# *Lake Destratification by Underwater Air Diffusion*

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Water quality problems in deep lakes and downstream releases can be caused by thermal and chemical stratification patterns that occur in lakes during summer and early fall. In the temperate climate of the southeastern United States, thermal stratification, a layering of water based on temperature-induced density differences, generally begins in early March with the warming of the surface waters of the lakes. This warmed and therefore less dense water floats on the colder denser bottom water. If the depth and shape of the lake are such that the wind action on the surface and the inflows cannot mix the lake vertically, the stable stratification pattern will continue until environmental conditions cool the surface waters and these denser surface waters sink to cause fall turnover and complete mixing.

The thermal stratification pattern in the lakes of the southeastern United States consists of an epilimnion, the warmer (25°–28°C) surface water layer of 6.1–7.6 meters; a thermocline, the water layer having the largest decline in temperature per unit of depth; and a hypolimnion, the lowest layer of cooler water of fairly uniform temperature.

## WATER QUALITY PROBLEMS IN STRATIFIED LAKES

Many of the dams of deep man-made lakes are designed for hydropower production with less expensive more efficient low-level intakes to the generators. During the stratification period, water released from the hypolimnion through these intakes can be devoid of oxygen, high in iron and manganese, and low in temperature. Although this water quality is desirable for cooling purposes, it is not suitable for aquatic life and can cause water treatment problems. In a rocky-bottomed stream bed, oxygen recovery is fast at low flows, but at high flows the opportunity for surface reaeration is low, and oxygen recovery can only occur over longer stream sections. The oxidation of iron, manganese, and gases is also dependent on stream reaeration.

Numerous structural designs and operational techniques have been used to mix epilimnial and hypolimnial waters to obtain an increase in and more uniform quality of dissolved oxygen in released waters. Past work has been aimed primarily at improving downstream water quality and has not resulted in any significant disturbance of the stratification pattern of the lake. The costs have been high, and the desired degree of control has been difficult to attain. There is also the danger that epilimnial waters of a high dissolved oxygen content will be exhausted through high-level discharges, so that there will not be any control of dissolved oxygen in the early fall. Mixing or breaking up the stratification offers many advantages for water quality improvement both in the lake and downstream.

## ALLATOONA LAKE DESTRATIFICATION PROJECT

In early 1968 the South Atlantic Division, with advice from Dr. James M. Symons of the U.S. Public Health Service and assistance from a number of federal and Georgia agencies, began the design and installation of an air diffuser system for Allatoona Lake to determine whether a large lake could be maintained in a destratified condition, what changes would occur in water quality, and the cost and efficiency of operating such a system. Prior to 1968 a limited amount of water quality and related data in and below the lake had been gathered over a 2½-year period from 1964 through 1966. This information was used initially as a basis for comparison with destratification results. Additional base data were obtained in 1970, when the destratification system was not operating.

Allatoona Lake, completed in 1955 and located about 48 km northwest of Atlanta, Georgia, is a multipurpose project for flood control, hydroelectric power generation, streamflow regulation, and other purposes. It receives considerable use for recreation (over 6 million people in 1969). Water is withdrawn a short distance below the dam for water supply. The 58-meter-high dam creates a lake with a surface area of 48 $km^2$ and a volume of 454 $hm^3$ at a normal summer pool level of 256 meters above mean sea level. Water depths near the dam are 46 meters, and one major arm of the lake backs water up the Etowah River for a distance of 45 km. Some municipal and poultry-processing waste effluents discharge into the upper reaches of the Etowah River and a tributary, the Little River.

The Allatoona Dam powerhouse consists of one small and two large turbine units. The large turbine unit penstocks are 6.1 meters in diameter, the center line of the intake being 27.4 meters below the normal summer pool level of 256 meters above mean sea level. The small turbine penstock is 1.7 meters in diameter, its center line being 16.8 meters below the normal summer pool level. Although the large turbines are below the small one, their discharges in the summer have dissolved oxygen levels about 2 mg/l higher than the discharge of the small turbine.

