Steichen used during 1973. The following aspects of water chemistry were monitored at Station 1 during 1974: nitrite, nitrate, ammonia, reactive phosphate, manganese, iron, pH, alkalinity, DOC, PC, and chlorophyll *a*. Four additional stations were established for sampling of algal density.

Limnological data were obtained during July and August when the lake was being circulated continuously. Usually the lake was not thermally stratified, but DO was often rather low below 4 m (Table 9). Several reduced compounds were high near the bottom, indicating stratified conditions (Table 10). There were somewhat higher concentrations of reduced substances at 9 m, indicative of stratified conditions; *i.e.* NH_4^+, PO_4^+, and $S^=$. However, the reducing conditions observed are not extreme.

Table 9. Water temperature and the concentration of dissolved oxygen in Ham's Lake during 1974. Samples taken 7/28/74 were obtained at ca. 2000 hrs. CDT.

Depth	Temperature °C			Dissolved Oxygen mg/l		
m	7/18/74	7/28/74	8/13/74	7/18/74	7/28/74	8/13/74
0	29.2	28.9	30.1	8.3	2.8	6.6
1	29.2	28.8	28.8	8.4	2.4	6.6
2	28.8	28.8	27.2	8.3	1.2	3.0
3	28.8	28.8	26.8	8.2	0.8	2.4
4	28.0	28.8	26.8	2.3	0.7	2.4
5	27.8	28.8	26.6	1.9	0.6	2.3
6	27.8	28.5	26.5	1.0	0.5	2.2
7	27.7	28.5	26.4	0.10	0.2	1.7
8	27.6	28.2	26.3	0.10	0.0	1.1
9	27.2	28.1	26.2	0.0	0.0	0.0

Table 10. Selected water quality parameters at Ham's Lake during 1974. * = not detected. ND = no data.

Depth	pH	Total Alkalinity (mg/l)		Particulate Carbon (mg/l)		Dissolved Organic Carbon (mg/l)		Sulfide-Sulphur (ug/l)	
	7/15/74	7/15/74	8/13/74	7/15/74	8/13/74	7/15/74	8/13/74	7/15/74	8/13/74
surface	6.98	184	124	1.88	0.73	36.6	30.6	5.8	*
5 m	6.98	186	124	1.87	0.80	26.8	36.3	13.1	*
9 m	6.98	186	120	1.80	0.87	29.2	48.8	14.0	*

Depth	PO_4 - P (ug/l)		NO_3 - N (ug/l)		NO_2 - N (ug/l)		NH_4 - N (ug/l)	
	7/10/74	8/13/74	7/10/74	8/13/74	7/10/74	8/13/74	7/10/74	8/13/74
surface	*	7.83	8.39	20.19	0.54	3.70	3.12	0.32
5 m	*	4.96	7.52	15.76	0.58	4.90	7.03	4.16
9 m	*	26.62	29.71	24.87	*	4.90	13.27	6.08

In general, the chemical parameters showed Ham's Lake to be eutrophic. For example, chlorophyll a sometimes exceeded 40 mg/m^3 (Table 13) and dissolved organic carbon often was in excess of 30 mg/l, indicative of a eutrophic condition (Table 10).

Orthophosphate was low or undetectable, but inorganic nitrogen was in good supply (Table 10). Of course, one cannot draw conclusions about the element likely to be limiting from data on standing quantity of nutrients, but since phosphorus (P) is generally limiting in fresh waters, I concluded that P was the most likely limiting nutrient. On August 13, 1974 the ratio of NO_3^- - N + NH_4^+ - N:PO_4^{+3} was 2.62:1, an indication of an abundance of P relative to N. Usually the above ratio in excess of 12:1 is considered growth limiting. The 1974 data will be discussed further below when I compare them to the 1975 data.

The data on algae did not reveal Dactylococcopsis in high density, as Steichen (1974) described for the period when the lake was being mixed during 1973 (Table 11). The reason is that Dactylococcopsis was probably misidentified in the 1973 samples.

The data revealed that up to 39 species of algae could be found by exhaustive examination of samples. However, about 20 species were usually observed. When the composite sample was examined 5 times, more than 90% of the species had been encountered. Examination of additional composite samples did not materially increase the number of species encountered.

