IMPROVING THE QUALITY OF WATER RELEASES FROM RESERVOIRS BY MEANS OF A LARGE DIAMETER PUMP

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In temperate climates, many lakes stratify during the summer. A typical stratified lake will have a warm oxygen-rich epilimnion, a thermocline, and a colder oxygen depleted hypolimnion. High levels of iron, manganese, hydrogen sulfide, and ammonia and dissolved hydrocarbons may occur in the hypolimnion. Many efforts have been made to destratify lakes, primarily by air bubbling. These methods require large energy inputs. A low-energy destratifier using 42-inch and 72-inch propellers to pump the water downward from the surface have been used successfully to destratify a 100 acre lake (35 feet deep) for 3 years. This project was an attempt to apply the same kind of device to Lake Arbuckle, a 2400 acre, 90-feet deep lake in south central Oklahoma. A 16.5-foot aircraft propeller was used to pump approximately 200,000 gallons per minute downward. Although the lake stability index was decreased by half, a corresponding reduction in the oxygen distribution index did not occur until the fall overturn. Thus, a lake can be weakly stratified thermally and strongly stratified chemically. The fall turnover occurred about a month earlier and more completely than normal during our two years of operation. The oxygen content in the outlet waters near the pump was increased 1 to 2 mg/L during the critical summer months.

Key words: Reservoir Destratification, Axial Flow Pump, Water Quality, Oxygen, Temperature

SIGNATURE OF PRINCIPAL INVESTIGATOR ______________________

PROFESSIONAL SCHOOL (medical, graduate, etc.) ______________________

Improving the Quality of Water Releases From Reservoirs by Means of a Large Diameter Pump

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James E. Garton and Charles E. Rice

Introduction

In temperate zones many lakes and reservoirs stratify in the summertime. The wintertime conditions of uniform temperature and oxygen throughout the depth are altered by the increase in incoming radiation. The body of water is not able to transmit the heat as rapidly as it is received at the surface, so three zones develop. The warm top layer, the epilimnion, is fairly uniform in temperature and usually has a high oxygen content. The middle layer, the thermocline, is a zone of rapidly decreasing temperature and oxygen. The bottom layer, the hypolimnion, is at a fairly uniform lower temperature and frequently is devoid of oxygen. In the hypolimnion high levels of iron, manganese, hydrogen sulfide, ammonia, dissolved hydrocarbons and other toxic substances may develop. Two-thirds to three-fourths or more of the depth of the lake may become anoxic. The volume occupied by aquatic life and the bottom area available for food production may be greatly reduced. Many reservoirs have been designed with the intake structure within the anoxic zone. When water is released from the reservoir it may result in fish kills in the river below the dam, or the level of hydrogen sulfide may be such that people wouldn't stay even if the fish did.

Acknowledgements: The work upon which this report is based was supported in part by funds provided by the United States Department of the Interior, Office of Water Research and Technology, as authorized under the Water Resources Research Act of 1964.

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Many of these reservoirs, some of which were constructed specifically to improve the quality of water in the stream, violate Environmental Protection Agency regulations when the water is released from the reservoir.

A recent concern is the levels of dissolved hydrocarbons in water. These substances pass through filtration plants. When the water is chlorinated to make it safe for drinking, some of these substances become chlorinated producing chlorinated hydrocarbons. These substances are not desirable in drinking water.

In the autumn at the end of a period of cloudy weather, the level of oxygen production by algae may be very low in the epilimnion. If the fall turnover of the reservoir occurs at this time, the high oxygen demand of the bottom waters may deplete the falling colder water of oxygen. The resulting low level of oxygen in the reservoir coupled with high levels of ammonia released from the hypolimnion may result in massive fish kills.

The high levels of iron and manganese cause staining of plumbing fixtures and may reach levels high enough to cause health problems.

For a comprehensive review of the subject of lake destratification, the reader is referred to the extensive bibliography developed by Toetz, Wilhm and Summerfelt (1).

Because of the almost universally beneficial effects of reservoir destratification, one might ask why more of it is not being done. The answer would seem to be that the equipment is expensive and complicated, the maintenance costs have been high and the methods used have a high energy requirement, resulting in high operating costs. Also, not enough is known about the physical relationships to accurately design a device for a given reservoir.

Prior to 1971, reservoirs were generally destratified by bubbling air from the bottom to the top, inducing a water circulation upward, or by pumping from the bottom to the top using existing pumping equipment.

Disregarding the high energy requirements and costly equipment, one might question the logic of moving the water from the bottom of a lake to the top. It would seem more logical to pump the oxygen rich surface waters to the bottom of the lake. The shock to the system might be less. A major deterrent to this approach was that no hardware was available to accomplish the task.

Analysis of the Problem

An analysis of the problem indicated that a large axial-flow pump would be required. The area of such a device is proportional to the square of the diameter. The head loss through the device is proportional to the square of the velocity. The rate of flow through the device is equal to the area times the velocity. The power requirement is proportional to the rate of flow times the head loss. The power required for a given flow rate should vary as the square of the diameter and the square of the rpm. To pump the large quantities necessary to destratify large lakes such a device should have an extremely large diameter and an extremely slow rotative speed. The velocity of the water through the device must be sufficient to reach the bottom of the lake.

In July 1971, Garton and Quintero (2) designed a lake destratifier using a 42-inch crop drying fan with a rounded entrance, a cylindrical throat and a fabric diffuser. The length and flare angle of the diffuser were varied. In the study, some tests were run without a diffuser. The diffuser increased the amount of water pumped at a given horsepower about 32 percent.

Preliminary Tests

During the summer of 1972 the device was moved to Ham's Lake five miles west of Stillwater, Oklahoma. Ham's Lake is an upstream floodwater detention reservoir of the SCS. It has supplemental irrigation water storage. The area of the lake is approximately 101 acres and the maximum depth is about 34.5 feet. The Volume stored is approximately 960 acre-feet. The device was operated during some preliminary tests for about 5 weeks and destratified the lake.

Caged catfish were being grown in the lake and the operator requested we not operate the device. During the six weeks that the device was not operating the lake restratified. At the end of the six week period the lake turned over at the end of a week of cloudy, cool weather. All of the fish in the cages died. One has a problem when he has one-hundred-fifty-thousand dead catfish which weigh almost two pounds each. After burying about 1/6 of the fish, the others were dumped in the lake. We then operated the pump for about another month.

During our operations, the crop drying fan blade was lost from the shaft. After several scuba tanks of air, we gave up and replaced it with a 42-inch cooling tower fan. This stamped sheet metal fan had nine blades compared to the seven bladed cast aluminum crop drying fan. Because of this fortunate accident we increased the amount we could pump with the same power about 17 percent.

During 1973, a sheet metal skirt with an upper diameter of 3.5 feet, a lower diameter of 7 feet,a length of 16 feet was constructed and installed. This skirt performed the same as the fabric skirt of the same dimensions. Because the skirt was awkward to install and required gimbals on the pump, we decided to see if the device would destratify Ham's Lake without a skirt. The pump was operated for a week and reduced the stability from an initial value of 3.95 KWH to a final value of 1.3 KWH. These values corresponded to a change in the temperature gradient of 14^{o} C initial to about 2.5^{o} C final thus eliminating most of the stratification. At the end of the week, the sheet metal skirt was installed and the device was operated the remainder of the summer with the skirt.

Steichen (3) reported calculated destratification efficiencies of 4.6 to 6.0 percent. Although these values may seem low, they were 3 to 200 times as efficient as others had reported. He also made extensive tests on the effects of lake destratification on water quality parameters.

The device was operated satisfactorily in 1974 without a skirt. A slightly lower efficiency was accepted to simplify the design of the raft.

Lake Arbuckle Studies, 1974

Because of our successes on Ham's Lake and the interest of federal agencies in efficient reservoir destratifiers we were able to obtain a grant from the Office of Water Research and Technology to develop and test a larger device on Lake Arbuckle.

There were no guidelines on what the significant parameters were for the design of such a device. After three years of testing by various universities and federal agencies, not enough is known to accurately design such devices. Lake Arbuckle has about 23 times the area of Ham's Lake, about 3 times the depth and about 75 times the volume. We were able to destratify Ham's Lake in about 2 weeks with about 10,000 gpm.

Some designs were developed for a device using a 28 foot cooling tower fan and pumping a calculated 650,000 gallons per minute. Because of lack of experience in building such things and having no experts to consult with we decided to build a smaller device. Some 16.5 foot Curtiss-Wright, variable pitch, three bladed propellers were available from surplus, so we decided to install one of them under a 20 x 20 foot redwood raft using expanded foam flotation.

An industrial engine using gasoline for fuel was purchased. A 67.4 to 1 right angle reduction gear was obtained. During 1974 the tip angle of the blades was set at 10 degrees and operated at various speeds up to 12 RPM. At 12 RPM the device pumped about 220,000 gallons per minute. This was found using a propeller current meter traverse 7 feet below the blade. The device was started July 17 and operated at 5 RPM for 7 days and at 9 RPM for 9 days. The speed was increased to 12 RPM on August 2 and operated until August 31. We were scheduled to make torque and power measurements on September 2, but a wind storm producing 4-foot high waves rendered the device inoperable the night of August 31. The shaft was bent so operation was stopped for 1974.

We learned many things the first year. The lake turned over in early September which was about a month earlier than usual. When it turned over the temperature and oxygen became almost uniform top to bottom. Another thing we learned was that it is impossible to keep a gasoline engine operating 100 percent of the time. We were able to operate about 92 percent of the available hours. Some other useful information was that we needed better guarding to keep the anchor ropes out of the propeller, that we needed a wind-actuated shut down device and that gasoline resistant foam should have been used. In September, the device was removed from the lake and transported to Stillwater for rebuilding.

Lake Arbuckle, 1975

During the winter the device was completely rebuilt with gasoline resistant foam flotation. A wind actuated shutoff device was used to deactivate the engine when wind speeds exceeded 35 MPH for 1 minute. Improved guarding of the blade was installed, the shaft was straightened and the blade angle on the new propeller set at a 6.5 degree tip angle. This tip angle was calculated to produce the flow at 20 RPM that the other tip angle produced at 12 RPM.

The device was transported back to Lake Arbuckle and during the week preceding Memorial Day we occupied about half of the boat launching area at the Point on Lake Arbuckle assembling the device. Figure 1 shows the pump being assembled. We decided to try a new launch procedure, which was made necessary by the improved guarding. Axles were installed at the lower end of the legs at each corner. (Figure 2). Rubber tires and wheels were mounted on the axles. As the device was rolling down the boat launching ramp on Friday morning, we discovered that a two-foot wheel will not roll over a one foot sand bar. We pulled it back out of the lake and installed 1000 pounds of flotation on the end of each leg. It still wouldn't clear the sand bar. An additional 500 pounds of flotation on the front wheels and we were afloat. This extra flotation caused the front end to rise and back end to sink. When all of the flotation was cut loose from the front end, it sank and the back end floated. Removal of the back flotation righted the raft. At 7:30 p.m. a relieved Park Service Ranger saw us afloat. By 9:00 p.m. on a moonless night we had the device towed to location and anchored. Our return to Lake Arbuckle was with an improved pump, improved instrumentation for measuring temperature and oxygen, and a year of good experience. Figure 3 shows the pump in place.

Measurements were made of flow rate, rotative speed and torque, Figure 4 . The device pumped 207,000 gpm at 20 RPM and required 7.32 horsepower. At 18 RPM the flow was 186,000 gpm and the power required was 5.33 horsepower.