The air diffuser system for mixing the lake was chosen over mechanical pumping and other methods because of its flexibility of operation, expected ease of installation, and higher destratification efficiency and oxygenation capacity, as shown by work done by Dr. Symons. Five 60.8-hp electrically powered rotary-type compressors were located on the north abutment near the dam for delivery of air to a diffuser array system located in 42.7 meters of water. Airflow of 118 l/sec per diffuser array was through a manifold with a rate of flow controller on each of the lines leading to five diffuser arrays. The system was designed for a maximum supplied air temperature of 70°C and a pressure of 70,310 $kg/m^2$. The diffuser array system was located 457–610 meters upstream of the dam, an array being placed at each of the quadrant points of a 152-meter-diameter circle and a fifth unit being placed in the center. Each diffuser array was in the form of a cross with 10 diffusers located on each of the four arms (Figure 1) for a total of 200 diffusers in the five arrays. The arrays were suspended 3 meters from the bottom by a buoy, anchor, and cable system, as is shown in Figure 2. The air supply line was attached at the center of the cross.

## AIR DIFFUSER SYSTEM OPERATIONS

The air diffuser system first began operation on May 9, 1968, and continued until September 30, 1968. One of the five air compressors was inoperative until August 12. During 1969 the five air compressors operated continuously from March 17 to September 30 except for minor shutdowns. Initially, eight sampling stations were established in the lake, and five were established downstream. Extensive sampling was done before the start-up of the destratification system. This sampling program continued with three intensive lake and downstream surveys during April, July, and September 1968. During the interim, temperature and dissolved oxygen profiles and other water quality determinations were made. A continuous recording monitor measured four parameters (temperature, dissolved oxygen, *p*H, and specific conductivity) 640 meters below the dam. A similar sampling program was carried out in 1969–1970. Hydrologic and meteorological data were obtained near the dam in 1968–1970. Supplemental meteorological data were obtained in 1969–1970 from a weather station established on the lake.

Equipment, design, procurement, fabrication, and installation of the system resulted in an investment of $82,500. Power and other operation costs for the calendar year 1968 were $10,300. The costs for the first year (1968) for sampling and evaluating the data were approximately $90,000. Future annual operational and depreciation costs are estimated at $35,000–40,000.

## DATA ANALYSES

The degree of thermal stratification was mathematically calculated as stability of the lake. Stability is the energy necessary to lift a body of water from its center of gravity under stratified conditions to its center of gravity under isothermal conditions. In Allatoona Lake the stability increases from about mid-March when the lake begins to stratify to a peak in mid-July. A gradual decrease in stability occurs until late August, and then a rapid decline occurs until turnover in early October.

Data for 1966, before destratification, were used as a basis for comparison with data gathered during the operation of the destratification equipment in 1968–1969. More comprehensive data were gathered in 1970, when the air diffuser system was not operating, to develop a mathe-

