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Induced Aeration of Small Mountain Lakes

U.S. ENVIRONMENTAL PROTECTION AGENCY

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INDUCED AERATION OF SMALL MOUNTAIN LAKES

by

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Post Office Box 1198
Ada, Oklahoma 74820

for

ENVIRONMENTAL PROTECTION AGENCY

Project #16080---

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ABSTRACT

Summer stratification in small mountain trout-fishery lakes restricts trout habitat to the thin layer of surface waters. As atmospheric temperatures increase during later summer months, the epilimnion waters reach temperatures intolerable for trout. A technique of managing trout-fishery lakes, through introduction of compressed air, was studied at Lake Roberts in southern New Mexico during the summer of 1969. Research findings and further research required for optimum development of induced aeration systems as management tools for trout-fishery lakes are discussed.

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SECTION I

CONCLUSIONS

Induced aeration research, described in this report, clearly showed that complete thermal destratification of small mountain lakes can be accomplished with a diffuser-type aeration system such as that used in this study. Destratification can be maintained with continuous aeration at low energy requirements at the expense of continually increasing the temperature of the water mass. Restratification develops rather quickly, however, when induced aeration is stopped.

Dissolved oxygen (D.O.) can be increased to more than 100 percent saturation in the hypolimnion due to circulation of highly saturated surface waters. The increase in D.O. in the hypolimnion is accompanied by a decrease in the epilimnion.

High concentrations of hydrogen sulfide (H_2S) in the hypolimnion can be quickly vented to the atmosphere through the plume of rising air bubbles above the air distribution system without adverse effects to the aquatic life or increasing concentrations of H_2S in the surface waters.

High concentrations of phosphates and nitrogen forms in the lower depths are drastically reduced during induced aeration without significant increases in the surface waters.

Certain metallic ions such as boron, iron, manganese, aluminum, and strontium are separated out of the bottom muds and increased in the entire water mass by as much as ten orders of magnitude by the circulation and mixing action of induced aeration. Bottom deposited organic material may also be circulated throughout the water mass to exert a significant oxygen demand.

Algal blooms in progress are not retarded by destratification as reported by others, but, in fact, may be slightly accelerated through an increase in nutrients within the photic zone. If large algal concentrations die-off during aeration, thermal destratification can occur without an increase in dissolved oxygen.

Induced aeration systems can be an effective management tool in trout fishery lakes. A large increase in habitable water resulted from induced aeration as shown by the redistribution of fish vertically and horizontally.

SECTION II

RECOMMENDATIONS

Certain aspects of induced aeration systems used as trout fishery management tools should be further investigated. Methods for controlling the increase in water temperature during destratification should be studied. These studies should include refrigerated air systems and mechanical systems which circulate the hypolimnion water only. Effects of various systems on the biological community should be investigated.

Aeration systems should be designed so that water withdrawn from the hypolimnion is carried to the surface at velocities low enough that sediment and organic materials are left undisturbed on the lake bottom. Investigations should also be made as to the feasibility of purposely inducing air to circulate organic bottom materials as a water quality management technique. Circulation of organic material in early spring could satisfy the oxygen demand prior to stratification. Aeration on a regular basis over a period of years should oxidize essentially all bottom organic material, allowing aeration during summer stratification to increase oxygen in hypolimnion waters at a greater rate.

Algal control techniques should be developed to retard blooms prior to and during operation of induced aeration systems. Algalcides should be tested to develop technology in algal management. Dosage, frequency of dosage, tolerance of fish to dosage, and long-range effects on water quality from algal treatment should be investigated.

Studies should be undertaken to compare destratification systems utilizing air with pure oxygen systems. These studies should relate to oxygenation efficiency, effects on water quality, and economics.

SECTION III

INTRODUCTION

The influence of thermal stratification in reservoirs on water quality has been given much attention in the past five years. Several methods of modifying thermally stratified reservoirs are being researched (1,2,3,4,5,6,7). These include discharges from multiple elevations in reservoirs (8), mechanical pumping of hypolimnion waters to the surface (9), and release of compressed air or pure oxygen near reservoir bottoms at different rates using various arrangements and types of distribution devices (3).

Induced aeration research was begun by the National Water Quality Control Research Program, Robert S. Kerr Water Research Center, in 1967 using compressed air diffuser systems (10,11,12). The objective of this research was to develop a system that could be used in small-to-moderate size reservoirs to mix the hypolimnion and epilimnion waters. Through the mixing process, the entire volume of water would become more useful. Anaerobic conditions could be halted in the hypolimnion and the chemical reduction process would be altered, resulting in reduced concentrations of sulfides, phosphates, nitrates, and other nutrients in the hypolimnion waters. The mixing process would provide greater volumes of improved quality for municipal and industrial uses and fish habitat, thereby increasing the value of these water resources. Mixing of the entire volume of the impoundment or localized mixing upstream of dams, depending upon the reservoir requirements, would improve the quality of release waters withdrawn from lower levels during power generation. Aeration of hypolimnion waters would create a greater potential for downstream flow augmentation by allowing waste assimilation to be accomplished with a higher quality release water--thereby requiring less water to accomplish the same assimilation results, thus conserving impounded water for other uses.