The pump was placed in operation on June 2 at 18 RPM and was operated until July 2 when the speed was increased to 20 RPM. The pump was operated until September 13. On that date the lake turned over and the pump was not operated again.

A regular program of readings at 6 locations on the lake was begun when the pump was started. These locations are shown on Figure 5 . The raft was located (labeled R) near Station 2. Readings of temperature and dissolved

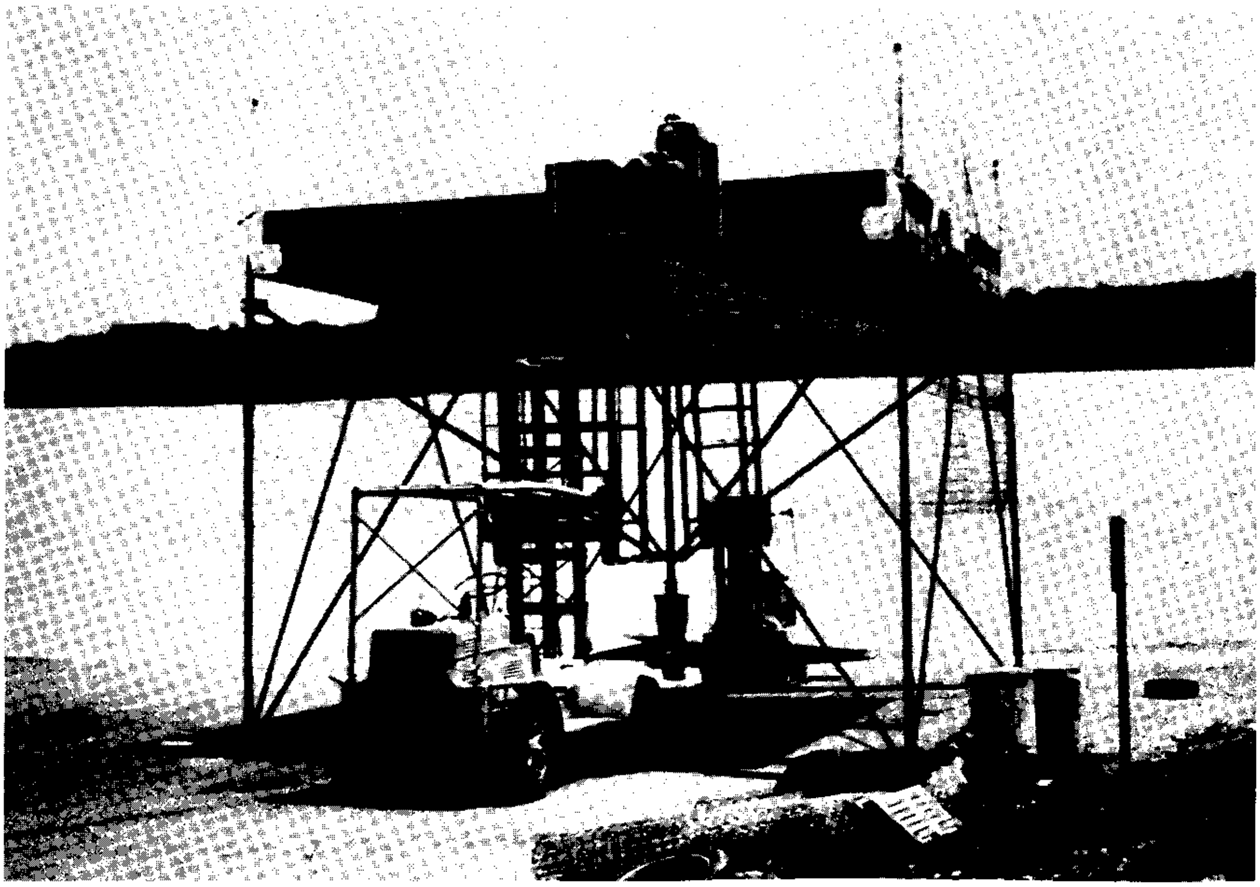

Figure 1. The raft being assembled at Lake Arbuckle in 1975. Two forklifts with extensions were used to lift raft.

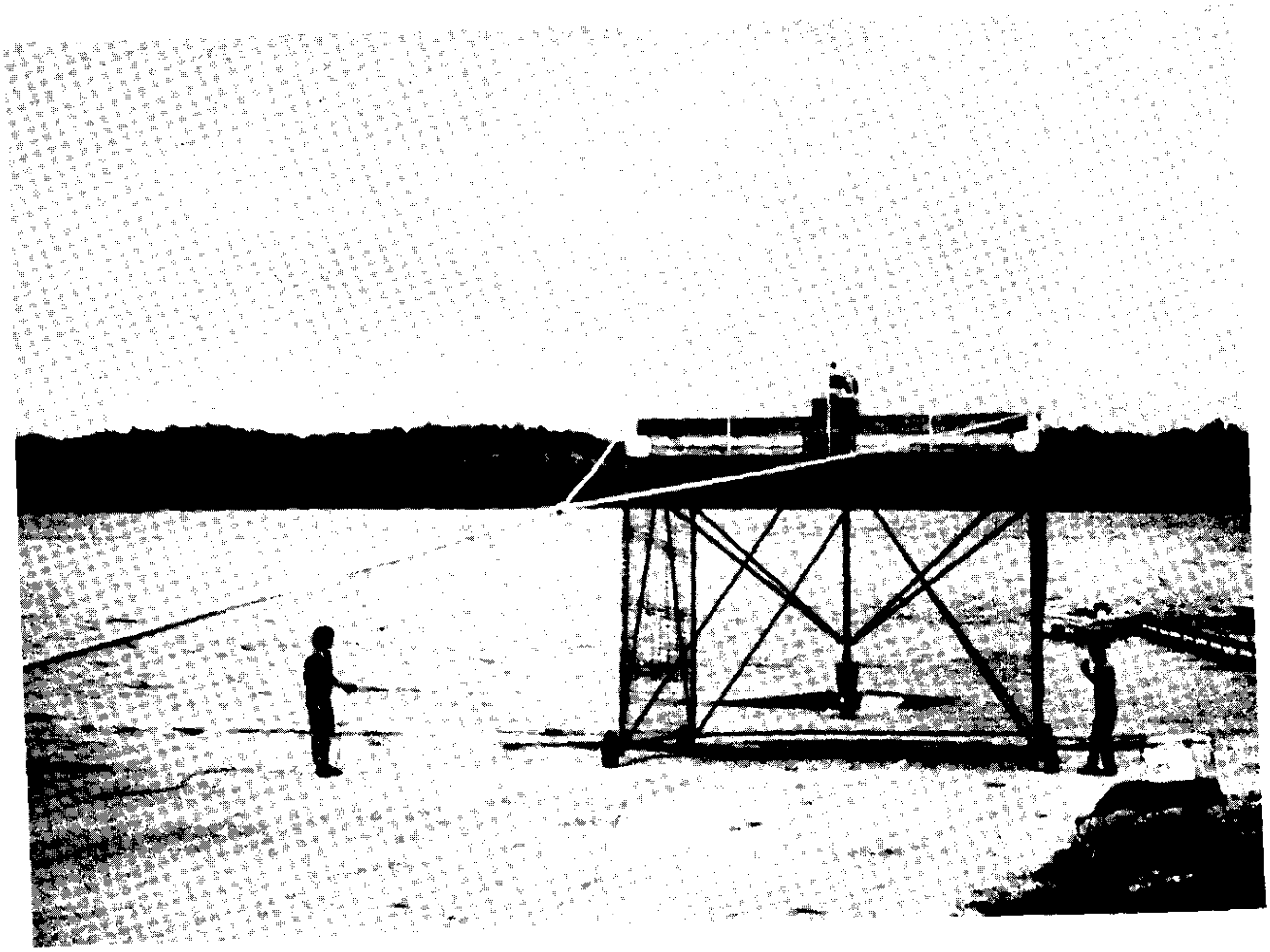

Figure 2. The raft being rolled down the boat ramp at Lake Arbuckle.

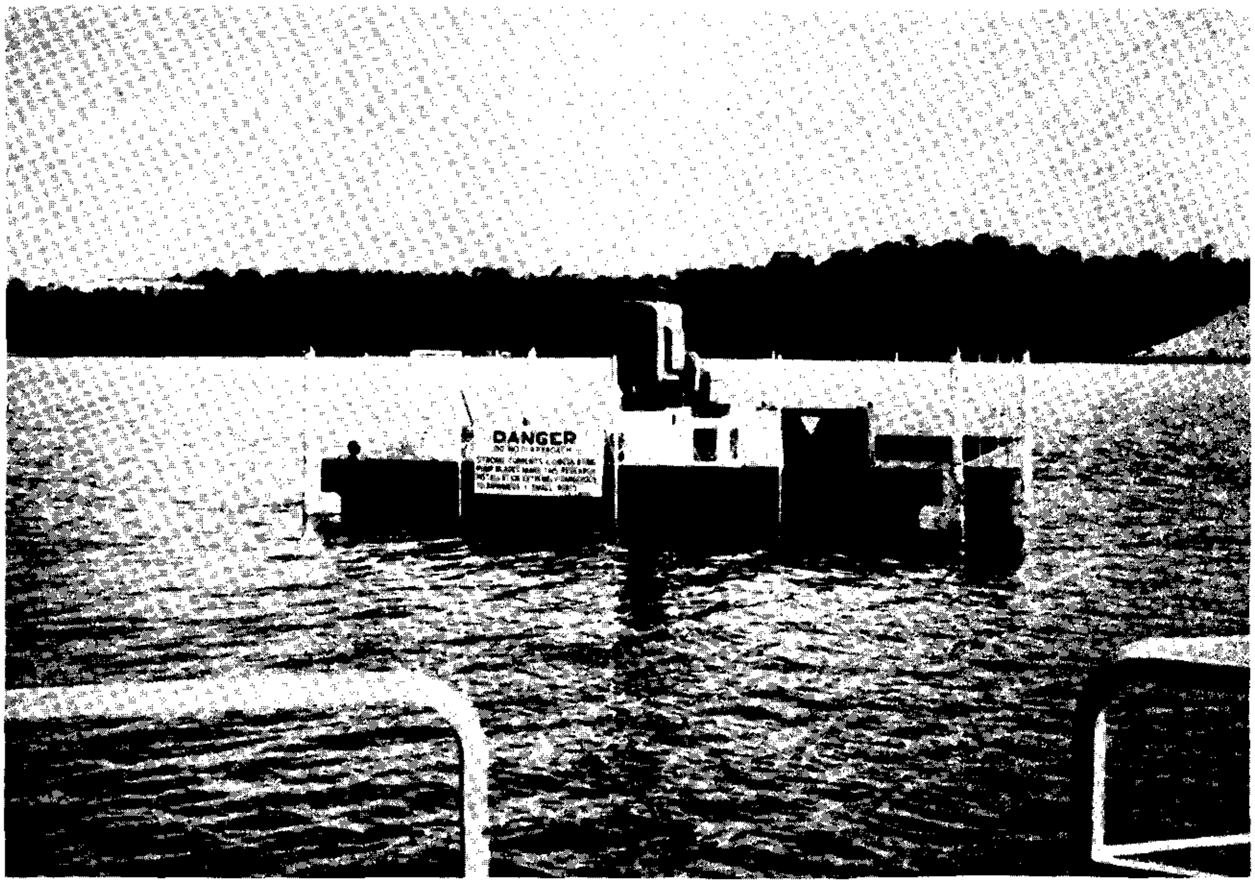

Figure 3. The raft anchored in place near the dam on Lake Arbuckle.