Diatoms species were most numerous, flagellate species least numerous (Table 11). A bluegreen alga, Anabaena, was always encountered. The data were too few to describe seasonal changes in abundance of algae, but the algal flora was dominated by species that should do well during lake mixing; shade tolerant diatoms and motile flagellates. There was no perceptible elimination of bluegreen algae or flowering of green algae, although the density of Anabaena was higher after the pump was shut down.

Table 11. Mean density of algae as number of organisms per ml in samples from Ham's Lake druing 1974. + = species observed but not enumerated.

	Date			
	7/18	7/28	8/13	10/17
CHLOROPHYTA				
Coelastrum microporum	0.0	0.0	1.5	6.3
Cosmarium sp.	0.0	0.0	0.2	1.5
Closterium sp.	0.5	6.8	5.5	23.6
Kirchneriella	0.0	0.2	0.8	0.1
Pediastrum duplex	0.0	0.0	0.0	0.2
Pediastrum simplex	0.0	0.7	3.3	20.5
Scenedesmus sp.	0.0	1.0	0.8	3.2
Sphaerocystis sp.	0.0	0.0	0.2	0.0
Staurastrum sp.	0.0	0.2	0.6	1.3
Tetraedon sp.	0.0	0.2	0.9	0.0
CHRYSOPHYTA				
Achnanthes sp.	0.0	0.0	0.1	0.0
Amphipleura pellucida	0.2	0.5	0.5	0.1
Cocconeis placentula	0.0	0.2	0.6	1.0
Cyclotella Meneghiniana	6.1	11.7	58.5	23.2
Cymbella	0.5	0.0	0.6	4.3
Diploneis Smithii	0.2	0.2	0.8	0.5
Frageilaria crotenensis	0.0	0.0	0.0	0.1
Fragilaria sp.	0.0	0.2	0.1	0.0
Gomphonema angustata	0.0	0.5	0.6	0.1
Gomphonema olivaceum	0.0	0.2	0.6	0.9
Gomphonema parvulum	0.0	0.0	0.0	0.0
Gyrosigma scalproides	0.0	0.2	0.4	0.0
Melosira distans	2.5	1.0	8.2	16.5
Melosira granulata	3.0	2.2	9.0	26.7
Melosira varians	0.0	0.0	0.0	0.0
Meridion circulare	0.0	0.2	0.0	0.0

	7/18	7/28	8/13	10/17
Navicula sp.	2.5	2.0	4.5	6.9
Nitzschia dissipata	0.2	1.0	1.6	1.5
Nitzschia sp.	0.0	0.0	0.2	0.0
Nitzschia sigmoidea	0.0	0.0	0.5	0.1
Nitzschia paradoxa	0.0	0.0	0.0	0.1
Nitzschia tryblionella	0.0	0.0	0.2	0.0
Pinnularia sp.	0.0	0.0	0.2	0.4
Stephanodiscus Hantzschii	0.0	0.0	3.2	0.5
Suriella ovata	0.0	0.0	0.1	0.0
Synedra ulna	0.2	0.0	1.8	3.2
Synura Adamsii	0.0	0.0	0.7	0.0
CYANOPHYTA				
Anabaena sp.	103.5	10.4	36.2	444.9
Dactylococcopsis	0.0	0.0	0.4	0.0
Merismopedia	0.0	0.2	0.2	0.0
Microcystis	0.0	0.0	0.4	0.0
Oscillatoria sp.	12.6	0.2	1.4	7.1
Spirulina sp.	0.0	0.0	0.1	0.0
EUGLENOPHYTA				
Euglena sp.	11.1	11.7	9.4	25.7
Phacus sp.	0.0	0.0	0.5	0.8
PYRROPHYTA				
Ceratium hirundinella	1.2	0.5	1.4	2.0
Glenodinium pulvisculus	0.0	0.0	0.4	0.0
Unknown				
u cells	16,112.8	5,185.0	0.0	0.0
Brown colonial spheres	19.5	18.8	44.2	6.1
Green colonial spheres	14.5	8.2	55.9	1.4

