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LIMNOLOGICAL CHANGES RESULTING FROM ARTIFICIAL DESTRATIFICATION AND AERATION OF AN IMPOUNDMENT

Progress Report

By

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BACKGROUND AND OBJECTIVES

Accelerated eutrophication of our lakes with accompanying nuisance algae blooms has rapidly become one of the most serious problems facing us today. Increased habitation around our lakes by greater numbers of people with correspondingly greater quantities of fertilizing nutrients entering the lakes from these and other sources is generally considered the cause of this problem (Hasler, 1947). While it may be possible to substantially limit the inflow of nutrients to a lake, an advanced state of eutrophication has already occurred, or is likely to occur, before the problem is recognized. Therefore, research into methods of reversing eutrophication seem particularly important for solving this problem.

While highly eutrophic lakes are generally considered to be fertile fish producers, they are also known to have environmental conditions that severly affect fish populations. Oxygen deficits that cause large-scale fish mortalities resulting in selective survival of less desirable species of fish is one example. Nuisance blooms of algae, particularly the bluegreens, may be measured as important primary producers of organic material, but the resultant anaerobic environment brought about by their turbidity and organic decay may prohibit the buildup of invertebrate animal populations and as a result, this energy source is not converted into fish flesh. Therefore, it seems logical to assume that if the environment can be improved for higher production of invertebrates (both planktonic and bottom dwelling) greater production of fish will follow. Such is the objective of a research project presently being conducted at Cox Hollow Lake in southwestern Wisconsin.

DESCRIPTION OF STUDY AREA

Cox Hollow Lake is a 96-acre impoundment with a volume of 1,200 acre feet and a maximum depth of 29 feet (Fig. 1). It has an inflow of between one and two cubic feet per second during low runoff periods and contains water of high fertility. It is located in a steep-sided, wooded valley in Governor Dodge State Park, a picturesque location typical of the Driftless Area in southwestern Wisconsin. The park receives heavy use for fishing, swimming, picnicking, hiking, and camping. No outboard motors are allowed on the lake.

The lake was formed when the dam was closed in 1958 although the basin was not completely filled until the snow melt occurred in the spring of 1959. It was stocked with 22 pairs of adult northern pike and 16 pairs of adult largemouth bass in 1958. Both reproduced, grew well and produced good angling which was first allowed on June 1, 1960. At that time a permit-type creel census was also initiated and has operated since to collect angler and fishery information.

MEASUREMENTS PRIOR TO DESTRATIFICATION

Chemical and Physical

Prior to environmental manipulation, a plan of chemical and physical measurements was established for the study. Vertical temperature profiles were measured with a calibrated electronic thermistor thermometer. Dissolved oxygen determinations were made at several depths to the bottom, or to the depth where it was depleted, by a modified Winkler method. Measurements of pH, ammonia, iron, manganese, and dissolved and total phosphate concentrations were made at three-foot intervals from surface to bottom at the central sampling location of the lake every three days for a period of seven weeks after the system began operation, and biweekly for another eight weeks. In addition, measurements of potassium, sodium, calcium, magnesium, chloride, nitrate nitrogen, Keldjahl nitrogen and methyl orange alkalinity were made at five to eight different depth levels in March, April, June, August, and October, 1966. All of these analyses were made at the Wisconsin Conservation Department's water analysis laboratory according to established methods.

Water transparency was measured at the same time temperature and dissolved oxygen measurements were made, and all of these measurements were taken at the three sampling points in the lake in order to ascertain the effects of mixing at distances from the Aero-Hydraulics system.

Harvest and Production

About 10,000 anglers per year used the lake during the first four years (Table 1). This figure dropped to 6,000 in 1964, and 5,000 in 1965. Anglers' effort, measured in hours per acre per year, ranged from about 300 to 350 hours during the first three years and declined to 120 hours per acre in 1965. An angling year is measured from April 1 to the following March 31.

Northern pike were caught in good numbers during the first three years of angling, but demonstrated a dramatic decline thereafter (Table 1). Largemouth bass were taken at a low level the first year, a much higher level the following two years, and then at a low level since. Bluegills, believed to have been illegally introduced, were first noted in 1961. They reproduced well in that year and were taken in large numbers by 1963, but the catch then dropped to less than half of the peak year by 1965. Their growth and condition has been poor, which limits their desirability to anglers.

The northern pike population has not produced a year class since 1962, while largemouth bass appear to reproduce every year. The anglers' catch of both species dropped off sharply when the bluegills entered the catch in large numbers, which suggests some interaction. Another factor affecting the northern pike catch was the addition of a 22-inch minimum size limit for this species at the beginning of the 1963 fishing season. No size limit existed in prior years. Although this restriction limited the catch, mark and recapture population estimates substantiated the fact that the population had previously been greatly reduced.

After the first two years the total catch began to drop until in 1965 it reached a low of 15 pounds per acre as compared to earlier catches of 50 pounds per acre.

TABLE I

Fishing Intensity and Success at Cox Hollow Lake, 1960-65

Season	Number Anglers	Hours Per Acre	Catch (Lbs. Per Acre)	Number Caught: Northern Pike	Number Caught: Largemouth Bass	Number Caught: Bluegills
1960	9,372	292	49.3	3,518	892	0
1961	9,874	348	52.1	4,353	3,985	15
1962	10,673	310	44.4	1,910	3,669	3,377
1963	9,264	221	39.1	196	796	19,590
1964	6,251	153	18.8	104	360	11,771
1965	4,880	119	15.2	39	343	8,616

ENVIRONMENTAL MANIPULATION

Thermal stratification and oxygen depletion are common during the summer months, and as much as 50 percent of the lake's volume may be affected. These environmental conditions are suspected to limit fish production by crowding fish into a shallow epilimnion and placing physiological stress on them -- both factors occurring during a large part of the growing season (Sprugel, 1951; Bouck and Ball, 1965; Douderoff and Shumway, 1966).