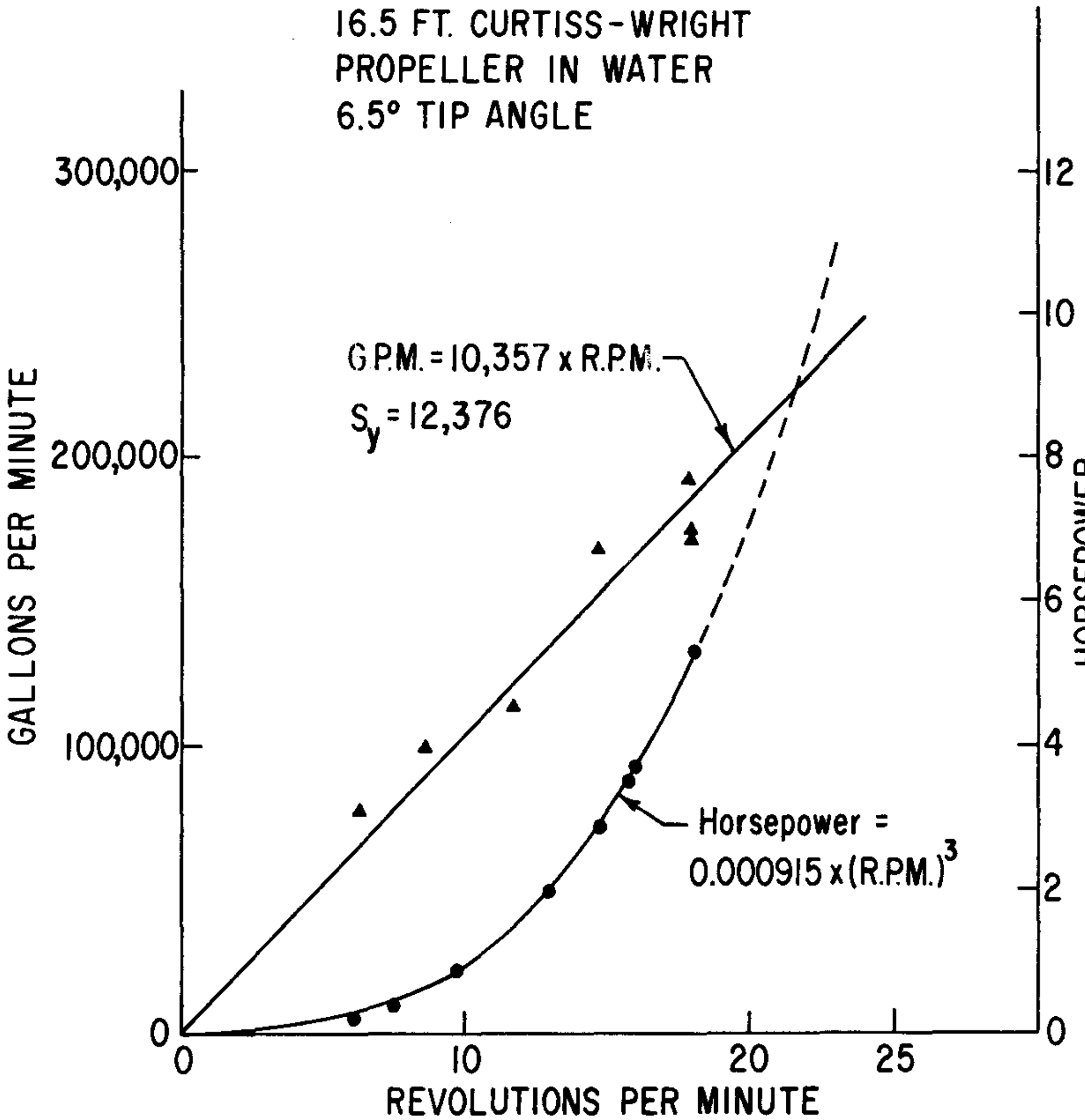

Figure 4. Performance curves for the pump used in 1975 on Lake Arbuckle

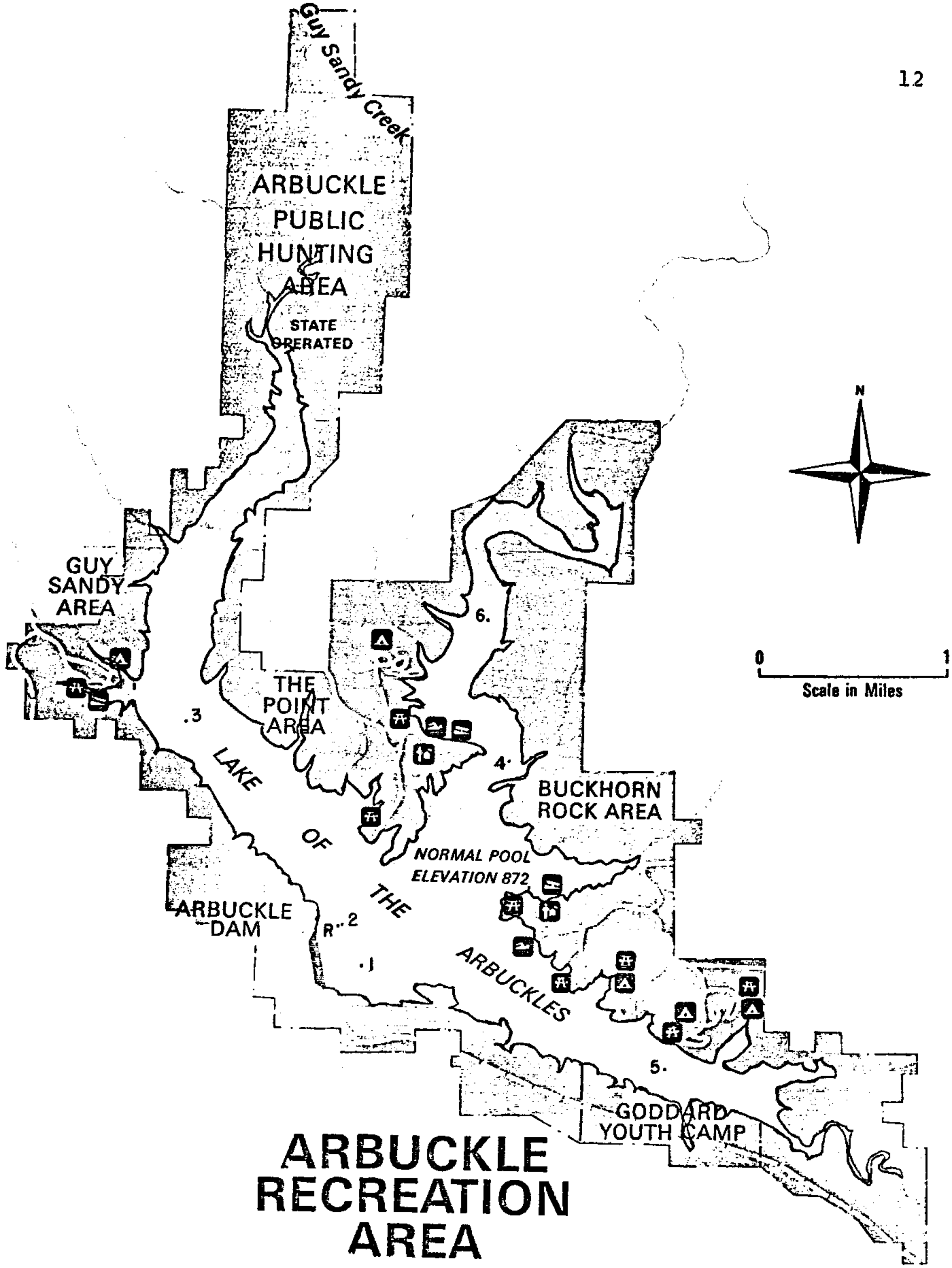

Figure 5. Map of Lake Arbuckle showing the numbered sampling locations. The raft, labeled R, is located 32 meters from station 2.

oxygen were made at one meter intervals at each location on a twice a week, or more often, sampling schedule.

Stability Index

A convenient method of reducing a large mass of temperature data to a single number is the stability index. This parameter is a measure of the energy required to completely destratify a lake. To calculate the stability index the lake is divided into one meter horizontal slices. The mean temperatures on each side of the slice are averaged and the density found for this temperature. The volume is assumed to be equal to the average end area times the one meter distance. The center of weight is assumed to be at the midpoint of the slice. The distance from the water surface to the midpoint of each slice is multiplied by the weight of the slice to find the moment about the surface. The sum of the moments divided by the total weight of the lake gives the distance to the centroid. The centroid is also calculated for a destratified lake, assuming a uniform temperature. The weight of the lake multiplied by the distance between the centroids is equal to the work required to destratify the lake.

The authors were not satisfied with the assumptions made in this calculation so they calculated the stability index using the slice as a truncated cone. The density of each face was calculated, and a weighted density found. The centroid of the variable density cone was found, and the moment calculated as above. A comparison between the two methods on two lakes for each sampling day indicated a maximum difference of less than 1% in the methods. Because of the simplicity of the presently used method, there does not appear to be sufficient loss of accuracy to change to the more complicated method.

The stability index is a single number which indicates the degree of lake stratification for a given lake. An index of zero indicates a completely mixed lake. A negative index indicates an unstable lake. Only small negative values are ever observed.

Oxygen Distribution Index

The authors have developed an oxygen distribution index to serve the same function for oxygen that the stability index serves for temperature. It is calculated in the same way except that the weight of oxygen in the slice is used instead of the weight of water. The oxygen distribution index gives a single number which is a measure of the oxygen distribution of the lake. The total oxygen content as well as the location will have an influence on the size of the index. A value of zero indicates that the lake is completely destratified for oxygen. Zero values are not usually achieved, as the values near the surface are almost always larger than the bottom values. As this is a new concept, the values of stability index versus oxygen distribution index are presented for both Ham's Lake, Figure 6, and Arbuckle Lake, Figure 7 . An interesting observation from the curve for Arbuckle Lake is that the oxygen stability index changed very little while the stability index was decreasing to about ¼ of its maximum value. Figure 8, which is a plot of oxygen distribution index and stability index versus date of reading for Ham's Lake, shows that the oxygen distribution index lags the stability index. The first few days of operation reduced the oxygen stability index by half and the lake was well mixed chemically after 26 days and was maintained in that condition.