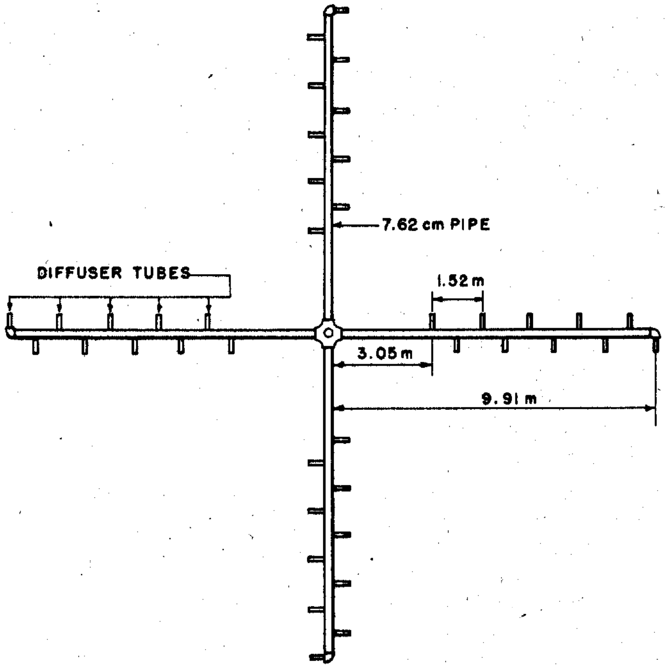


Fig. 1. Plan (not to scale) of the air diffuser unit.

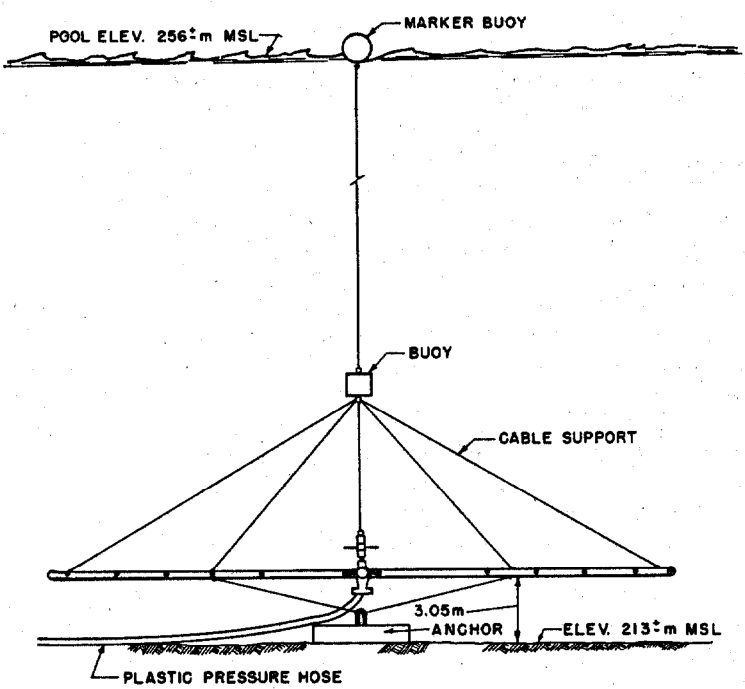


Fig. 2. Elevation (not to scale) of the air diffuser unit.

matical model that could be used to predict what the temperature and dissolved oxygen conditions of the lake would have been in 1968–1969 if the destratification equipment had not been operating. Predicted conditions were used for further evaluation of the operation.

The data for 1966 show that thermal stratification begins to develop in Allatoona Lake about mid-March and that by mid-May there is a well-defined 6.1-meter epilimnion with temperatures of 20°–23°C and dissolved oxygen of about 9 mg/l. The thermocline is 3 meters in depth and exhibits a 3°–5°C drop in temperature. The hypolimnion at that time is that part of the lake below 9.1 meters with temperatures from about 18°C at 9.1 meters to 11°C at the bottom (39.6 meters) and corresponding dissolved oxygen levels of 7 mg/l to 5 mg/l. The depth of the epilimnion reaches about 16.7 meters in early September with temperatures in the 25°–28°C range, dissolved oxygen levels of 6–7 mg/l in the top 6.1 meters decreasing to <1 mg/l at the 9.1-meter level and below. Dissolved oxygen is exhausted below 24.3 meters. In late September, thermal stratification begins to disappear, and there is some improvement in dissolved oxygen; complete turnover occurs about October 10. The temperature and dissolved oxygen profiles of the lake for 1970 generally paralleled those for 1966. In early July the thermocline was at the 6.1- to 9.1-meter level above which the dissolved oxygen was 7–8 mg/l. Below 9.1 meters the dissolved oxygen was 2 mg/l or less, and by mid-August 1970 the dissolved oxygen had been exhausted below 9.1 meters. The major difference between operations for 1966 and those for 1970 was that in 1970 the normal pool level started dropping in early July because it was necessary to generate power to overcome shortages. By early August 1970, pool levels were 0.9–1.2 meters below normal.