Therefore, several methods of environmental manipulation were considered; complete drawdown to facilitate removal of all fish and restocking with a different combination; mechanical pumping of the hypolimnion to mix the lake; and the use of compressed air to mix and aerate the lake.

The first consideration was rejected because it would probably be only a temporary measure, yield little new information regarding this management method, and would not likely change existing environmental conditions.

The second consideration appeared to present too many mechanical and equipment maintenance problems to be practical, and would detract from aesthetics of the park.

The third method appeared to be the simplest to install and maintain, and also included an aeration feature which was desirable (Schmitz and Hasler, 1958).

A report of the successful destratification of Blelham Tarn by the Freshwater Biological Association of Great Britain led to an inquiry to the Aero-Hydraulics Corporation of Montreal, Canada, manufacturers of a device for underwater mixing and aerating called an "Aero-Hydraulics Gun" (Bryan, 1965). An agreement was reached on the design and installation of an Aero-Hydraulics System which incorporated six aerating and mixing "guns" for the destratification and mixing of Cox Hollow Lake. This kind of equipment is capable of moving large volumes of water while introducing air at the same time. In addition, operation and maintenance is simple as there are no moving parts under water and the likelihood of any maintenance due to wear or breakage is very small. The only foreseeable maintenance required is at the air compressor located on the shore.

An Aero-Hydraulics system was installed in Cox Hollow Lake in July, 1966. It consists of 6 mixing and aerating "guns" each 12 feet long, 12 inches in diameter and placed approximately 50 feet apart in a cluster at the deepest point in the lake (Figs. 1 & 2). Compressed air is furnished by a single-stage, two-cylinder, air-cooled compressor that delivers 72 cubic feet per minute at 14 pounds per square inch pressure. The compressor is driven by a 7.5 hp electric motor with a power consumption of 6.2 kw per hour. Compressed air is delivered to the guns by polyethylene piping which is anchored along the bottom of the lake.

The air is fed into an air distributor at the bottom of each semi-buoyant, vertically aligned gun until a quantity of air (determined by air distributor design) breaks a water seal and is released as a single large bubble. The rising bubble acts as an expandable piston, forcing water up the stack, and drawing water behind it through the port. These bubbles are released intermittently which provides for a continuous flow of water through the gun. The stream on leaving the gun muzzle acts as a free turbulent jet which entrains additional quantities of water in its upward movement towards the surface. Oxygenation of water takes place as the air fills the distributor, when the bubbles rise in the gun, as these bubbles burst and rise on leaving the gun, at the turbulent surface boil above the gun, and surrounding this boil as the water spreads radially away from the upwelling region.

The system is calculated to lift 16.8 cubic feet of water per second through the guns, and since the flow of water from the muzzle of each gun acts as a free jet, entrainment of additional water from the muzzle level to the surface roughly adds another 67 cubic feet per second for a total water transfer of approximately 84 cfs or 166 acre feet per day. Based on oxygen transfer computations the system is capable of adding 14.5 pounds of dissolved oxygen per hour at a level of 0.0 dissolved oxygen.

RESULTS FOLLOWING MANIPULATION

Temperature and Dissolved Oxygen

Measures of temperature and dissolved oxygen were made at the three sampling points in the lake (Fig. 1) in order to determine if destratification was simultaneously taking place in the entire lake. The upper limits of the thermocline (taken as a change greater than 1°F per foot drop in depth) dropped rapidly. At the beginning of the operation it was at 5 feet, at the end of a week it was at 16 feet and after two weeks it was at 20 feet (Fig. 3). During the first three weeks of operation the air compressor shut down periodically due to excessive heat brought about by poor air circulation in the compressor building which tripped the low temperature circuit breakers in the electrical system. In addition, incorrect sheave size on the electric motor reduced the output of the air compressor to approximately 50 cubic feet per minute. On July 21 there was no thermocline but a gradual temperature gradient of 6°F existed from top to bottom. By July 28, the temperature distribution was nearly linear, and on August 11, it was perfectly homothermous at 72.5°F in the deepest part of the lake.

Temperatures in different areas of the lake varied at the surface before mixing started, in fact on a windless June 30 the surface temperature in the south arm was 89°F and at the central station it was 84°F. After mixing started there was seldom more than a 1°F difference between the three stations at any depth except near the bottom, where mud temperatures apparently affected adjacent water temperatures.

Dissolved oxygen concentrations prior to mixing exhibited rapid depletion between 5 and 10-foot depths, with less than 2 parts per million at 10 feet at all three sampling points. After one week there were 4 ppm at a depth of 15 feet at the central sampling point, but less at the same depth at the north and south arm sampling points, 0.6 and 1.0 ppm, respectively. On July 14, (Fig. 4), a dark rainy day, the dissolved oxygen was low at all three stations (4.1 to 5.9 ppm) at the surface; at 10 feet it was 3.5 to 5.5 ppm, and at 15 feet it was 2.4 ppm at the central sampling point. By July 18, there were 0.2 ppm D. O. at 25 feet, and after that date, anaerobic conditions were never noted. Dissolved oxygen concentrations continued to improve in the deep water and parallelled the thermal mixing. However, the upper levels of the lake were less than saturated due to their contribution to the oxygen demand of deeper areas brought about by mixing. Dissolved oxygen concentrations remained at 60 to 70 percent saturation until September 22 when it was up to 75 percent, over 80 percent on September 28, and between 90 and 100 percent saturation from October 6 to the present (December, 1966).