Figure 9 which is a plot of oxygen distribution index and stability index versus date of reading for Lake Arbuckle, shows that the lakes did not behave similarly. The graph indicates that a lake can be weakly stratified thermally and strongly stratified for oxygen. Figure 10 shows that on

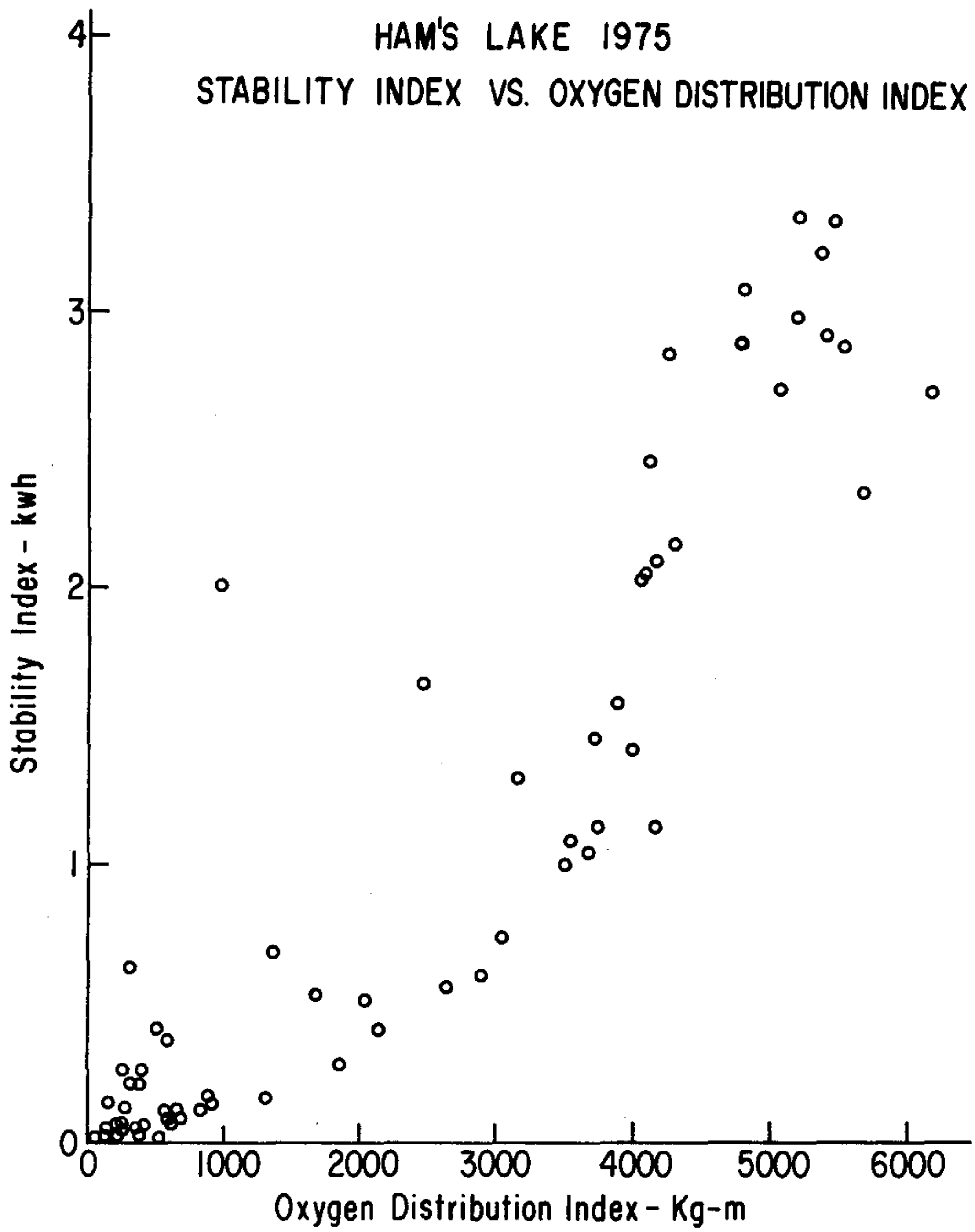

Figure 6. Stability index versus oxygen distribution index for Ham's Lake, 1975.

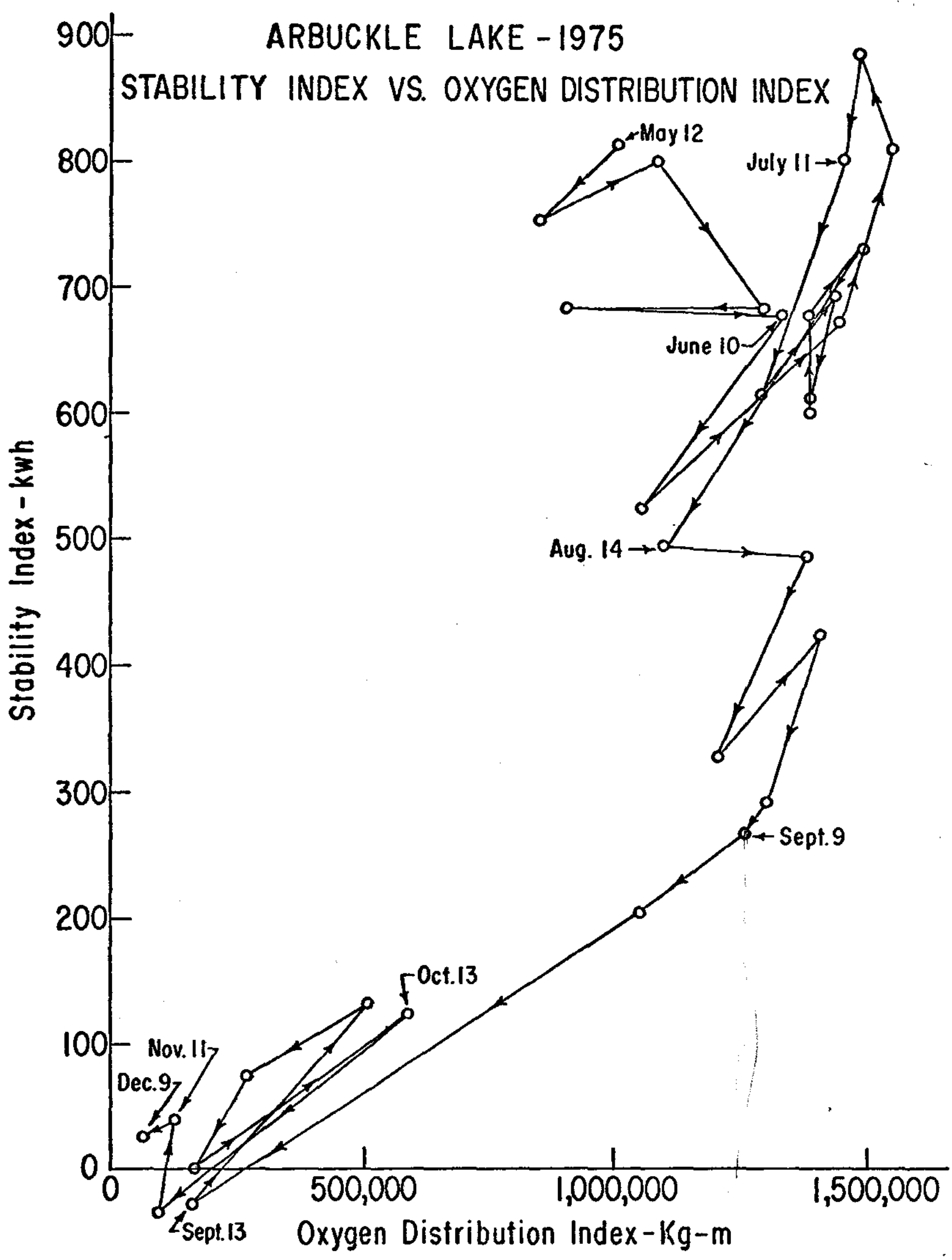

Figure 7. Stability index versus oxygen distribution index for Lake Arbuckle, 1975. Note the rapid change in oxygen distribution and stability index between Sept. 9 and Sept. 13.

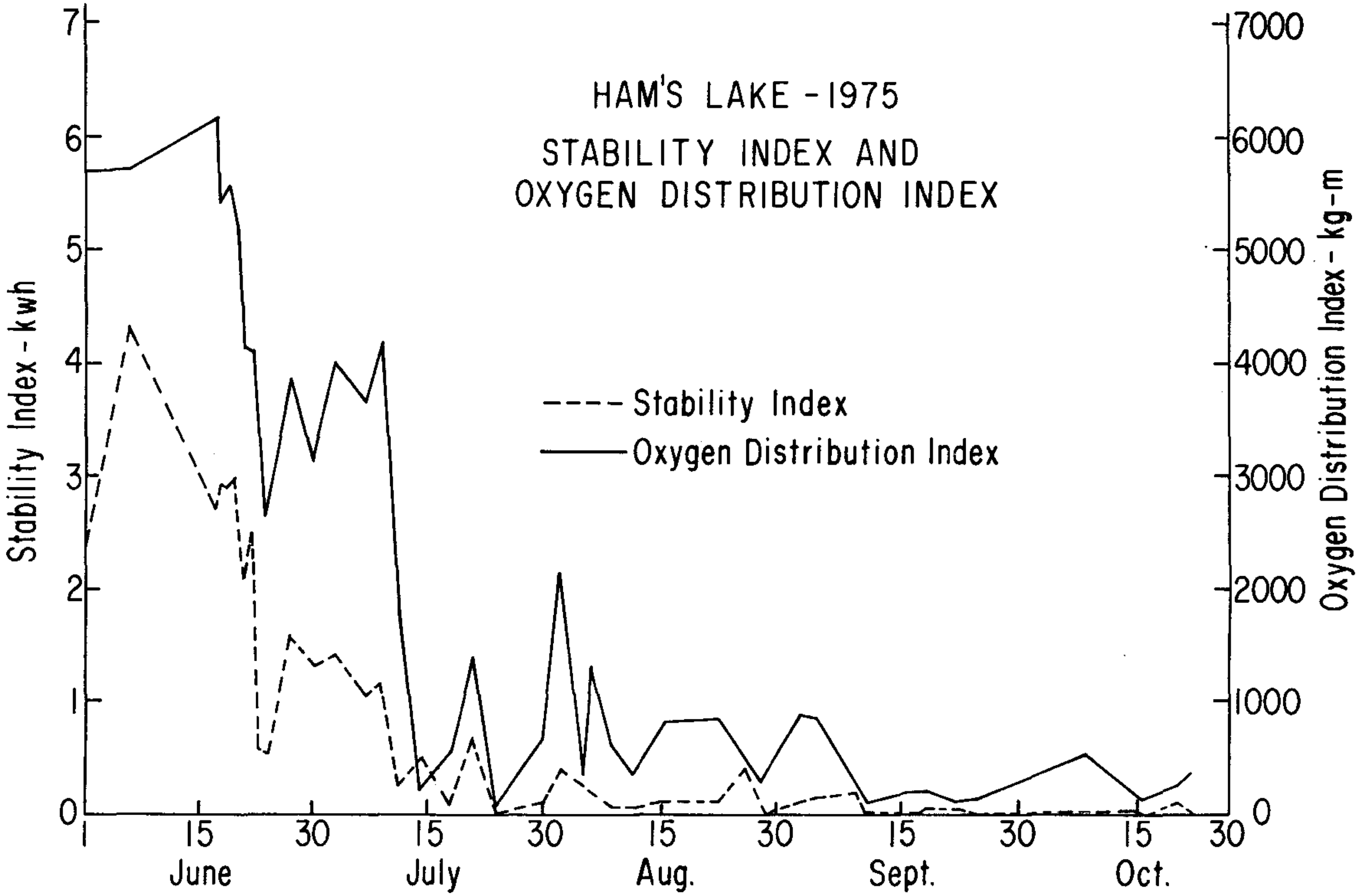

Figure 8. Stability index and oxygen distribution index for Ham's Lake during different dates for 1975.