A comparison of the temperature and dissolved oxygen profiles for 1968 with those for 1966 shows a decrease in water temperature in the top 6.1 meters and an increase below 9.1 meters and an increase in dissolved oxygen for depths from 6.1–20.1 meters and decreases above and below this zone. During late August and early September, dissolved oxygen is normally low or absent except in the epilimnion; in 1968 it became uniformly mixed in the lake at concentrations of 4–5 mg/l (Figure 3).

Since downstream dissolved oxygen contents are different for low and high discharges, comparisons are made for each flow condition. In May–October 1966 the dissolved oxygen content of the low discharges ranged from 7.5 to 0.7 mg/l with levels <4.0 mg/l for 3 months. During the same period of 1968 the low discharges were maintained at >4.0 mg/l except for the third week in August. Water quality comparisons for high discharges indicate dissolved oxygen levels for the 2 years to be about the same except from early July to early August, when the dissolved oxygen levels for 1968 fell to 2.5 mg/l or about 1 mg/l below the high-discharge results for 1966. In late August and September, however, the dissolved oxygen levels for 1968 increased significantly over those for 1966.

Results of the analyses of iron and manganese are not too conclusive owing to differences in sample analysis techniques during 1966 and 1968.

During 1968, three intensive biological surveys were conducted in Allatoona Lake in mid-April, mid-July, and mid-September. The air diffuser operations had minor short-term effects on the benthic and planktonic communities in the lake. The most noteworthy biological change was the appearance of freshwater jellyfish surrounding the diffusers in September. They seemed to have been feeding on the midge larvae transported upward in the air column. Qualitative studies of the benthic biota below the dam indicated a more diverse community than that that had existed during a survey in 1961.

An examination of bacteriologic data failed to demonstrate any effect of artificial destratification on bacterial density or vertical distribution patterns. The distribution and density of total coliforms near the diffusers were similar to those at sampling sites several miles upstream.

As was indicated earlier in this paper, there was a late start-up of the equipment in 1968, one compressor being inoperative for 3 months. The start-up was about 2 months after stratification began. In 1969 the start-up coincided with the beginning of stratification, and all five compressors operated from March 15 to September 30. The results of the operations of 1969 compared with those of 1968 and of the base year 1966 indicate that the dissolved oxygen levels at the greater depths were higher, dissolved oxygen in both low and high discharges was higher, and the downstream dissolved oxygen did not fall below 4.0 mg/l except for a short period in early August. Thermal stratification developed in June