In 1969, the New Mexico Department of Game and Fish requested assistance of the Kerr Research Center personnel in studying destratification systems as a management tool in their mountain trout fishery lakes. The lake selected for study was Lake Roberts in southwestern New Mexico where annual fish kills had occurred as a result of summer stratification, depleting the dissolved oxygen at lower depths and restricting the trout to surface waters where temperatures were too high for survival. Lake Roberts is managed as a rainbow trout fishery lake on a put-and-take basis since the waters are too warm for reproduction. The lake is stocked before the start of the fishing season each spring. The total annual stocking is approximately 17,500 fingerlings and 25,000 catchable-size trout of 9 inches or larger. The fish are released at different times of the year with 3,500 being released in April, May, and June; 1,050 in July and August; 1,900 in September; and 1,750 in October, November, December, January, February, and March.

Lake Roberts is located on Sapillo Creek on the western slope of the Continental Divide near Silver City, New Mexico (Figure 1). The spillway and normal lake surface is located at an elevation of 6,035 mean sea level (msl). The

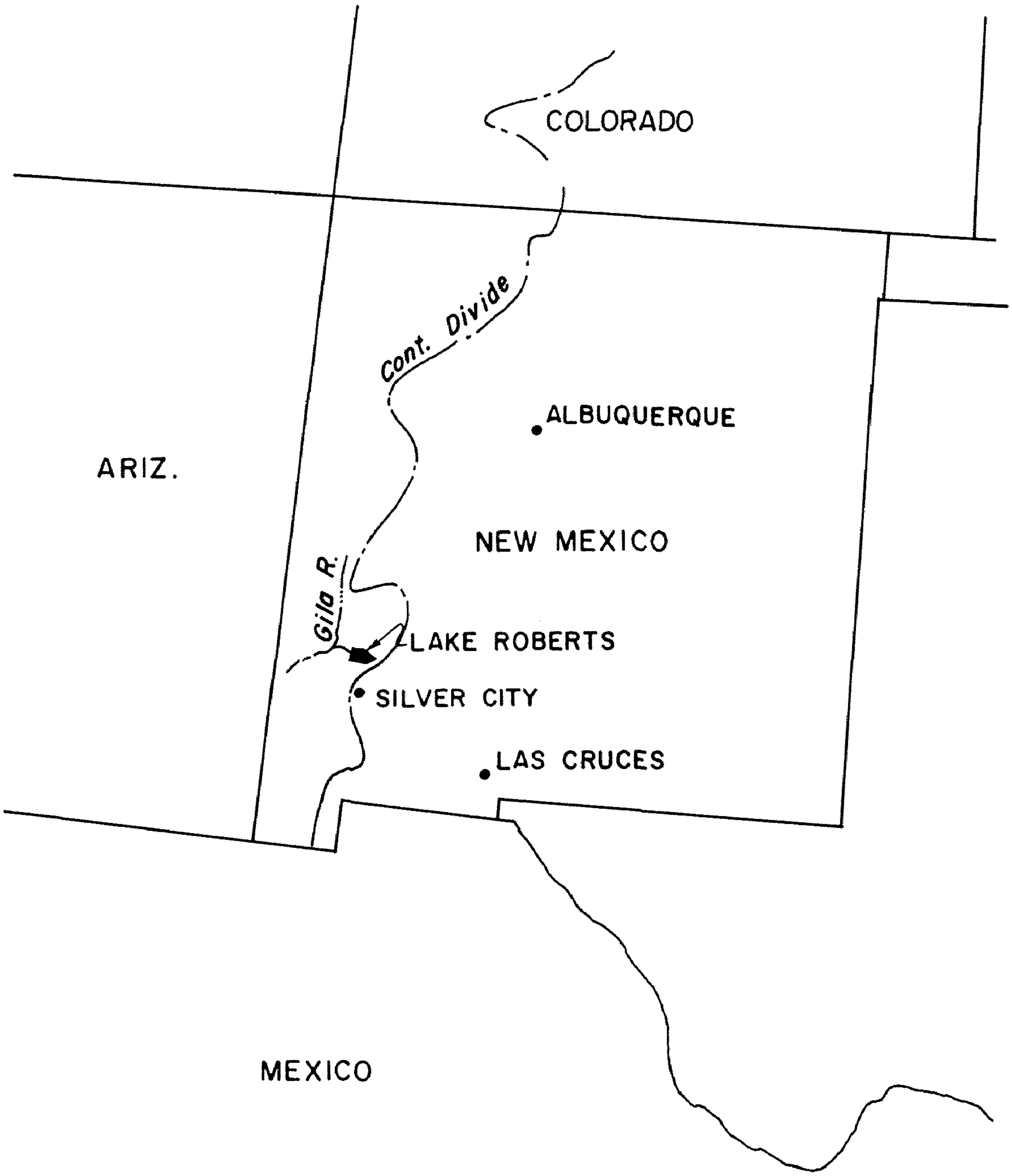


FIGURE 1 - VICINITY MAP

lake is 30 feet deep near the dam, covers an area of about 70 acres, and has a volume of approximately 1,000 acre-feet at the spillway crest (Figures 2 and 3). The lake was built in 1963 by the Game and Fish Department and is fed by subsurface springs in the upper reaches which had total discharges of about 1 cfs before they were submerged.

Sapillo Creek, dry most of the time upstream of the lake except during local heavy rainstorms in late summer, drains 5,372.0 acres of forest and range land. The upper reaches of Sapillo Creek are primarily range land and used for cattle grazing. The lower portion of the drainage above the dam is in the densely forested Gila National Forest. General hydrologic data are presented in Table 1.