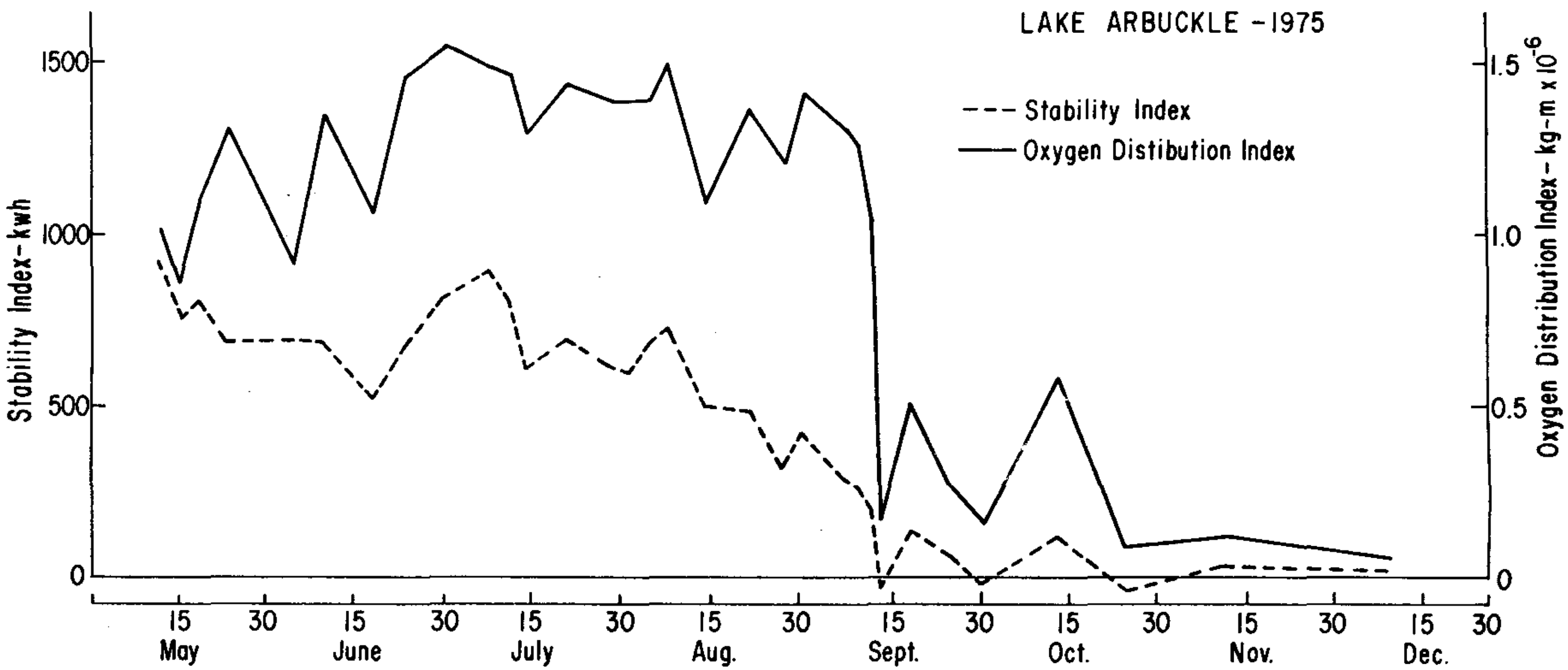

Figure 9. Stability, index and oxygen distribution index for Lake Arbuckle during different dates for 1975. Note no decline in oxygen distribution until lake turned over on Sept. 13.

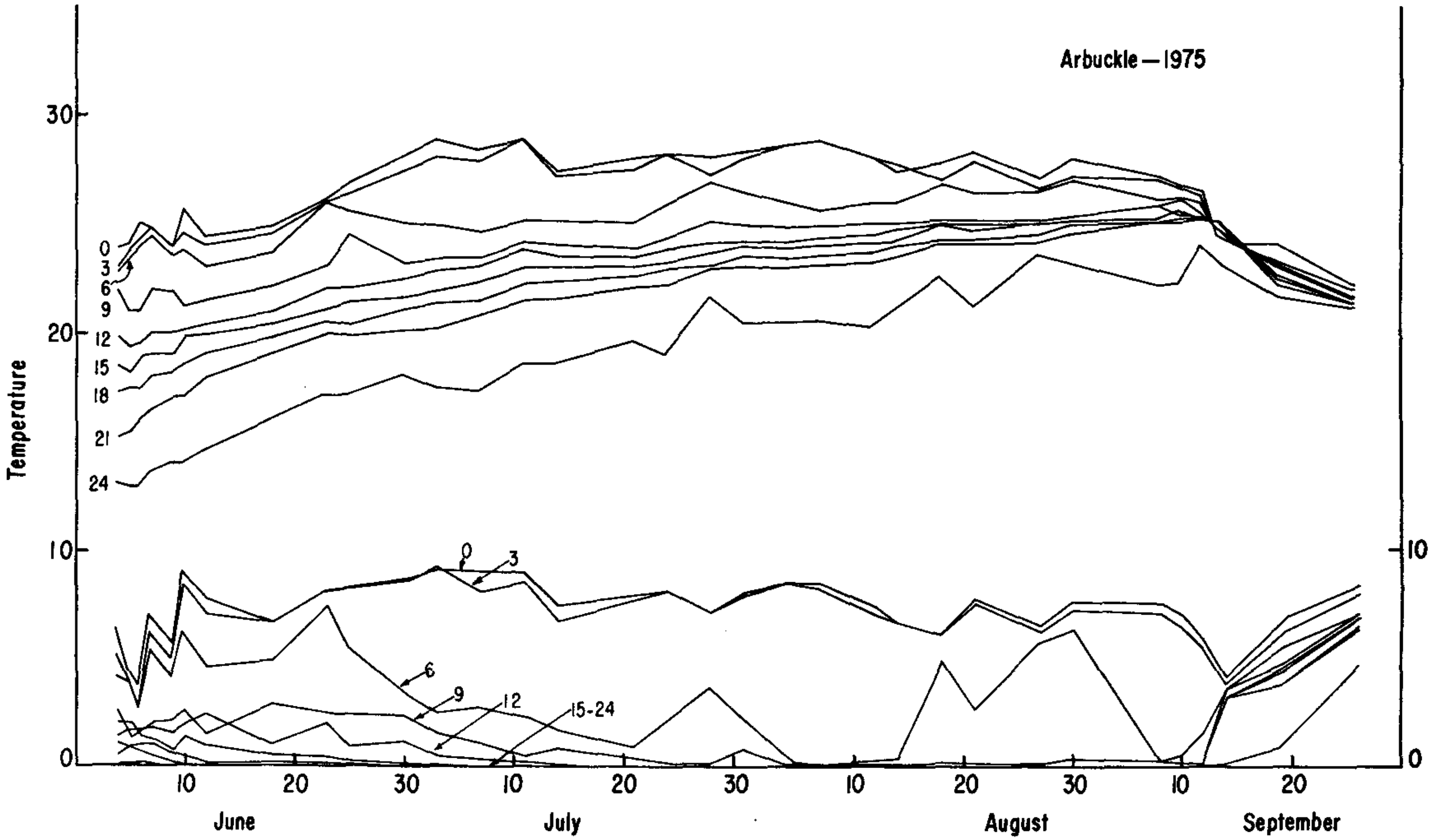

Figure 10. Temperature and dissolved oxygen for various depths, in meters, for Lake Arbuckle, summer, 1975.

September 7, the temperature difference between the surface and the 21 meter depth was less than 2.5 degrees, but the oxygen content below 5 meters was essentially zero. A week later the stability index was zero, and the oxygen distribution index was a very low value. The conclusion to be reached is that anything less than total thermal destratification might not achieve chemical mixing.

Figure 11 indicates that the stability index in 1975 was maintained at a level about half that of the previous two years. The lower stability index was not accompanied by a lower oxygen distribution index. The oxygen distribution index in 1975 was comparable to the values obtained in 1973, but 1974 had two periods during which the oxygen was much more poorly distributed than in 1973 and 1975.

Figure 12 shows the average temperature and average dissolved oxygen values for different dates during 1975. The average oxygen content was generally lower than values obtained during 1973 and 1974. The average temperature was lower in 1973 than in 1975. Until July 30, the average water temperature in 1974 was higher than in 1975, but after that date the readings were lower than in 1975.

The average dissolved oxygen content was plotted against the average water temperature in Figure 13 . A plot of the oxygen solubility curve is also included. There seems to be a slight hysteresis loop in the data. At a given temperature, lower oxygen values were observed while the lake was warming than while it was cooling. This was probably related to lake stability in that the oxygen values did not increase greatly until after the fall turnover.

Figure 10 , a plot of temperature and oxygen at different depths (in meters) during the summer of 1975 shows that the device was ineffective in redistributing the oxygen in the lake until after the fall turnover on Sept. 13. On that date uniform temperatures were read to 21 meters. At the fall

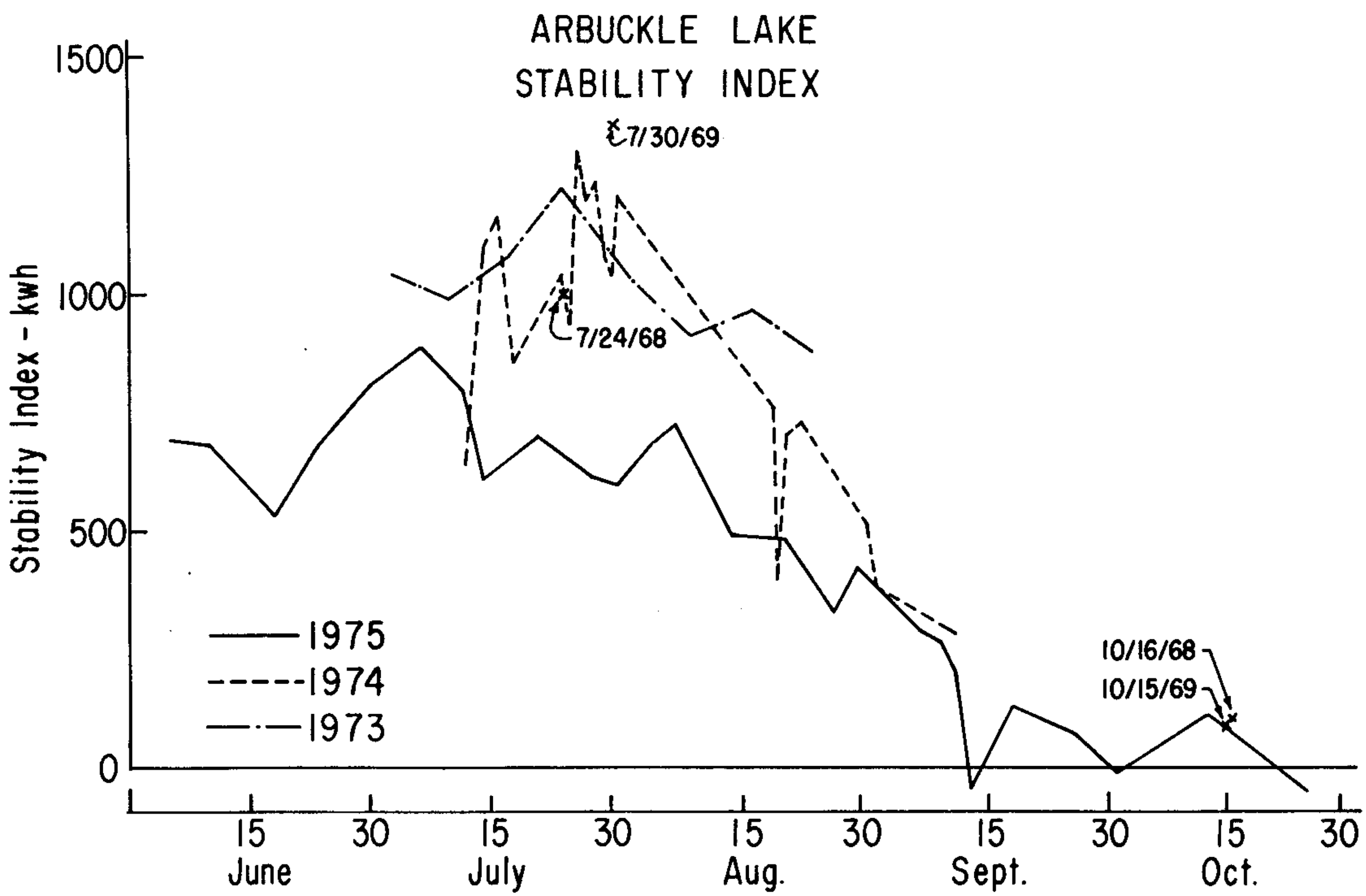

Figure 11. Stability index on different dates for Lake Arbuckle.