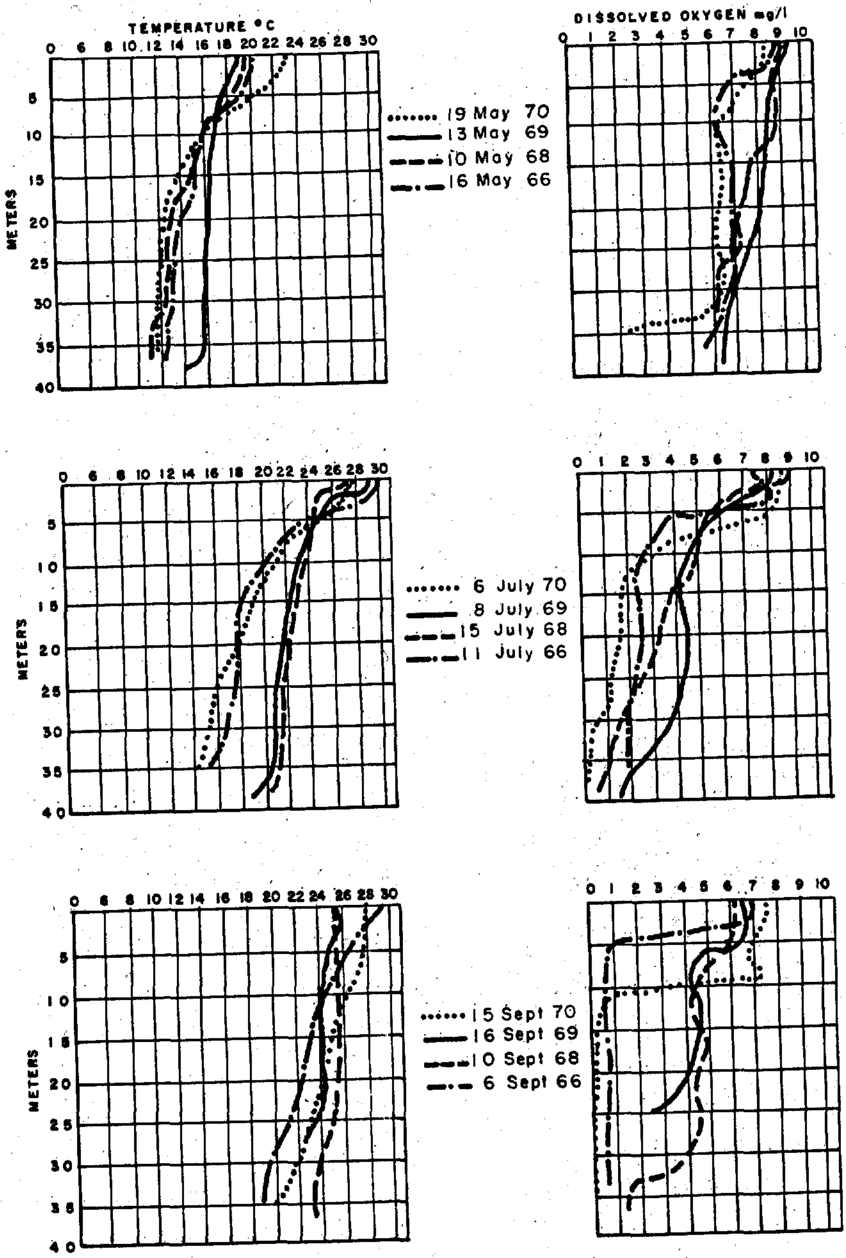


Fig. 3. Allatoona Lake destratification equipment test.

1969 in the upper 3–6 meters of the lake but was held at this level throughout the summer. Again, in late August 1969 an early turnover began, and dissolved oxygen conditions improved throughout the lake and downstream.

## SUMMARY

The operation of an air diffuser system for the stratification periods of 1968–1969 in Allatoona Lake, Georgia, has provided useful information regarding operations and water quality improvement.

1. The system is sized sufficiently to maintain the lake in an adequately destratified condition if the equipment is started when stratification begins and is operated continuously during the stratification season.

2. Water quality 4–5 km upstream of the dam and 3–5 km downstream was improved when the equipment was operated at about 80% capacity and was started 2 months after stratification began. When the equipment was started when stratification began and was operated at full capacity, dissolved oxygen levels in both low and high discharges were maintained at 4.0 mg/l and better except for a few days in early August.

3. Temperatures of the discharged waters were elevated a maximum of 6°–8°C above those of discharges from a stratified lake at the same season.

4. Effects on iron, manganese, and biological life appear to be beneficial. No difference was noted in bacteriologic conditions. Further evaluation is needed.

5. Annual operation costs (including depreciation and excluding monitoring and sampling) for a 454-$hm^3$ lake with physical, meteorological, and hydrologic characteristics similar to those of Allatoona Lake are approximately $40,000. Initial investment costs are $85,000–100,000. Evaluations of other destratification systems on a cooperative basis are needed to determine whether such systems may be more efficient and more economic.