RESEARCH PROJECT ACCOMPLISHMENTS -- HAM'S LAKE - 1975
Limnology and Phytoplankton

The 1975 objectives were basically the same as in 1974. Ham's Lake was allowed to stratify normally during the spring of 1975. By May 20 the profile of DO was clinograde (Figure 14). The Garton Pump was started on June 17 and in a few days the lake was completely mixed and remained so for the rest of the summer. However, the vertical profiles of DO suggest that the lake was more completely mixed on certain dates than at other dates (Figure 14). Apparently, wind assisted the mixing process. When wind was absent, DO depletion occurred in deep waters.

The horizontal extent of mixing was investigated by comparing profiles of DO and temperature taken at stations 1-5. In general, the profiles at stations 2, 3, and 4 were similar to profiles at station 1, demonstrating that the lake was completely mixed (Figure 15). However, a comparison between stations 1 and 5 suggests that destratification did not occur at station 5. It is likely that station 5 is situated directly over a spring since temperatures at the bottom (6.1 m) were 9.7° C colder than temperatures at 6.0 m at station 1. Vertical profiles of NH_4^+ at station 5 also suggest the lake was stratified at this point.

The hypothesis that anoxic conditions at station 5 were due to a spring will be checked during the winter of 1975. If the hypothesis is true, then water at the bottom of station 5 ought to be warmer than bottom water at other stations.

During early May, Ham's Lake was turbid and the water level was high due to large muddy inflows from the watershed. Figure 16 shows a dramatic decrease in PO_4^{+3} concentration as the lake cleared and a gradual increase in chlorophyll a. By early June the standing crop of algae was probably maximum for the lake and PO_4^{+3} was undetectable. Shortly after mixing began, there was an increase

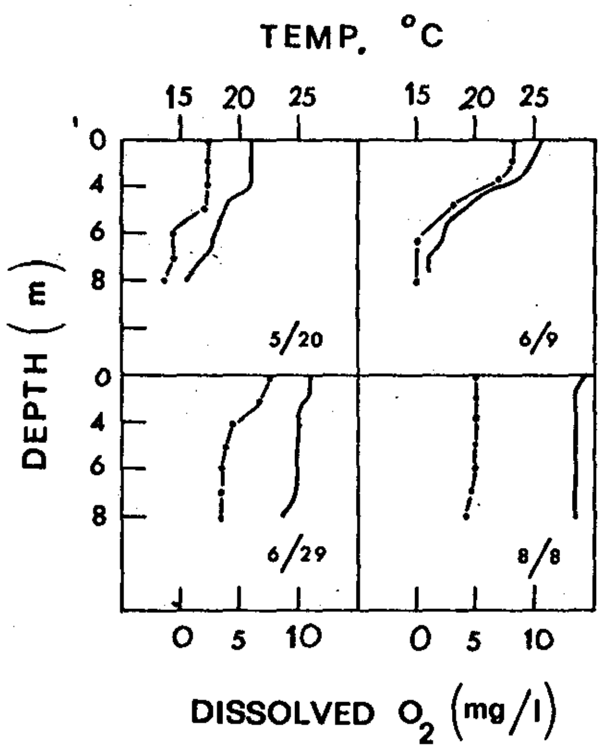

Figure 14. Vertical distribution of temperature (solid line) and dissolved oxygen (broken line) on 4 dates at station 1 at Ham's Lake during 1975.