TABLE I

HYDROLOGIC DATA

Meterologic Condition	Average Annual Precipitation Inches	Average Annual Evaporation Inches	Average Annual Runoff to Lake Roberts Acre-Feet
Dry Year	9.84	81	882
Average Year	16.20	51	3,265
Wet Year	27.48	29	11,095

The objective of the Water Quality Control Research Program in this study was to study the dynamics of an induced air system in a small reservoir for comparison with the effects of previous large reservoir studies. The objective included evaluation of changes in selected chemical parameters throughout the water mass, resulting from two periods of induced aeration separated by a restratification period. Chemical changes resulting from destratification with an air distribution system of the proposed type had not been evaluated in prior studies. In addition to chemical quality changes, aeration efficiency in terms of pounds of dissolved oxygen pumped per horsepower-hour, vertical oxygen distribution, and saturation changes as well as economics were to be evaluated.

The New Mexico Game and Fish Department's interest in induced aeration was to utilize existing aeration technology to develop an induced aeration system as a useful tool in fisheries management. The primary factors proposed for evaluation were change in occupancy of fish habitat, reduction in seasonal stress factors, and comparison of long-range increases in fish productivity resulting from nutrient circulation by induced aeration during critical summer months. Biological data collected by the New Mexico Game and Fish Department are not included in this report.

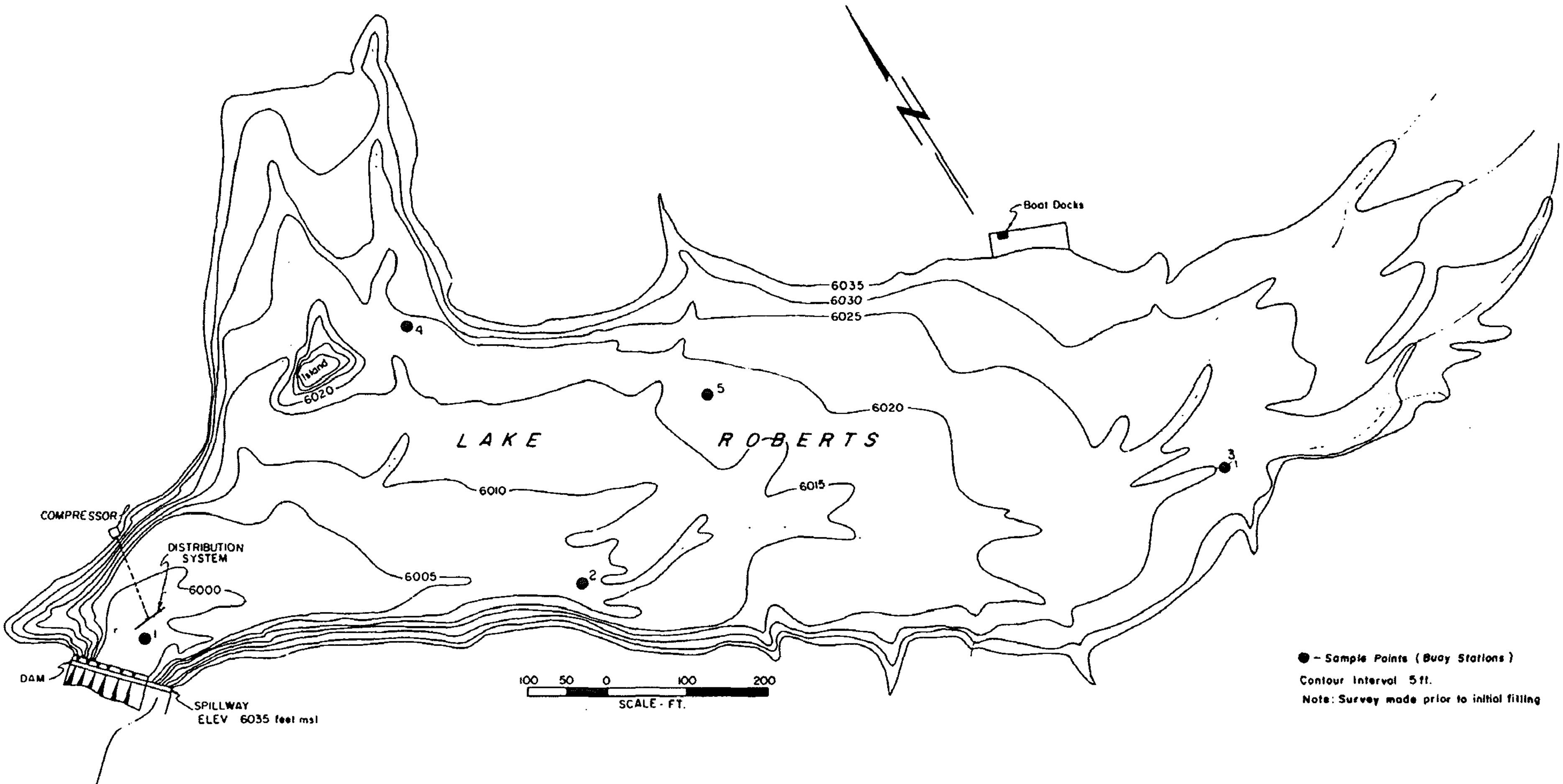
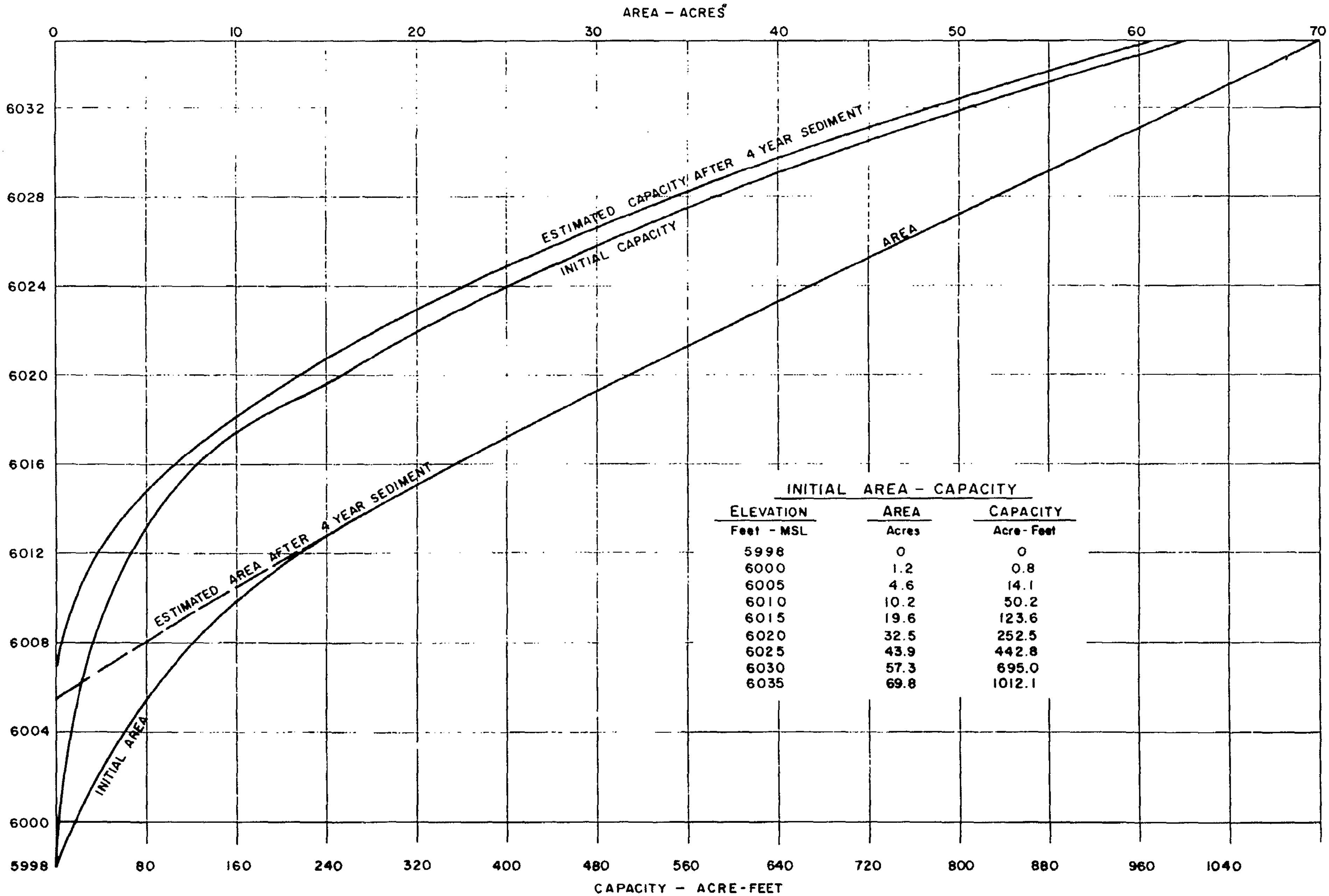