Dissolved oxygen levels varied at the different sampling points and indicated that aeration was more pronounced at the central sampling point, since higher concentrations were usually found here during the first month of operation. For example, dissolved oxygen measures were made of the water column at the three sampling locations on 14 different days spaced through the month of July. At the 10-foot depth the dissolved oxygen concentration was highest at the central station (average 2.3 ppm) on 13 of the 14 days. At the 5-foot level the D.O. was highest at the central station (average 1.3 ppm) on 10 of the 12 days that it was measured at all three stations. After July this tendency was not as apparent.

During periods of quiet weather some thermal and chemical stratification was noted to reappear which indicates that wind-driven currents are necessary to insure mixing at a sufficient rate to offset stratification.

Chemical Analysis

Iron and manganese both responded similarly to mixing and were greatly diminished from the hypolimnion. By September 22 each was present at a lower concentration at all levels measured than at the start of mixing (Tables 2 & 3). Dissolved phosphate concentrations diminished at all depths but most dramatically from deeper areas. The same is true for total phosphates (Table 4). Ammonia almost completely disappeared by the middle of August and by September 7 was not measurable in any of the eight vertical samples taken from top to bottom (Table 5). The increase on September 22 was presumed caused by the usual fall die-off of rotted vegetation in the lake.

A comparison of chemical analyses for other chemicals before and after mixing is shown in Table 6 for the period of summer stratification in August and just after fall turnover in October. The results of the August and October 1966 samples are shown at the 6-foot and 21-foot levels to correspond to epilimnion and hypolimnion samples which were the only ones taken previously.

TABLE 2

Manganese (ppm) in Cox Hollow Lake, 1966

	Date Sampled				
Depth (Ft.)	June 29	July 14	July 28	August 18	September 22
3	0.12	0.26	0.28	0.14	0.09
6	0.12	0.37	0.24	0.14	0.09
9	0.19	0.50	0.30	0.19	0.10
12	0.69	0.67	0.32	0.19	0.11
15	1.36	0.94	0.41	0.19	0.10
18	0.84	1.00	0.37	0.20	0.09
21	1.42	1.84	0.27	0.20	0.10
24	1.53	2.30	0.50	0.26	0.11

TABLE 3

Iron (ppm) in Cox Hollow Lake, 1966

	Date Sampled				
Depth (Ft.)	June 30	July 14	July 28	August 18	September 22
3	0.12	0.25	0.10	0.08	0.07
6	0.16	0.22	0.10	0.08	0.07
9	0.15	0.30	0.10	0.09	0.07
12	0.13	0.26	0.09	0.19	0.07
15	0.12	0.31	0.14	0.11	0.15
18	0.44	0.25	0.14	0.14	0.09
21	1.00	0.38	0.15	0.16	0.13
24	1.39	0.34	0.30	0.14	0.11

TABLE 4

Phosphate (ppm as PO_4) in Cox Hollow Lake, 1966

Depth (Ft.)	June 30 D*	June 30 T**	July 11 D	July 11 T	July 28 D	July 28 T	August 18 D	August 18 T	September 22 D	September 22 T
3	0.060	0.067	0.006	0.280	0.040	0.213	0.017	0.133	0.033	0.100
6	0.070	0.123	0.030	0.066	0.077	0.150	0.017	0.180	0.030	0.120
9	0.050	0.573	0.065	0.100	0.067	0.176	0.037	0.097	0.030	0.096
12	0.026	0.180	0.133	0.453	0.100	0.193	0.060	0.210	0.030	0.110
15	0.050	0.116	0.046	0.180	0.130	0.187	0.043	0.197	0.034	0.128
18	0.236	0.447	0.100	0.116	0.100	0.167	0.026	0.203	0.060	0.103
21	0.537	0.650	0.203	0.283	0.153	0.230	0.050	0.250	0.061	0.483
24	0.917	1.353	0.580	0.733	0.183	0.246	0.053	-	0.022	0.170

* Dissolved Phosphate
** Total Phosphate

TABLE 5

Ammonia (ppm) in Cox Hollow Lake, 1966

Depth (Ft.)	Date Sampled June 30	July 14	July 28	August 18	August 24	September 22
3	0.0	0.0	0.003	0.0	0.0	0.099
6	0.0	0.0	0.035	0.0	0.0	0.089
9	0.0	0.0	0.125	0.0	0.0	0.115
12	0.0	0.006	0.160	0.0	0.0	0.137
15	0.006	0.080	0.195	0.064	0.0	0.096
18	0.289	0.102	0.198	0.102	0.0	0.032
21	0.689	0.400	0.240	0.115	0.0	0.083
24	1.137	0.753	0.323	0.147	0.010	0.083

Water Transparency

Water transparency was measured with a Secchi disc at the same time temperature and dissolved oxygen measurements were made. These measures were averaged for the months of July, August, and September and compared with measurements taken in previous years (Table 7). The sporadic readings taken in previous years suggest that the water was more transparent during the first three years of impoundment and then became less so in most recent years as algae populations built up. After mixing was initiated in 1966, water clarity improved as shown by the average transparency values of 1963 and 1965. Although an initial bloom of algae might have been expected due to pumping nutrients into the epilimnion when mixing began, such did not occur. In fact, transparency improved during the first two weeks of operation until a bloom began during the third week in July which diminished by August (Fig. 5). From August into September, water transparency continued to gradually improve but decreased to about 6 feet in October. At no time during the summer and fall period did an offensive nuisance algae bloom occur such as was noted in previous years. Because of the forested watershed, mineral soil turbidity does not occur in the lake, therefore water transparency is a reasonable measure of algal density.