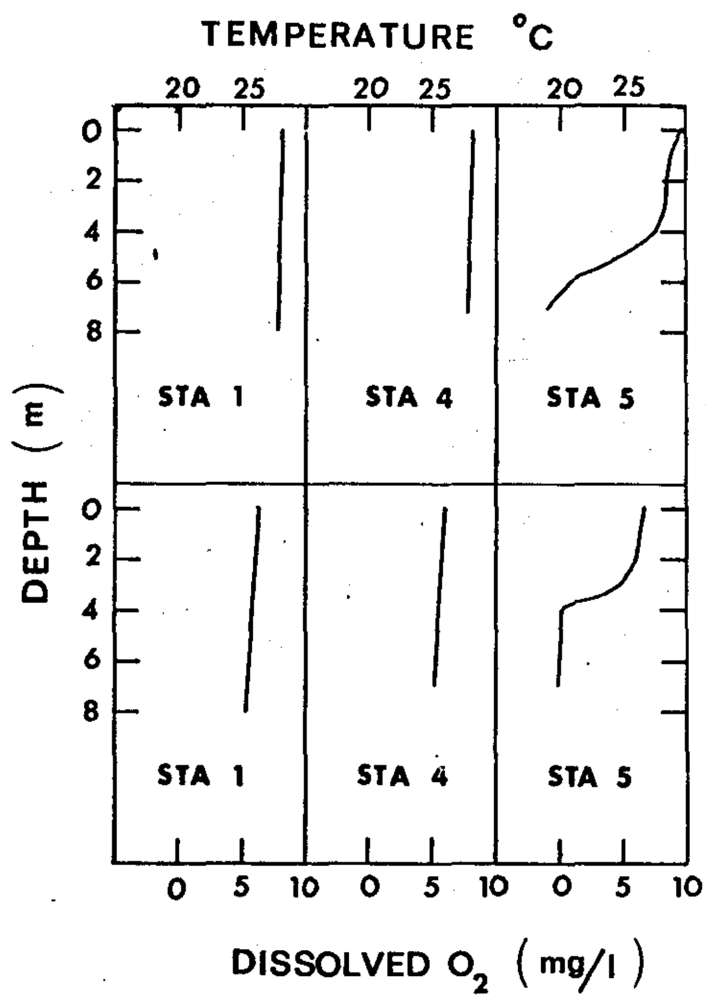

Figure 15. Vertical distribution of temperature and dissolved oxygen at three stations at Ham's Lake on 12 August 1975.