FIGURE 2 - PROJECT LOCATION AND HYDROGRAPHIC MAP



ELEVATION Feet – MSL	AREA Acres	CAPACITY Acre-Feet
5998	0	0
6000	1.2	0.8
6005	4.6	14.1
6010	10.2	50.2
6015	19.6	123.6
6020	32.5	252.5
6025	43.9	442.8
6030	57.3	695.0
6035	69.8	1012.1

FIGURE 3 — AREA - CAPACITY CURVES

SECTION IV

PROCEDURES AND EQUIPMENT

The project plan consisted of five sequential phases, exclusive of equipment assembly and installation. Phase I consisted of background monitoring during the normal spring stratification period. Samples for chemical analysis were collected as well as determination of vertical profiles of temperature and dissolved oxygen. After stratification had reached a static condition, Phase II was initiated, which involved the operation of the aeration equipment and monitoring the progress of destratification.

When the lake reached an isothermal condition and the selected chemical parameters had reached stability, the lake was allowed to restratify during Phase III. During the restratification phase, monitoring of temperature, D.O., and chemical parameters was continued. When the lake had restratified, Phase IV was initiated consisting of once again operating the aeration system and monitoring the occurrence of destratification. Phase V consisted of monitoring restratification after aeration was halted. This monitoring continued until after the normal fall overturn.

During the background monitoring of Phase I, the New Mexico Game and Fish Department determined the vertical and horizontal distribution of fish and phytoplankton. These studies were repeated regularly during the first aeration phase to determine the depth and lateral extent of improved habitat resulting from destratification.

The air distribution system was assembled on the lake shore on June 14 (Figure 4). The design of the air distribution system was a modification of the system used in Eufaula Reservoir during the summers of 1967 and 1968. The distribution manifold was constructed from two 40-foot lengths of 4-inch diameter aluminum pipe, joined with a tee connector. The pipes were plugged on the ends and each 40-foot section had eight equally spaced upright microporous diffusers. The diffusers were commercially fabricated porcelain, hollow candles with bubble-forming capilliaries of 25×10^{-4} cm average radius. The manifold was supported on six A-frame legs, 2.5-foot high, to allow distribution of air above the mud-water interface on the bottom. The manifold was anchored to the bottom at a depth of 30 feet, approximately 150 feet upstream of the dam with the piping placed parallel to the longitudinal axis of the lake. The air supply source was a diesel-powered air compressor. Air was piped from the compressor through a filter for oil removal and then through a volume gauge. Pressure and temperature gauges were attached to the air discharge pipe at the exit from the filter (Figure 5). Air was supplied to the distribution manifold through two 300-foot lengths of 3/4-inch standard quick-coupling air compressor hose connected to the volume gauge.