TABLE 6

Comparison of Chemical Analyses Before and After Mixing, Cox Hollow Lake, 1965 and 1966 (in mg/l)

Date	Depth	pH	T. Alk.	Cl^-	Ca++	Mg++	Na+	K+	NO_3N	PO_4(T)
Aug. 1965	Epilimnion	8.5	147	1.90	22.5	22.5	1.95	2.32	0.02	0.17
Aug. 1965	Hypolimnion	6.9	239	3.05	44.3	22.5	2.70	2.02	0.00	16.2
Aug. 1966	Epilimnion	8.3	177	3.67	20.9	25.5	4.52	1.76	0.041	0.180
Aug. 1966	Hypolimnion	8.3	178	4.36	22.2	26.7	2.66	1.76	0.027	0.145
Oct. 1965	Epilimnion	7.5	179	2.80	31.5	18.2	1.87	2.50	0.06	0.128
Oct. 1965	Hypolimnion	7.4	182	2.95	33.0	17.8	3.00	2.40	0.07	0.110
Oct. 1966	Epilimnion	8.3	182	4.8	27.3	31.6	3.00	2.08	0.090	0.100
Oct. 1966	Hypolimnion	8.3	185	4.6	24.7	33.8	2.85	2.15	0.042	0.22

TABLE 7

Water Clarity as Measured with Secchi Disc, Cox Hollow Lake* (In Feet)

	Year					
Month	1960	1961	1962	1963	1965	1966
July	10.7 (3)	15.5 (1)	4.9 (1)	2.6 (1)	-	5.6 (13)
August	8.7 (3)	12.4 (3)	6.8 (1)	5.6 (1)	4.4 (2)	5.9 (7)
September	7.7 (5)	7.6 (3)	-	-	5.7 (2)	7.5 (4)

*Measurements were normally made at three locations. The average clarity was determined for each date and these were averaged on a monthly basis. The number in parenthesis is the number of sampling dates per month.

SIGNIFICANCE

Limnological Changes

Continuous mixing to prevent stratification of lakes shows great promise as a means of improving the environment for invertebrates and fish and as a means of reversing eutrophication.

(1) By maintaining oxygen in the deeper areas of a lake, anaerobic conditions favorable for bringing nutrients into solution from bottom muds will be limited and oxidation of nutrients to bring about precipitation to insoluble forms will be facilitated.

(2) Aerobic conditions and warmer temperatures in the deeper areas provide for more rapid oxidation of organic deposition than did the colder anaerobic environment.

(3) Continuous mixing and aeration will provide an improved and enlarged environment for animals in limnetic and benthic regions, providing for better utilization of primary production and transformation of energy to higher trophic levels. These higher levels, such as fish, may then be subject to harvest which would further reduce nutrient levels in the lake.

(4) By providing higher levels of dissolved oxygen, fish and probably other animals as well, can physiologically better utilize available food to improve growth.

(5) Mixing alone may limit blooms of algae, particularly bluegreens, by (a) lowering epilimnion water temperatures, but more importantly by (b) preventing stratification which allows algal cells to maintain a position in the epilimnion where they are in the photic zone all or most of the time. With continuous vertical mixing, algal cells will be carried out of the photic zone regularly which should limit their growth (Fogg, 1965).

Recreational Improvement

(1) Cooler surface water temperatures at Cox Hollow Lake during the summer of 1966 were regarded by swimmers as a definite improvement in water quality. Surface water temperatures from 85^{o} to 89^{o}F were recorded prior to initiation of mixing. Afterwards, even though several "heat waves" occurred, temperatures were never recorded higher than 78^{o}F and it was estimated that they remained about 10^{o}F cooler than they would have if the lake had remained stratified.

(2) It appears that severe nuisance algae blooms may be discouraged if not prevented by continuous vertical mixing. Whether or not these conditions will encourage more rooted aquatic plant growth is not known, but rooted growth is usually more readily controllable than plankton algae in specific areas used for recreation.

(3) Although not measured in this study, evaporation will decrease as surface water temperatures decrease. Koberg and Ford (1965) reported this in their California study. Evaporation is an important consideration in water poor areas.

(4) Greater fish production potential should definitely enhance recreational values in lakes where present environmental conditions limit fish populations to the more hardy but less desirable species. For example, in Cox Hollow Lake, water temperatures and dissolved oxygen levels may improve to the point where rainbow trout could survive. In lakes that are presently borderline as concerns trout environment, there is little doubt that destratification would maintain a suitable environment. The Aero-Hydraulics Corporation suggested that even cooler water temperatures may be obtained by operating the system 12 hours daily during nighttime hours in summer, rather than continuously as we are operating.

(5) The use of lime in bog-stained lakes has been shown to improve water transparency, which in turn enlarged the photic zone and provided more oxygen so that these lakes supported rainbow trout (Hasler, Brynildson and Helm, 1951). By continuously mixing a bog lake the products of the photic zone, oxygen for example, could be carried to the hypolimnion for the same purpose.

Other Applications

Artificial destratification is also being used to improve water quality in reservoirs for industrial and domestic use (Koberg and Ford, 1965; Symons, Irwin and Robeck, 1965 and 1966; Thackston and Reece, 1966); to treat waste water (Anon.,1966a and 1966b); and to maintain ice free navigation channels (Anon., 1965). The improvement of fish production and water quality seems very probable and can be done on an economical basis.

What deleterious effects the loss of stratification will have on a lake is difficult to estimate. Perhaps the greatest loss will be centered about the nostalgia of losing some common limnological terms: the epilimnion, the thermocline, and the hypolimnion!