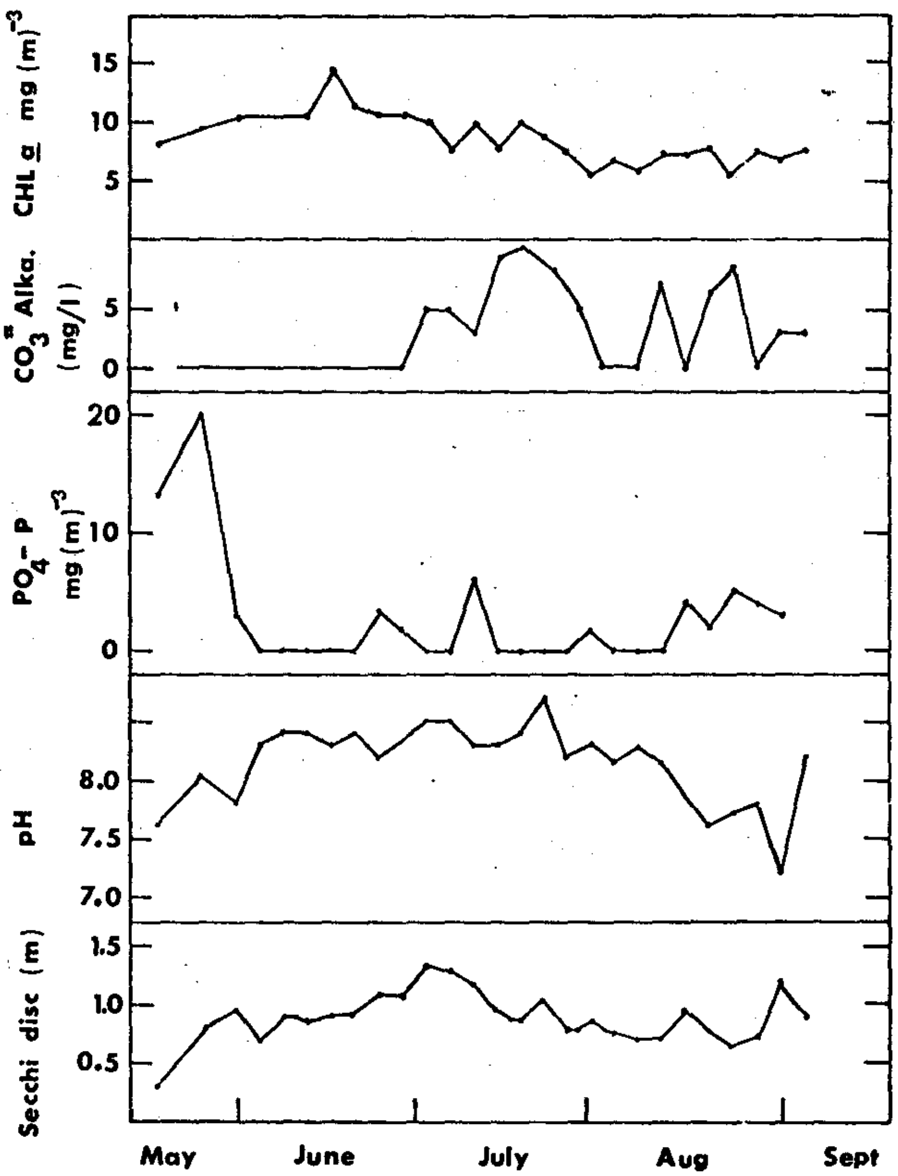

Figure 16. Mean concentration of chlorophyll a in the eutrophic zone, mean concentrations of carbonate and phosphate at the surface, mean pH at the surface, and Secchi disc transparency at five stations at Ham's Lake during 1975.

in chlorophyll a, which may have resulted from an increase in algal density that occurred after an upwelling of nutrients. Nitrate and ammonia were usually in good supply in the epilimnion(> 50 μg N per liter), but PO_4^{+3} was often undetectable. The mini bloom lasted about one week and thereafter the concentration of chlorophyll a decreased; the concentration was 5 - 10 μg/l during most of the summer indicating a mesotrophic status for the lake.

The transparency of the water increased after mixing began (Figure 16), but then decreased during August. Unlike 1973 when the lake was also artificially mixed, we found surface waters often had pH in excess of 8.5 and carbonate alkalinity. Usually artificial destratification decreases pH and eliminates carbonate alkalinity in the epilimnion. The most probable reason for high pH and carbonate alkalinity is because of demand for CO_2 by the littoral hydrophytes, which were not abundant before June. High turbidity and high lake level probably checked their growth until late June. After 13 June, Secchi disc transparency (SDT) varied from 0.64 to 1.18 m. We used a submersible photometer to expand Secchi disc transparency to the compensation point (CP). In general, SCT x 2.5 equaled CP. Therefore, the CP in Ham's Lake varied from 1.60 to 2.95 m after mixing began.

During 1975 the algal flora was similar to that observed during 1974, in general. There was a relatively large population of bluegreen algae at the outset of mixing in June, which increased further after mixing began, only to decrease shortly thereafter to moderate densities (Table 12). Aphanizomenon was the dominant bluegreen alga in the mini-bloom that occurred after mixing began.

The density of the dominant species of phytoplankton increased markedly during early June, as the lake began to clear (Table 12). Highest densities were reached shortly after mixing began. The fact that the density of the dominant bluegreen alga rose and declined in phase with other species argues

Table 12. Density of dominant algae in Ham's Lake during 1975 as cells or filaments per milliliter. + = organism seen but not enumerated.

Taxon	Date								
	5/20	6/9	6/21	7/3	7/19	8/4	8/20	10/7	10/31
Chlorophyta									
Chlorococcum	32	94	176	112	140	56	40	48	94
Coelastrum	3	422	410	321	333	20	0	0	83
Pediastrum	8	47	24	56	72	56	56	59	27
Cyanophyta									
Aphanizomenon	4	670	1624	555	40	12	12	37	59
Chrysophyta									
Cyclotella	12	311	80	209	161	143	96	37	94
Melosira	178	978	965	1113	530	50	28	48	295
Euglenophyta									
Euglena	42	94	281	112	56	9	28	+	83

against a cause and effect relationship between mixing and elimination of bluegreen algae; although such a relationship is possible. In any event, during the period of lake mixing, bluegreen algae were not a nuisance.

Apparently, Ham's Lake is becoming more oligotrophic. For example, DOC and algal biomass measured as chlorophyll a decreased between 1974 and 1975 (Table 13).