Assembly of the distribution system was completed on June 14, and the system was installed on June 15. The manifold was floated to the pre-selected location with air being pumped through the system by the compressor for floatation. When the manifold was in the correct position, the compressor

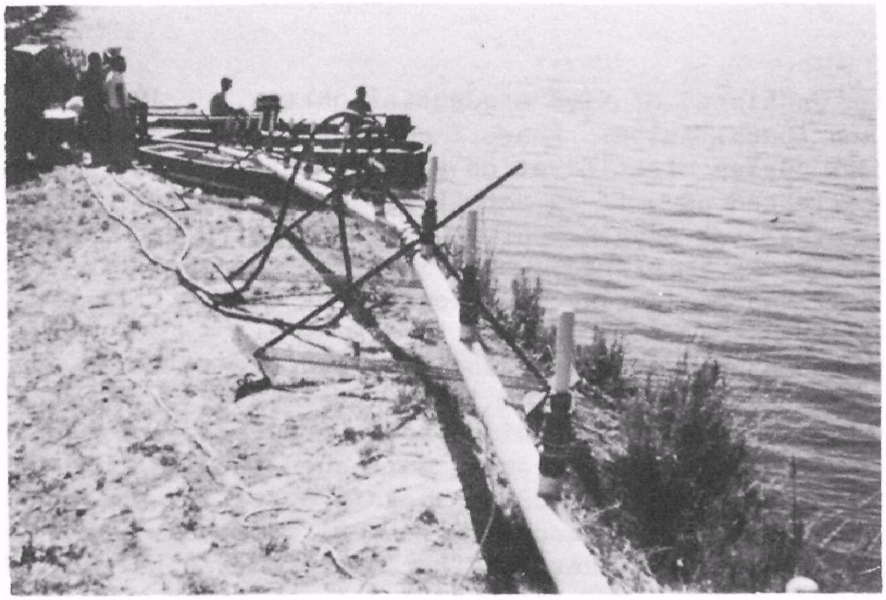


Figure 4 - Air Distribution System

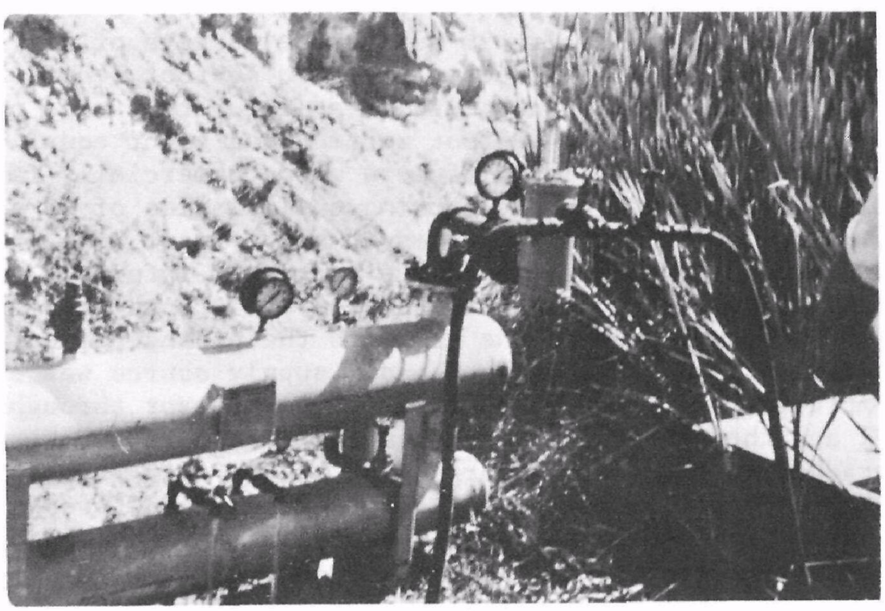


Figure 5 - Air Filter and Monitoring Equipment

was stopped and the manifold was flooded with water and lowered to the bottom with lines from anchored boats. The system was anchored to the bottom by divers.

Five sampling stations were located for monitoring changes in water quality parameters during the project (Figure 2); these stations were permanently marked by buoy installations. Samples were collected from three depths or at 5-foot intervals at these stations for analyses of the various chemical, physical, and biological parameters. Sample analyses for sulfide, D.O., temperature, pH, and conductivity were made in the field. Samples for the other parameters were ice-packed or chemically fixed following collection and flown to the Robert S. Kerr Water Research Center for analysis (Appendix Table 1).

Dissolved oxygen was measured in situ at 5-foot depths using a battery-powered Weston and Stack Dissolved Oxygen Analyzer, Model 300, equipped with Model A-15 DC-powered sampler. This equipment was routinely checked and adjusted against the standard Winkler Method using the azide modifications. The oxygen analyzer was equipped with temperature readout which was used for collecting temperature data at 5-foot depths. Conductivity and pH data were collected in the field using battery-powered pH and conductivity meters.

The trace metal analyses, recorded in Appendix Table 2, were made by emission spectroscopy of nitric acid fixed samples. These samples were concentrated by evaporation by heating to a temperature just below the boiling point. The samples were concentrated to contain approximately the same dissolved solids as standards. A volume of the sample was analyzed using the rotating disc attachment in conjunction with a direct reading emission spectograph.