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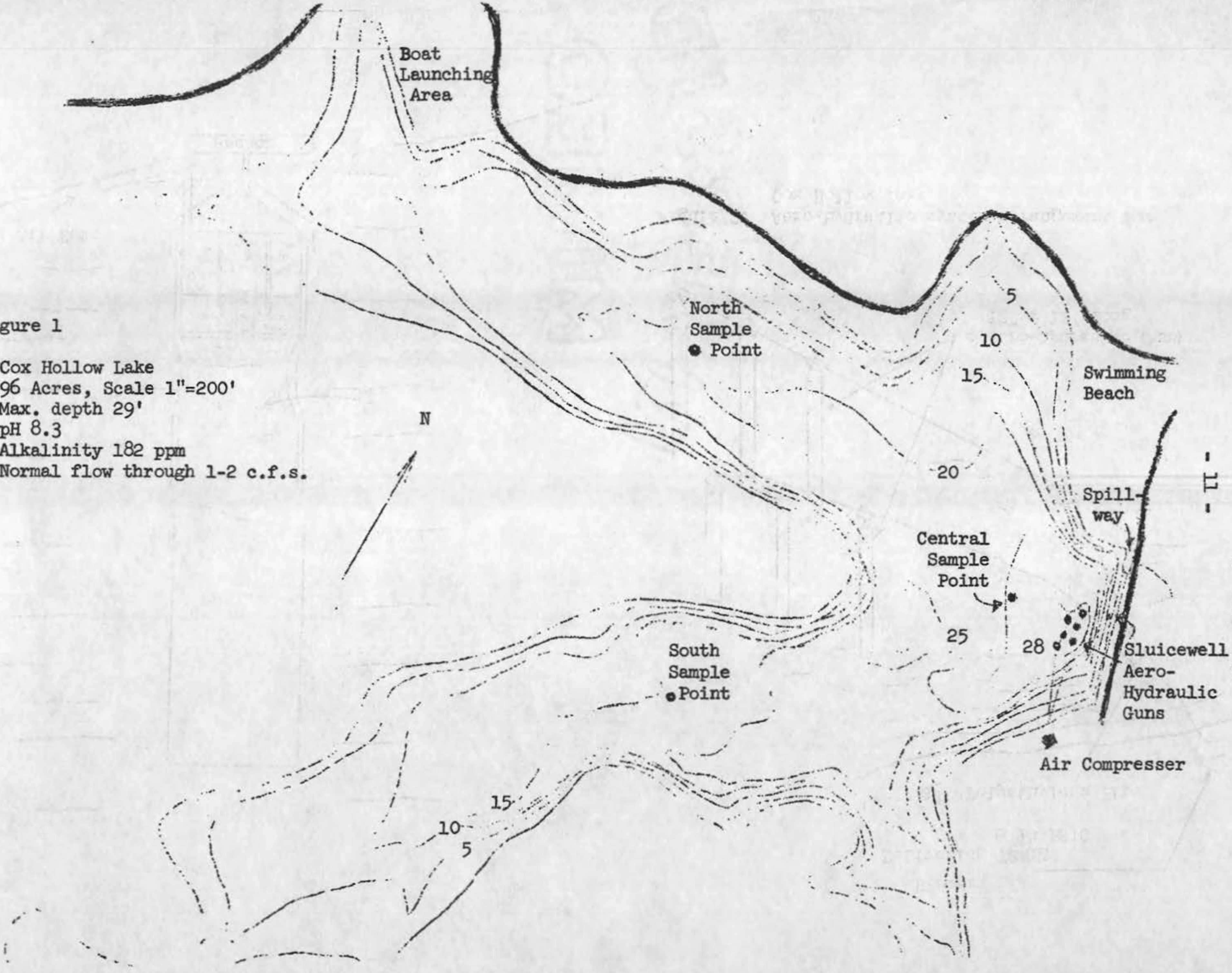
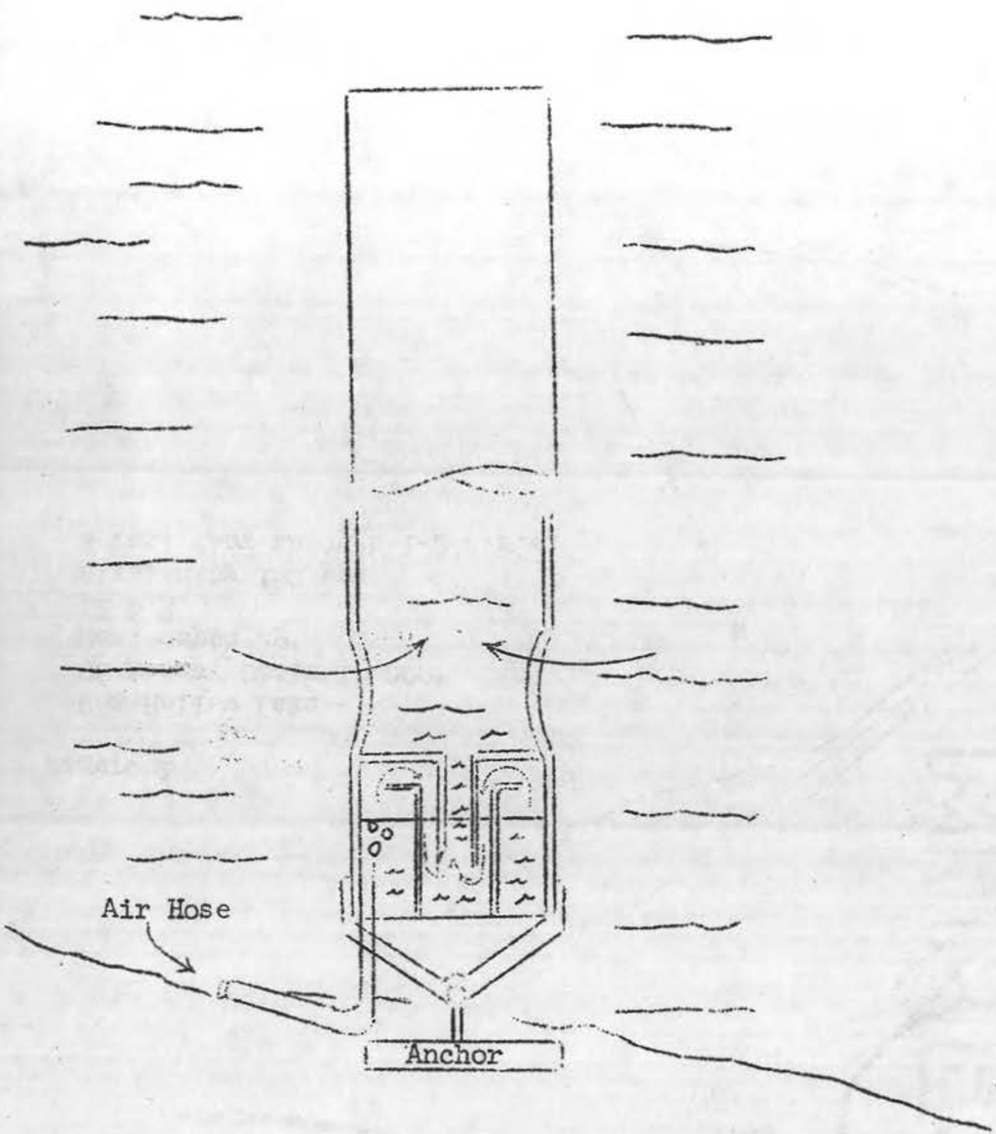