Table 13.

Concentration of dissolved organic carbon and chlorophyll a at Ham's Lake, July and August 1974 and 1975.

Dissolved organic carbon mg/l		Chlorophyll a ug/l		
1974 **	1975 **	1974 **	1975 *	1975 **
29.2-48.8	18-30	8.8-66.3	8.0-10.4	5.92-14.60
0,5 and 9 m	0, 4, 8 m	$\bar{x}$ = 35	$\bar{x}$ = 9.52	$\bar{x}$ = 9.02
		3 dates	4 dates	12 dates
		surface	0-2.5 m	0-2.5 m

* before mixing

** during mixing

Fisheries

The largemouth bass, Micropterus salmoides, is a popular sport fish and it was hoped that data on its growth rate and fishing success for this species would be useful in determining results of longterm effects of lake mixing.

Data for age and growth was obtained from specimens taken by angling over the course of the summer: total length, weight and scales. A survey form was provided for each angler to complete; virtually all anglers did so, since the lake had controlled access. The survey was conducted during July and August, but the interest in angling fell off in August and July data are used here. Scales were used to determine age of the fish. Mean length of each cohort was determined at each annulus by back calculation.

The data in Table 14 demonstrate that largemouth bass grew at a rate that was about average for the state. Growth in the first year of life of all year classes is surprisingly similar. One would expect a major energy subsidy such as wasted catfish food might be translated into greater growth during 1971. This was apparently not the case, since there was no statistical difference between the length attained at a given age by any year class.

Fishermen reported satisfactory angling for largemouth bass; two trophy sized fish (> 7 lbs.) were captured. Fishing for largemouth bass was generally done by one or two anglers who fished in the evening and who usually returned their catch to the lake. The rate of catch of fish > 12 inches total length was 0.2 fish per man hour, which is excellent angling success. For all bass captured the rate of catch was 1.0 per man hour.

Table 14. Mean length and weight of largemouth bass, Micropterus salmoides, and length at each age, determined by back calculation. Also shown are data on rate of growth in the state of Oklahoma.

Year Class	n	Ave. Length mm	Ave. Wt. gm	Length at Age 1	2	3	4
1973	9	229.9	157	128.0	213.8		
1972	22	288.8	376	140.5*	221.5	271.3	
1971	14	334.7	488	129.2	238.3	287.8	319.9
1970	6	402.7	1218	131.7	241.8	301.8	349.8
1969	2	464.0	1668	136.7	222.6	316.7	362.0
State - fastest growth				284.5	391.1	510.5	553.7
State - Average growth				139.7	246.4	317.5	378.5
State - Slowest growth				63.5	124.5	170.2	264.2

*Length not significantly different from same age fish in 1971 and 1973.

Horizontal experimental gill nets were fished on the bottom near station 1 before and after the onset of mixing. The gill nets were 1.97 x 984 m and made up of 4-246 m segments, each of which had the following mesh sizes; 2.5, 5.1, 7.6, and 10.2 cm, square.

Between June 9 and June 19, DO was depleted below 4 m to concentrations that would not support fish life, i.e. 0.05 mg/l DO. Mixing began on 17 June and four days later DO was present throughout the water column in sufficient amounts to support fish. Table 15 shows that before 19 June no fish were captured at 5-6 m, but several fish, notably channel catfish, Ictalurus punctatus, were captured there afterward. In addition, several other species were captured in the deep water shortly after lake mixing began, e.g., largemouth bass, Micropterus salmoides, at 5-6 m on June 19, and at 7-8 m on June 29, and black bullhead, Ictalurus melas, at 7-8 m on June 29. Channel catfish were captured in several instances at 8-9 m after lake mixing began but not before, e.g., at 8-9 m on June 26 and June 29. Therefore, lake mixing extended the depth distribution of fish in Ham's lake; fish previously restricted to the epilimnion rapidly invaded formerly anoxic depths.