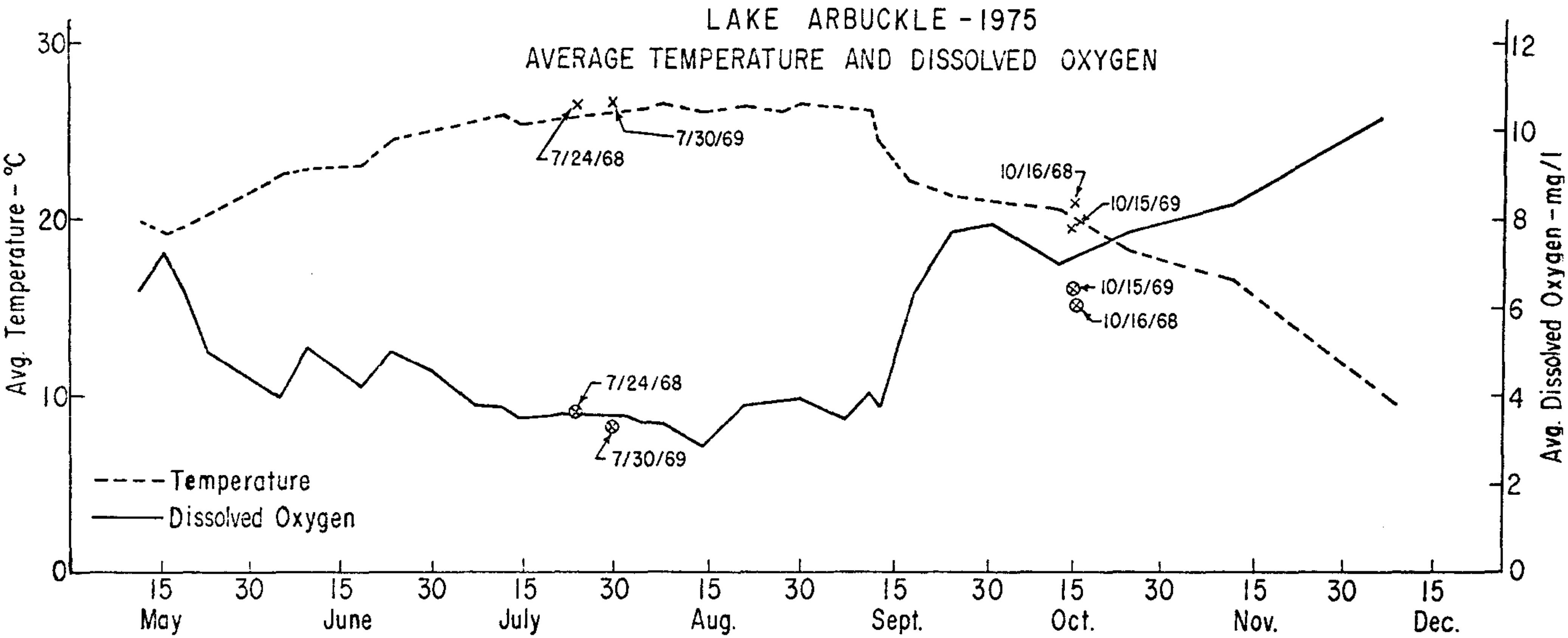

Figure 12. Average temperature and average dissolved oxygen for Lake Arbuckle, summer, 1975.

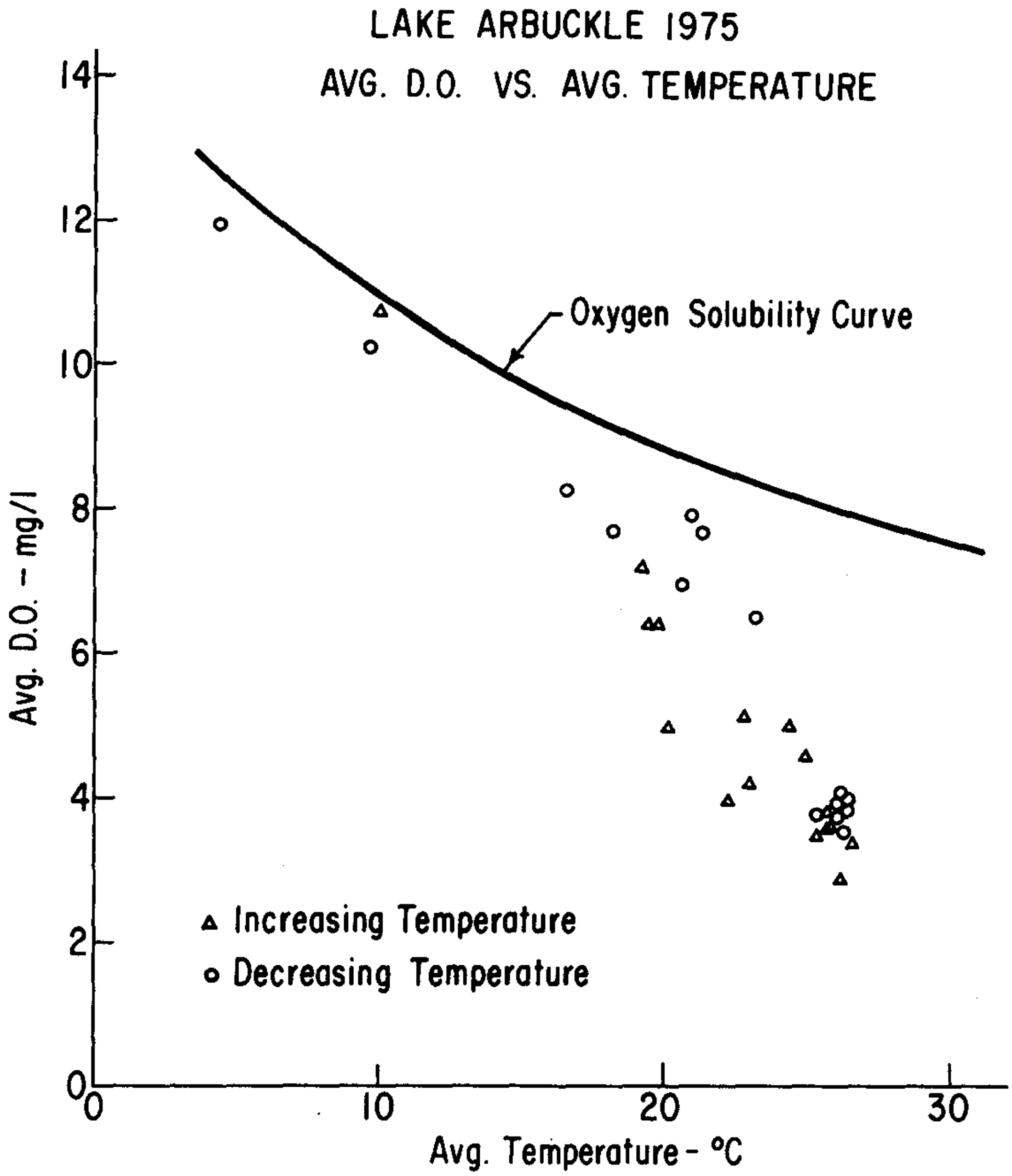

Figure 13. Average dissolved oxygen versus average temperature for Lake Arbuckle, 1975.

turnover, the oxygen content from 6 to 21 meters increased from zero to about 2.5 mg/L. This was accompanied by a drop in the surface oxygen from 7.0 to about 4.2 mg/L.

The temperature in the depths of the lake increased continuously from the start of our pump until the fall turnover. Although the data is skimpy, it appears that the mixing effort increased the average temperature about 1° C in August compared with 1973 and 1974. This data, supported by our data on Ham's Lake does not show a great reduction in surface temperatures by mixing. On Ham's Lake in 1975 the bottom temperatures increased 12.5° C. during the first 18 days of operation, and on the 18th day the surface temperature exceeded 30° C.

Figure 14 is a plot of the temperature at different depths on selected dates for Arbuckle Lake. A comparison of profiles on July 24 for 1968 (obtained from Duffer and Harlan (4)) and 1975, shows somewhat more uniform temperatures in 1975 with a warming of the deeper depth more noticeable. A comparison of September 13, 1975 with October 16, 1968 indicates that the lake had destratified during the fall turnover about a month earlier and more completely in 1975.

Figure 15 is a similar plot of oxygen distribution of different selected dates. The oxygen on July 7, 1975 was only slightly better distributed than July 24, 1968. By September 7, 1975 the distribution was much poorer. The oxygen content below 5 meters on that date was essentially zero. Six days later, the oxygen content varied only from about 3.5 at 23 meters to 4 ppm at the surface. Compare the September 13, 1975 the oxygen distribution with the October 16, 1975 distribution. This evidence that the fall turnover occurred a month earlier is much more striking than the comparable temperature data.