Figure 1

Cox Hollow Lake
96 Acres, Scale 1"=200'
Max. depth 29'
pH 8.3
Alkalinity 182 ppm
Normal flow through 1-2 c.f.s.



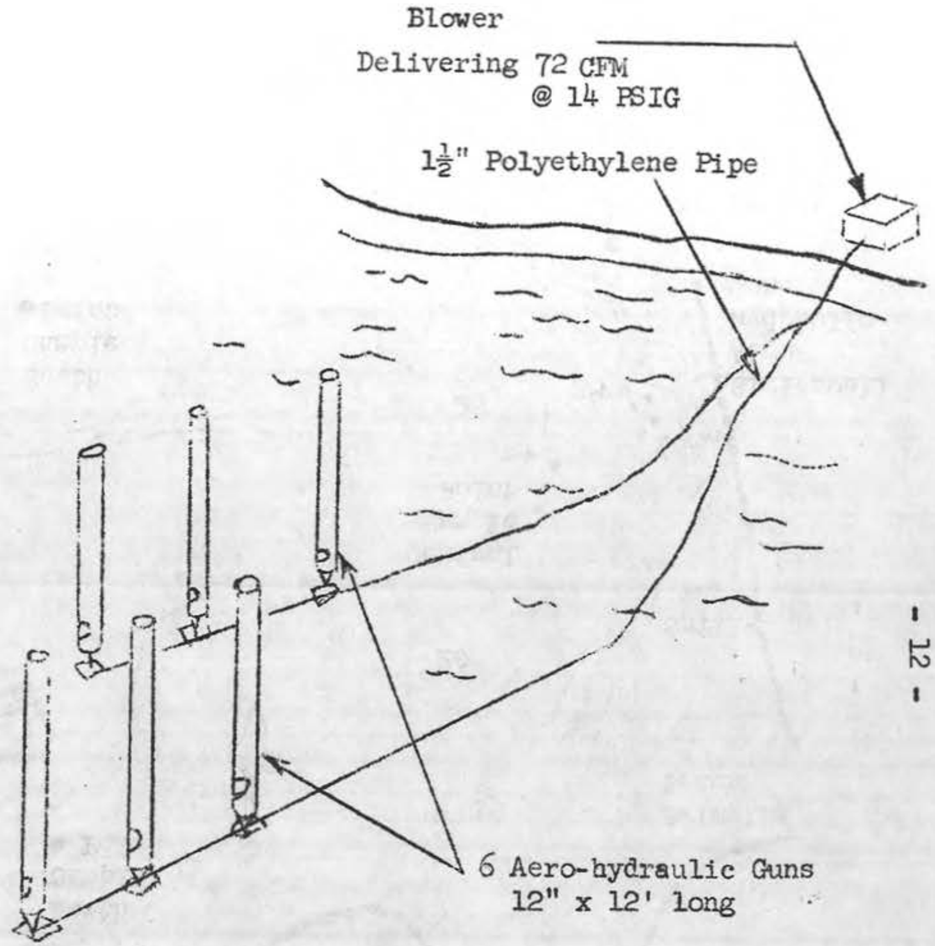


Figure 2. Aero-Hydraulic system arrangement for Cox Hollow Lake

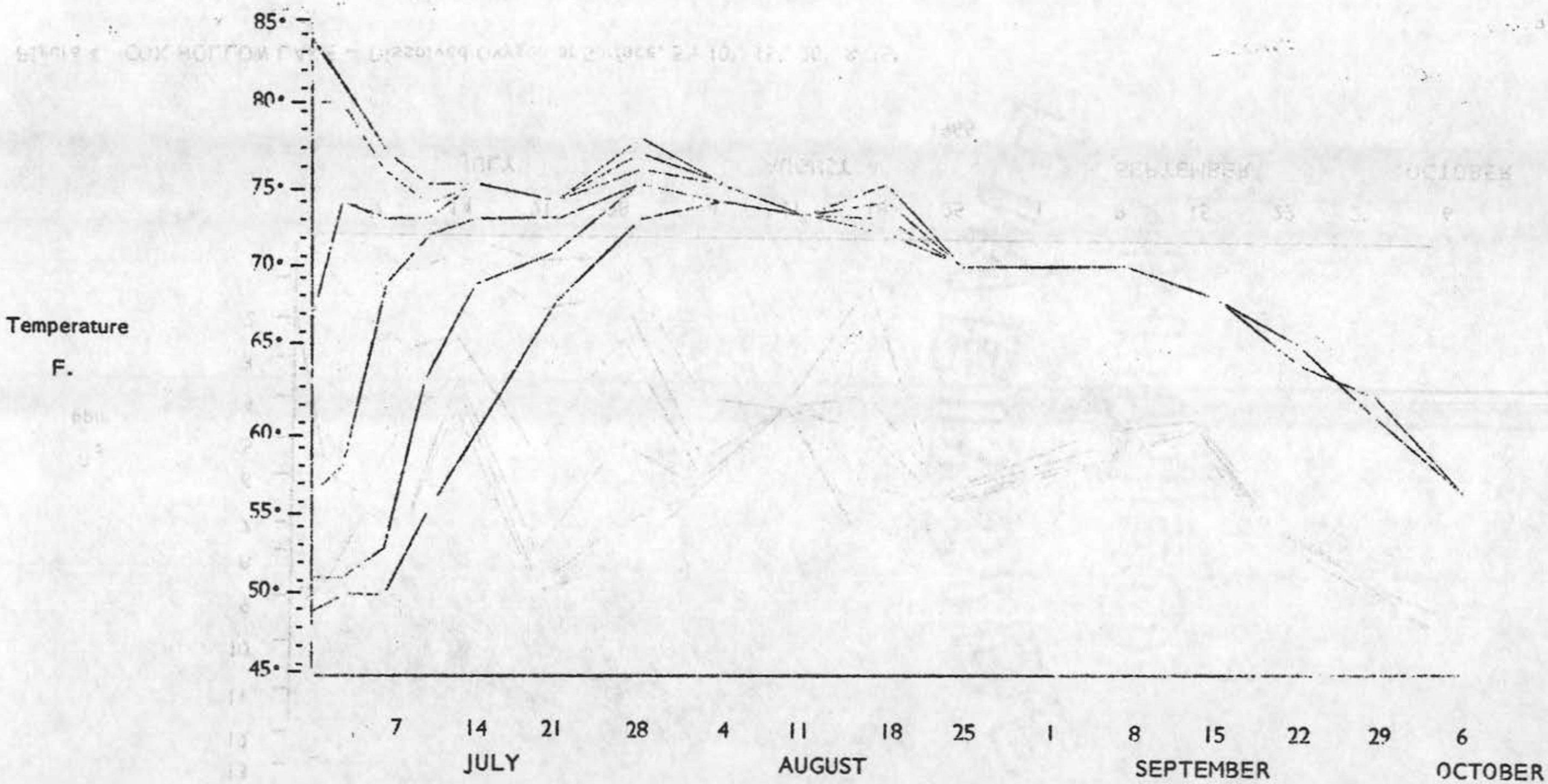


Figure 3. COX HOLLOW LAKE – Temperatures at surface, 5', 10', 15', 20', & 25'