Two vertical gill nets (30 m and 24 m wide) were constructed from 4 panels of netting (mesh size 2.5, 3.3, 5.1 and 6.3 cm, square). Each panel was 1.8 m wide. These nets were fished from June 25-July 7 near station 1, from July 8-July 27 near station 3, from July 28-August 3 at station 5 and from August 5-August 8 at station 1. The objective of this effort was to learn how adult fish were distributed in the pelagic zone, when the lake was being mixed.

Table 15. Number of fish captured with horizontal gill nets near station 1 at Ham's Lake during 1975.

Period	Species			Depth
	Ictalurus punctatus	Lepomis macrochirus	Pomoxis sp.	m
June 9-11	37	10	1	1
	0	0	0	5-6
June 12-14	30	12	1	1-1.3
	0	0	0	5-6
June 15-18	0	2	0	2-3
	4	1	0	3-4
	0	0	0	5-6
June 19-21	0	0	4	2-3
	5	0	8	3-4
	1	1	2	5-6
June 22-24	2	2	15	2-3
	1	3	4	3-4
	8	0	1	5-6
June 25-July 1	1	0	8	1-2
	0	0	0	3-4
	4	1	2	5-6
	2	0	0	8-9

Table 16. Number of fish captured with vertical gill net at various depths in Ham's Lake during 1975.

Period	Station	Species: *Ictalurus punctatus*	*Lepomis macrochirus*	*Pomoxis* sp.	Depth m
June 25-July 7	1	0	0	1	2-3
		1	0	1	4-5
		1	0	0	7-8
July 8-July 27	3	0	2	0	1-2
		0	5	2	2-3
		1	0	1	4-5
		1	0	2	5-6
July 28-Aug. 3	5	0	2	0	2-3
		0	1	0	3-4
Aug. 5-Aug. 8	1	1	0	0	0-1
		1	0	0	1-2
		0	1	0	3-4
		0	1	0	4-5
		0	1	0	6-7

Most of the fish captured were bluegills, Lepomis macrochirus, and crappie, Pomoxis sp., but largemouth bass were taken at 2-3 m on August 3 and at 1-2 m on June 29. The data in Table 16 also demonstrate that fish invaded the previously anoxic depths. But, the data in Table 16 are too few to accurately predict where fish will be found in Ham's Lake during the summer when it is completely mixed. The chief problem was that even with two gill nets, the rate of catch was very low, resulting in a disappointing number of specimens for statistical analysis. The reason so few fish were captured is not known. However, the bluegills and crappies captured were never taken in the larger meshes (5.1 and 6.3 cm), so apparently only half the net was effective. In fact, only one fish was captured in 5.1 cm mesh. Thus, only 4.9 linear m of net was effective in capturing fish over the water depth fished. More linear feet of net will be needed to raise the capture rate, if the above analysis is accurate.

Moreover, juvenile fish < 75 mm were not taken because the smallest mesh size was only 2.5 cm. Juvenile centrarchids use the pelagic zone of small lakes in summer and are numerically abundant there (Werner 1969). Thus, it should be possible to describe the response of juvenile fish to lake mixing more easily than adult fish in a small lake.

CONCLUSIONS

The Garton pump delivered oxygen to previously anoxic depths of Arbuckle Lake in 1974 and increased the heat budget of the lake in 1975. The pump should be able to move high quality epilimnetic water toward the outlet at the very least. But, it could improve water quality below the depth of the outlet after design changes have been made. Water quality in Arbuckle Lake has not changed appreciably over the period 1968-1975 and "aging" effects of the lake were not evident in the data taken.

Artificial mixing of Ham's Lake for three successive summers following the enrichment with catfish feed is apparently returning the lake to a less eutrophic state. During 1975, artificial destratification produced a small increase in the biomass of algae (chlorophyll _a_), shortly after the mixing began. However the increase in chlorophyll _a_ was not great and within a week the concentration of chlorophyll _a_ declined. Bloom forming obnoxious algae were low in density, while mixing was practiced. Ham's Lake is mesotrophic.

Fish rapidly invaded previously anoxic depths in Ham's Lake after lake mixing began. The growth of largemouth bass was about average compared to the state average before and during lake mixing. During July, 1975, fishing for largemouth bass was excellent.