All other samples were chemically analyzed according to procedures of the Federal Water Pollution Control Administration Methods for Chemical Analysis of Water and Waste, November 1969 (13).

SECTION V

OPERATION PHASE

Phase I

Field activities were initiated by collecting background samples from Stations 1, 2, and 3 at Lake Roberts on May 22, 1969. Temperature and D.O. were measured at 5-foot intervals, and it was observed that the lake had begun to stratify. Hydrogen sulfide had formed in the lower depths while an algal bloom had developed. The thermocline had become well established at a depth of 13-18 feet with zero mg/l (milligrams per liter) D.O. below 20 feet near the dam (Figures 6 and 7).

Sampling stations were monitored again on June 15 prior to the start of aeration. Data collected showed the lake had stratified to even shallower depths (12-16 feet) since the May sampling. Oxygen had become completely depleted below 16 feet (Figure 7). Using the area-capacity curve (Figure 3) constructed from the hydrographic map (Figure 2), it was determined that about 25 percent of the volume had less than 4.0 mg/l D.O. The bottom water layers near the mud-water interface had 2.6 mg/l H_2S, while the upper half of the water column had about 0.4 mg/l which was approaching the toxic level for rainbow trout.

Other parameters such as ammonia nitrogen, total Kjeldahl nitrogen, manganese, total phosphate, ortho-phosphate, pH, specific conductance, and total iron showed significant stratification and indicated a very anaerobic environment in the lower depths. The algae bloom identified as Anabaena Spiroides had completely developed by mid-June, forming a thick "pea soup" scum over the entire lake surface during the late evening through the early morning hours.

Phase II

The first aeration test was started at 12 noon on June 16, 1969. Air was supplied to the distribution system at the rate of 100 cfm (corrected for altitude and temperature) with a pressure of 34 psig at the flow meter. Compressor performance, compressed air flow rate, air flow temperature, and pressure were recorded four times daily. The compressor was operated continuously except for periods of approximately ten minutes when it was stopped for servicing and refueling.

During the first aeration phase, the lake was monitored at Stations 1 through 4 for D.O., temperature, conductivity, pH, and H_2S each morning and afternoon to detemine the radiating effects of aeration. D.O. and temperature profiles were measured at 5-foot intervals from surface to bottom.

After three days of continuous aeration, the entire lake volume reached a minimum of 6.0 mg/l D.O. (Figure 8). The H_2S had disappeared and all measured chemical parameters indicated complete mixing. Temperature changes