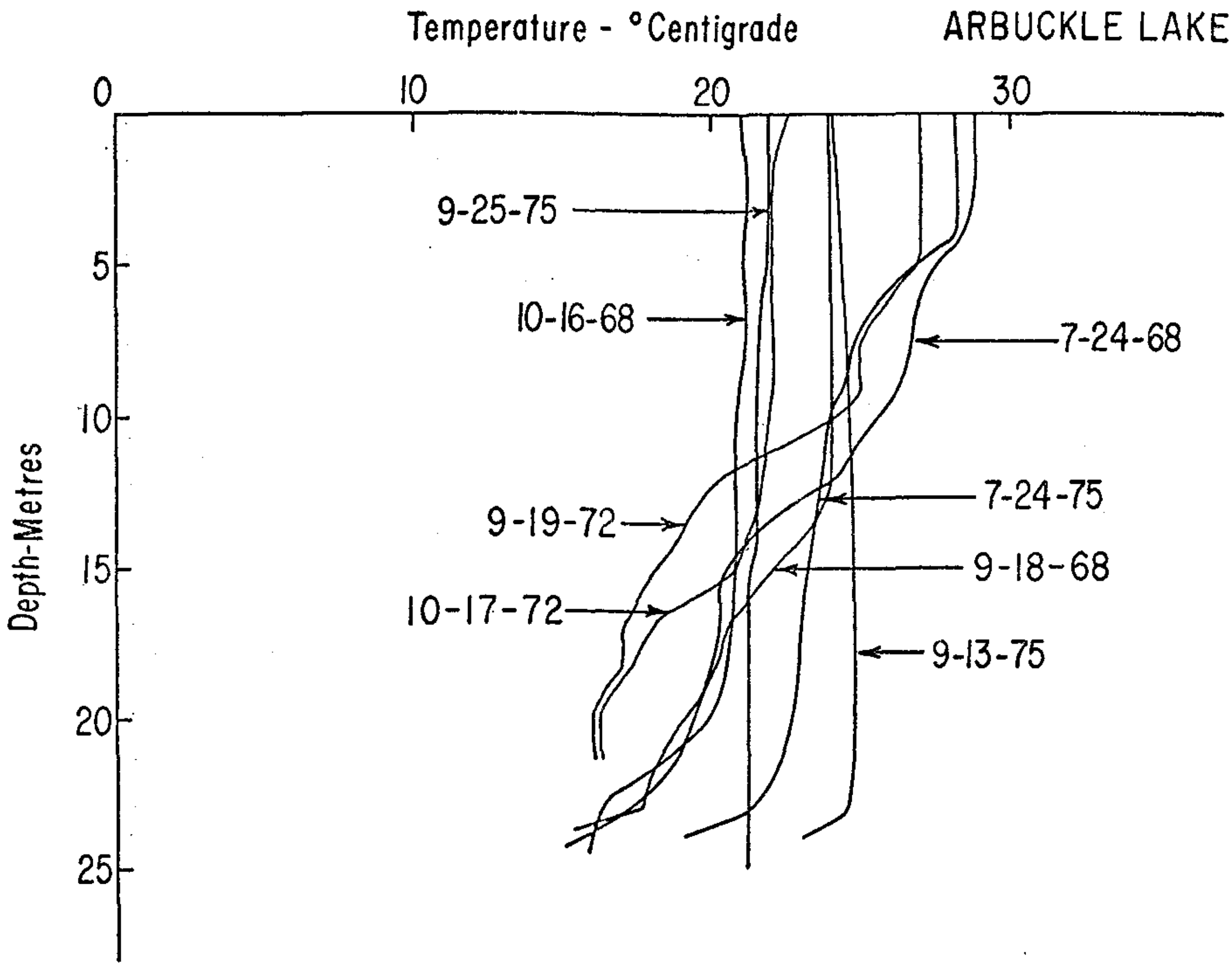

Figure 14. Comparison of temperature profiles on selected dates, 1968 and 1975, for Lake Arbuckle.

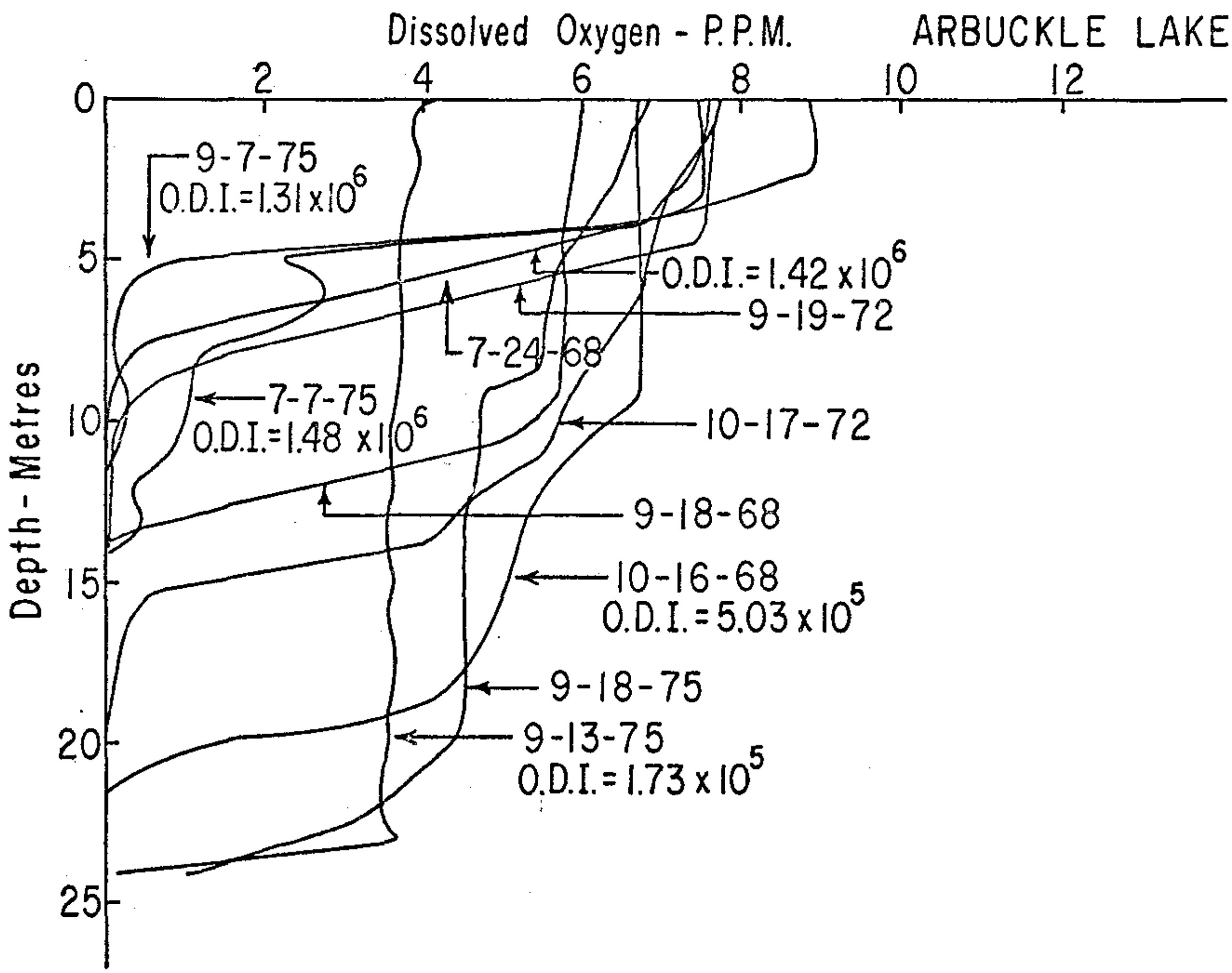

Figure 15. Comparison of dissolved oxygen on selected dates, 1968 and 1975, for Lake Arbuckle.

This graph provides a means of visible comparison of the oxygen distribution index associated with different oxygen distributions. The value for September 7, 1975 is 1.3 X 10^6 Kg-M and for July 7, 1975 is 1.5 X 10^6. The value for October 16, 1968 is 5.0 X 10^5 Kg-M. The sum of the moments about the surface is a function of both the amount of oxygen and its distribution, so the index might not be a very sensitive measure of poorly distributed oxygen. The value for September 13, 1975 is 1.7 X 10^5 Kg/M. The lower index values are associated with a better oxygen distribution. A judgement as to the usefulness of the index is left to the reader.

Quality of Released Water

The major objective of the project was to improve the quality of the water released from the reservoir. We had hoped to completely destratify the lake chemically, and by adding oxygen to the lower waters, to improve the quality of the water in the bottom 20 meters of the entire lake. We were not able to chemically destratify the lake.

The destratifier was located near the outlet from the lake. The deepest portion of the lake at station number 1 was 1300 feet away from the pump.

The temperature and oxygen contents of the released water were sampled periodically by drawing water from a tap on the supply pipe. The oxygen level at the elevation of the outlet (21 feet) at sampling stations number one and two were obtained by interpolation.

Figure 16 is a plot of the levels of dissolved oxygen at the three locations for the period of mid-July to late August. As can be seen from the plots, the levels at station two and the outlet water were closely correlated. These levels were usually one to two parts per million higher than the levels at station one at the deepest part of the lake. In retrospect, it would have

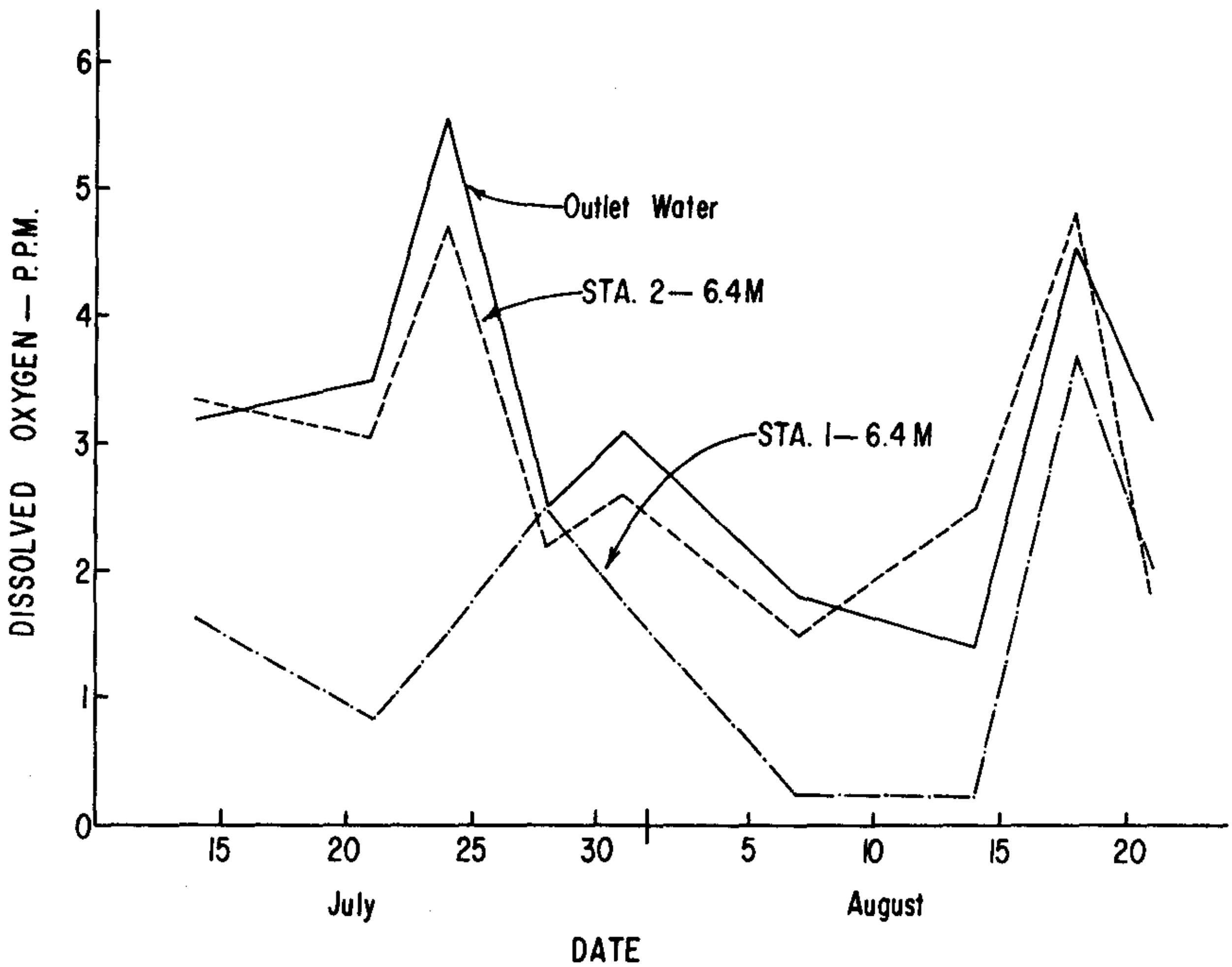

Figure 16. Comparison of oxygen content in outlet water with oxygen content at stations 1 and 2, Lake Arbuckle, 1975.

been wise to locate the pump directly over the outlet. We have proposed to do this on a shallow Corps of Engineers lake in Mississippi. It might be more conservative of energy to simply pump the surface waters down to be discharged through the outlet. One would not reap the benefits of redistributing the oxygen, but it may be easier to achieve the limited objective. A large conduit might help to contain the surface waters to the bottom of the lake.