OTHER PROJECT ACTIVITY

During 1975 this project gave logistic assistance to Dr. Jerry Wilhm. Project technicians used the Winkler method for DO analysis on many occasions to check on the accuracy of the oxygen probe and meters that were used by technicians at Arbuckle and Ham's Lake, respectively.

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REFERENCES

American Public Health Association. 1965. Standard methods for the examination of water and wastewater. American Public Health Association, Inc., New York. 769 p.

Bernhardt, H. 1967. Aeration of Wahnbach reservoir without changing the temperature profile. J. Am. Water Works Assoc. 59(8):943-964.

Bernhardt, H., and Hötter, G. 1967. Moglichkeiten der verhinderung anaerober verhaltnisse in einer trinkwassertalsperre wahrend der sommer-stagnation. Archiv. Hydrobiol. 63:404-428.

Duffer, W. and C. Harlin. 1971. Changes in water quality resulting from impoundment. EPA Project Report, No. 16080 GGH.

Fast, A. W. 1966. Artificial destratification of lakes and its significance in fisheries management. Calif. Dept. Fish and Game Inland Fisheries Admin. Report, No. 66-16. 16 p.

Fast, A. W. 1968. Artificial destratification of El Capitan Reservoir by aeration. Part 1: Effects on chemical and physical parameters. Calif. Div. Fish Game, Fish. Bull. No. 141.

Fast, A. W. 1971. The effects of artifical aeration on lake ecology. Ph.D. Thesis, Michigan State University, East Lansing. 566 p.

Flick, W. 1968. Dispersal of aerated water as related to prevention of winter kill. Prog. Fish Cult. 30:13-18.

Ford, M. E. 1963. Air injection for control of reservoir limnology. J. Am. Water Works Assoc. 55(3):267-274.

Hooper, Frank F., Robert C. Ball and Howard A. Tanner 1953. An experiment in the artificial circulation of a small Michigan lake. Trans. Am. Fish Soc. 82:222-241.

Hutchinson, G. E. 1957. A treatise on limnology. Vol. 1: Geography, physics, and chemistry. John Wiley and Sons, Inc., New York. 1015 p.

Irwin, E. W., J. M. Symons and G. G. Robeck 1966. Impoundment destratification by mechanical pumping. J. Sanit. Eng. Div., Proc. Am. Soc. Civ. Eng. 92(SA6):21-40. Republished in 1969, pp. 251-274.

Laverty, G. L. and H. L. Nielsen 1970. Quality improvements by reservoir aeration. J. Am. Water Works Assoc. 62(2):711-714.

Leach, L. E. 1968. Eufaula Reservoir aeration research - 1968. Okla. Acad. Sci. 49:174-181.

McNabb, C. D. 1960. Enumeration of fresh water phytoplankton collected on the membrane filter. Limnol. Oceanogr. 5:57-61.

Meyer, O. L. 1962. Aeration system increases lagoon capacity---adds operating flexibility. Public Works 93(8):79-80.

Parsons, T. R. and J. D. H. Strickland. 1963. Discussion of spectrophotometric determination of marine-plant pigments with revised equations for ascertaining chlorophylls and carotenoids. J. Mar. Res. 21:155-163.

Riddick, T. M. 1957. Forced circulation of reservoir waters yields multiple benefits at Ossining, New York. Water and Sewage Works 104(6):231-237.

Solórzano, L. 1969. Determination of ammonia in natural waters by the phenolhypochlorite method. Limnol. Oceanogr. 14:799-801.

Steichen, J. 1974. The effect of lake destratification on water quality parameters. Ph.D. Thesis, Oklahoma State University. 108 p.

Strickland, J. D. H. and T. R. Parsons 1968. A practical handbook of seawater analysis. Fisheries Res. Board Can., Bull. 167. 311 p.

Toetz, D., J. Wilhm and R. Summerfelt. 1972. Biological effects of artificial destratification and aeration in lakes and reservoirs---analysis and bibliography. Bureau of Reclamation, Denver. 177 p. REC-ERC-72-33.

Werner, R. 1969. Ecology of limnetic bluegill (*Lepomis macrochirus*) fry in Crane Lake, Indiana. Am. Midl. Nat. 81(1):164-181.