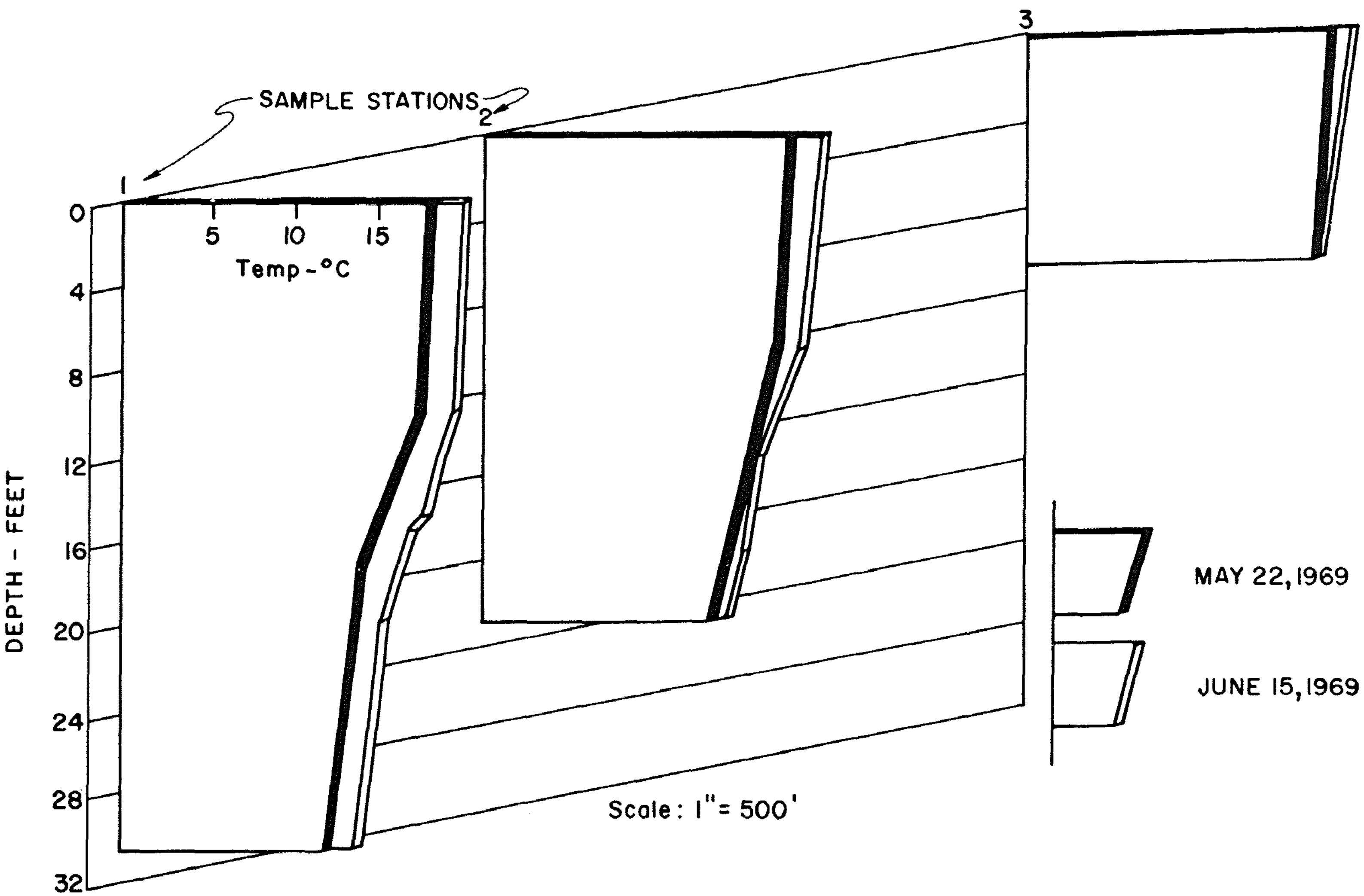


FIGURE 6 — STRATIFICATION BEFORE AERATION

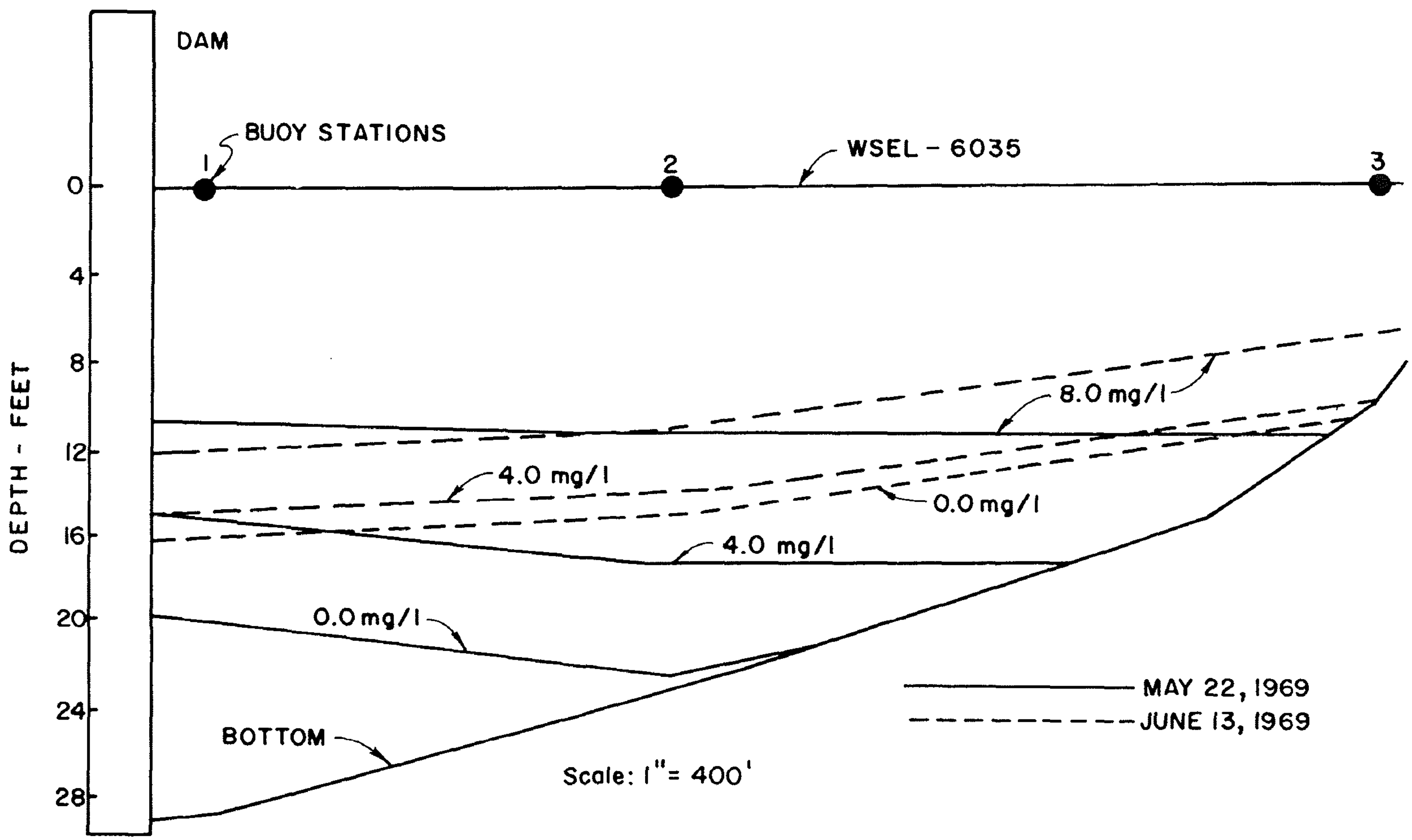


FIGURE 7 — BACKGROUND DISSOLVED OXYGEN

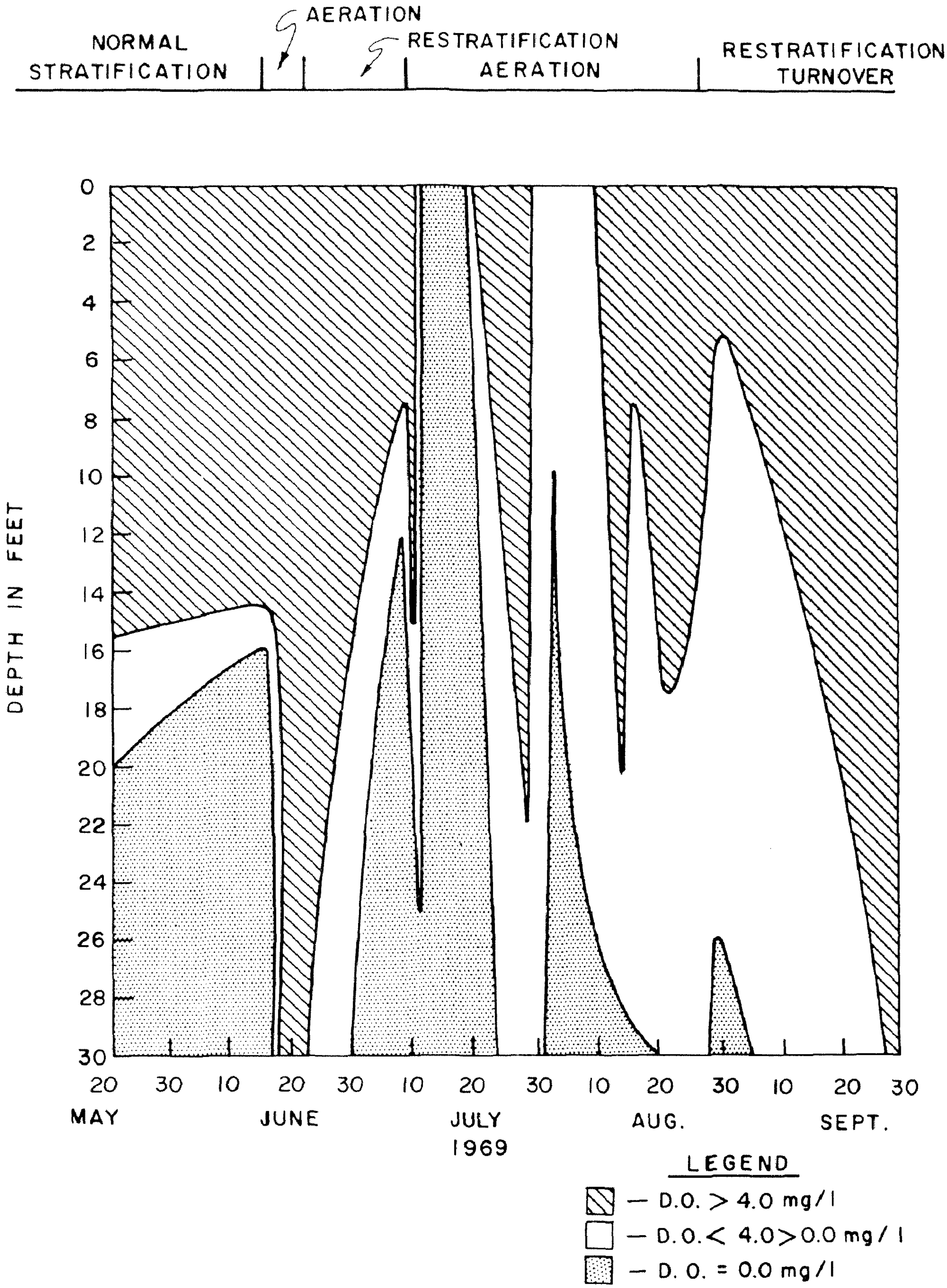


FIGURE 8 — EFFECTS ON DISSOLVED OXYGEN

were significant during the first three days of aeration (Figure 9). Thermal stratification was destroyed during three days of aeration and the lake became isothermal. Injection of warm compressed air resulted in raising the temperature of the entire water mass to temperatures near those of the surface waters prior to destratification (Figure 10).

Fish distribution studies conducted by the New Mexico Game and Fish Department showed that before mixing fish were well distributed horizontally but restricted to the upper 12 feet of water depth by the oxygen-void hypolimnion. Fishing prior to aeration had been relatively poor. After the first day of aeration, fishing was greatly improved with most anglers taking their daily limits. The distribution was significantly changed with greatest concentrations of fish near the aerator at all depths. Station 2, approximately 1,100 feet upstream of the aerator, had fish to depths of 20 feet after the first day of aeration. However, after the third day of aeration, fish were equally distributed at all depths throughout the water mass.