1966

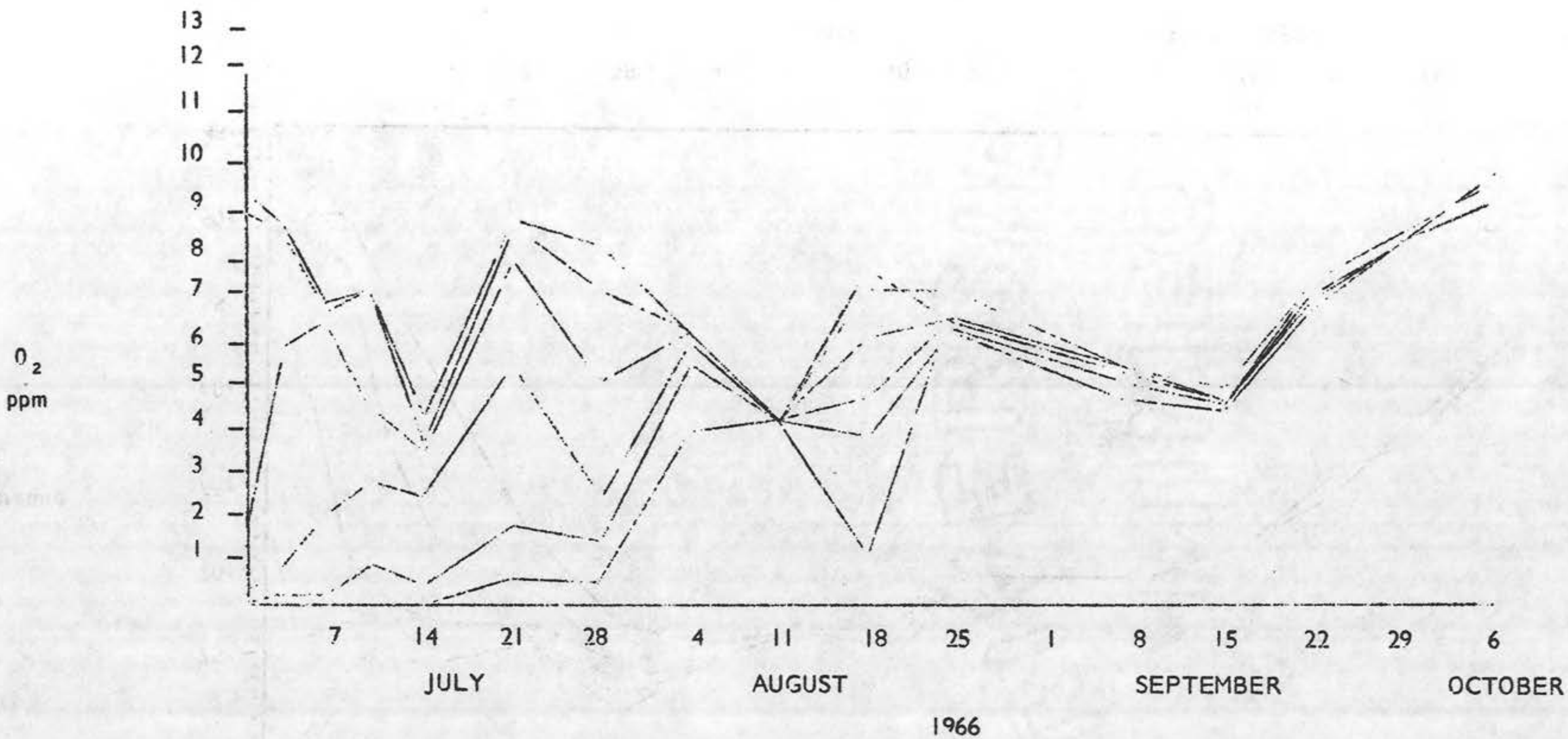
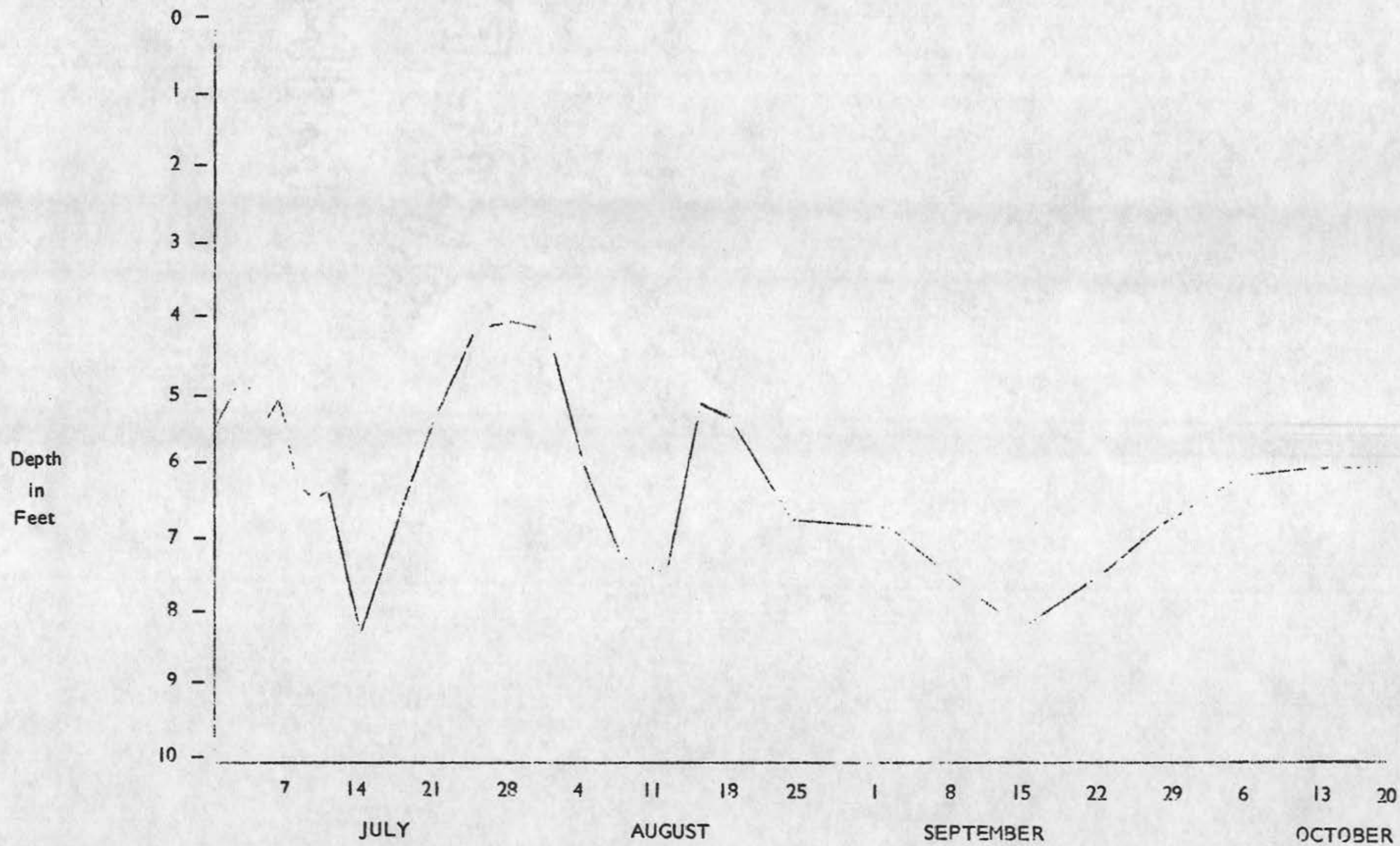


Figure 4. COX HOLLOW LAKE – Dissolved Oxygen at Surface, 5', 10', 15', 20', & 25'

Figure 5. COX HOLLOW LAKE WATER TRANSPARENCY (Secchi Disc), 1966



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