Summary and Conclusions

A 16.5 foot diameter pump was assembled and installed on Lake Arbuckle. The pump was operated for six weeks during 1974 and for three months during 1975. Performance information was obtained for the 1975 pump having a 6.5 degree tip angle. The 1975 pump was operated at 186,000 gallons per minute for a month and then increased to 207,000 gallons per minute. Although the physical relationships are not accurately known, our data indicates that this pumping rate needs to be increased by a factor of 2 or 3 to chemically destratify the lake in a reasonable time. Even though we decreased the stability of the lake by half, the lake remained strongly stratified for oxygen.

Lake Arbuckle turned over in the fall about a month earlier than usual. At the time of turnover the lake was more completely mixed than in previous years.

The oxygen content in the outlet water was maintained at a level about one to two ppm higher than the level in the main body of the lake.

The knowledge of how to design, build and operate this type of pump has been advanced considerably. The sizing of such a device to a given lake is still not an exact science.

In retrospect, we probably should have designed and built the 28 foot diameter pump. This approach to lake destratification has a lot to recommend it. Some progress has been made, but much more remains to be learned.

APPENDIX

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TABLE I

OBSERVED AND CALCULATED DATA FOR VARIOUS DATES, LAKE ARBUCKLE

CATE	TIME (MEDIAN)	SURFACE ELEVATION (METERS)	CENTROID ELEVATION (METERS)	TOTAL VOLUME (HA-M)	SURFACE AREA (HECTARES)	AVERAGE TEMPERATURE (DEG. C)	AVERAGE D.O. (MG/L)	TOTAL OXYGEN (KG)	STABILITY INDEX (KWH)	OXYGEN DISTRIBUTION INDEX (KG-M)
JULY 24 68	8:00 AM	265.87	258.82	9006.9	958.0	26.3	3.6	323872.	1005.5879	1421048.
CCT 16 68	8:00 AM	265.90	258.84	9030.3	959.6	20.9	6.1	550099.	111.6789	503315.
JULY 3C 69	8:30 AM	265.69	258.68	8836.0	946.3	26.4	3.3	292592.	1357.2632	1263408.
OCT 15 69	8:30 AM	266.27	259.12	9390.9	984.0	19.4	6.4	596835.	102.7808	317348.
JULY 12 74	3:00 PM	265.78	258.75	8913.7	951.9	24.8	5.7	512397.	909.4409	1620290.
JULY 14 74	3:00 PM	265.78	258.75	8911.9	951.9	26.1	5.0	445304.	1322.4155	1488773.
JULY 16 74	3:30 PM	265.78	258.75	8911.9	951.9	26.2	5.7	508207.	1396.4587	1880804.
JULY 17 74	4:00 PM	265.78	258.76	8911.9	951.9	25.5	5.[illegible]	475065.	1175.1860	1975510.
JULY 18 74	3:40 PM	265.77	258.75	8907.9	951.5	25.7	5.5	498528.	1158.6750	2027131.
JULY 24 74	11:05 AM	265.75	258.73	8882.9	949.9	27.3	4.3	383697.	1248.9531	1656497.
JULY 25 74	3:55 PM	265.74	258.72	8875.9	949.3	26.4	4.7	415447.	1268.9810	1368630.
JULY 26 74	11:10 AM	265.74	258.72	8879.3	949.3	26.9	4.4	386429.	1335.4719	1239481.
JULY 27 74	10:55 AM	265.74	258.72	8879.3	949.3	27.0	5.1	453846.	1243.9666	1395735.
JULY 28 74	5:00 PM	265.74	258.72	8874.2	949.3	27.1	5.3	469758.	1478.8772	1657605.
JULY 29 74	12:00 PM	265.73	258.72	8867.2	948.7	27.5	4.4	394393.	1429.7954	1440337.
JULY 30 74	10:45 AM	265.72	258.70	8864.8	948.3	26.8	4.1	362025.	1065.3188	1206043.
JULY 31 74	12:15 PM	265.72	258.70	8859.0	947.9	26.8	4.4	386651.	1240.2581	1349627.
AUG 19 74	1:40 PM	265.75	258.73	8893.7	950.3	24.8	4.5	397842.	785.5591	1484187.
AUG 20 74	9:45 AM	265.74	258.73	8878.8	949.5	25.4	4.4	395049.	593.7317	1303244.
AUG 21 74	11:10 AM	265.73	258.71	8873.5	948.9	24.6	3.9	342407.	728.6506	1491286.
AUG 23 74	11:25 AM	265.73	258.71	8865.2	948.5	25.1	5.7	508898.	804.7925	2078362.
AUG 3C 74	4:10 PM	265.76	258.73	8896.6	950.5	24.9	5.0	448612.	569.4219	1680683.
AUG 31 74	10:55 AM	265.76	258.73	8896.6	950.5	27.4	5.2	461193.	549.0015	1291920.
SEPT 1 74	10:30 AM	265.76	258.73	8896.6	950.5	27.4	4.8	424645.	412.4514	1110146.

DATE	TIME (MEDIAN)	SURFACE ELEVATION (METERS)	CENTROID ELEVATION (METERS)	TOTAL VOLUME (HA-M)	SURFACE AREA (HECTARES)	AVERAGE TEMPERATURE (DEG. C)	AVERAGE D.O. (MG/L)	TOTAL OXYGEN (KG)	STABILITY INDEX (KWH)	OXYGEN DISTRIBUTION INDEX (KG-M)
MAY 17 73	10:00 AM	265.81	258.78	8943.6	953.9	19.8	6.9	618032.	467.3372	770488.
JULY 3 73	10:00 AM	265.82	258.78	8953.9	954.5	24.8	3.3	295628.	1047.3594	1138877.
JULY 10 73	10:00 AM	265.84	258.79	8971.4	955.7	23.7	3.5	317588.	999.4888	1418986.
JULY 17 73	10:00 AM	265.84	258.80	8977.2	956.1	24.6	3.9	348768.	1075.4888	1486325.
JULY 24 73	10:00 AM	265.88	258.82	9009.2	958.2	25.2	4.0	358354.	1227.5322	1490415.
AUG 1 73	10:00 AM	265.85	258.80	8980.1	956.3	25.1	5.1	454257.	1037.0798	1421988.
AUG 8 73	10:00 AM	265.82	258.78	8956.8	954.7	25.4	4.6	413501.	919.2712	1438288.
AUG 16 73	10:00 AM	265.82	258.78	8951.0	954.3	25.9	4.3	387413.	969.3245	1259116.
AUG 24 73	10:00 AM	265.79	258.76	8930.7	952.9	24.5	4.4	395393.	878.1790	1549119.
SEPT 11 74	6:15 PM	265.82	258.78	8956.8	954.7	24.3	6.5	578752.	286.1042	770100.

DATE	TIME (MEDIAN)	SURFACE ELEVATION (METERS)	CENTROID ELEVATION (METERS)	TOTAL VOLUME (HA-M)	SURFACE AREA (HECTARES)	AVERAGE TEMPERATURE (DEG. C)	AVERAGE D.O. (MG/L)	TOTAL OXYGEN (KG)	STABILITY INDEX (KWH)	OXYGEN DISTRIBUTION INDEX (KG-M)
MAY 12 75	12:00 PM	265.79	258.76	8932.2	952.9	19.9	6.4	572911.	813.0081	1023967.
MAY 16 75	4:20 PM	265.82	258.78	8959.7	954.9	19.2	7.2	643111.	756.1257	860183.
MAY 19 75	12:45 PM	265.79	258.76	8924.9	952.5	19.5	6.4	568759.	801.9829	1089696.
MAY 23 75	1:30 PM	266.08	258.98	9212.1	971.8	20.2	5.0	460477.	682.7004	1303595.
JUNE 5 75	11:00 AM	265.80	258.76	8933.6	953.1	22.3	4.0	352961.	683.9749	911051.
JUNE 10 75	1:00 PM	265.95	258.88	9082.2	963.2	22.8	5.1	459933.	679.0415	1334345.
JUNE 16 75	12:45 PM	265.81	258.78	8948.1	954.1	23.0	4.2	376049.	526.6091	1061742.
JUNE 23 75	10:00 AM	265.79	258.76	8927.8	952.7	24.4	5.0	448803.	674.8652	1452057.
JUNE 30 75	10:40 AM	265.80	258.77	8936.5	953.3	25.0	4.6	409927.	811.9758	1546884.
JULY 7 75	10:45 AM	265.82	258.78	8959.7	954.9	[illegible]	3.8	342347.	887.7681	1484028.
JULY 11 75	10:45 AM	265.82	258.78	8959.7	954.9	[illegible]	3.3	343356.	802.3003	1459757.
JULY 14 75	11:45 AM	265.82	258.78	8953.9	954.5	25.5	3.5	311742.	614.5366	1294820.
JULY 21 75	11:10 AM	265.82	258.78	8951.0	954.3	25.7	3.6	326167.	697.0308	1439093.
JULY 29 75	12:05 PM	266.07	258.97	9194.1	972.8	25.9	3.6	331495.	613.3059	1384999.
JULY 31 75	11:45 AM	265.80	258.77	8936.5	953.3	26.1	3.6	324394.	600.4888	1380744.
AUG 4 75	10:20 AM	265.76	258.74	8901.8	950.9	26.2	3.4	299065.	580.8767	1393349.
AUG 7 75	11:45 AM	266.07	258.97	9191.1	970.6	26.5	3.4	309011.	733.4299	1486213.
AUG 14 75	11:45 AM	265.73	258.72	8872.8	948.9	26.1	2.9	258324.	495.4971	1106025.
AUG 21 75	11:20 AM	265.75	258.73	8890.2	950.1	26.4	3.8	335068.	487.9988	1375616.
AUG 27 75	4:25 PM	265.73	258.71	8869.9	948.7	[illegible]	3.9	343046.	329.5916	1216023.
AUG 30 75	11:55 AM	265.74	258.72	8878.6	949.3	[illegible]	4.0	351163.	425.2798	1419230.
SEPT 7 75	12:15 PM	265.72	258.71	8864.2	948.3	[illegible]	3.5	310894.	292.4055	1310322.
SEPT 9 75	3:45 PM	265.72	258.71	8861.3	948.1	[illegible]	3.8	338142.	267.7691	1265807.
SEPT 11 75	6:15 PM	265.72	258.71	8861.3	949.1	26.2	4.1	366911.	203.5256	1059445.
SEPT 13 75	6:55 PM	265.73	258.72	8869.9	948.7	24.4	3.8	340245.	-43.1991	172807.
SEPT 18 75	4:55 PM	265.79	258.76	8927.8	952.7	23.2	6.3	553545.	132.5625	511792.
SEPT 25 75	5:00 PM	265.78	258.75	8913.3	951.7	21.4	7.7	683750.	76.9464	273686.
OCT 1 75	3:20 PM	265.78	258.76	8914.6	951.9	21.0	7.9	706298.	-1.3868	170572.
OCT 13 75	9:55 AM	265.76	258.74	8898.9	950.7	20.6	7.0	625832.	126.4425	590885.
OCT 25 75	10:35 AM	265.75	258.73	8883.1	950.3	18.2	7.7	690598.	-44.7550	94870.
NOV 11 75	3:05 PM	265.77	258.74	8904.5	951.1	16.7	8.3	737910.	39.5111	126701.
DEC 9 75	3:30 PM	265.75	258.73	8890.2	950.1	9.7	10.3	912173.	25.3983	56752.