Destratification effects during the first aeration tests were significant since it was the first time 100 percent oxygen saturation had been reported at all depths in similar aeration tests. Even though all parameters improved in the hypolimnion during aeration, the concentration of algae continued to increase reaching nuisance bloom proportions. Algae began to concentrate, forming thick mats on the surface during the night and early morning hours, thus reacting contradictory to the findings reported by Robinson (14).

Phase III

After seven days of continuous aeration, the lake was allowed to restratify (Figures 8, 9, and 10). During the restratification period, the air distribution system was modified for a second induced aeration test. Modification of the air distribution system was accomplished by divers who disconnected the manifold at the tee and plugged off one branch of the tee allowing compressed air to be released through only half the distribution system. An additional buoy station (Station 5) was added to the existing four sampling stations to have more comprehensive coverage of restratification rates.

Twice a day monitoring of D.O., temperature, pH, conductivity, and H_2S was continued at the five stations through the restratification period to determine the rate of reformation of the hypolimnion and H_2S buildup.

Chemical samples from Stations 1,2, and 3 were collected at the surface, mid-depth, and bottom at 8-day intervals during restratification. The chemical parameters sampled were the major nutrients measured during the first aeration test (Appendix Table 1). Analysis of these samples indicated an increased concentration of chemical nutrients in the bottom waters by the end of the restratification test.

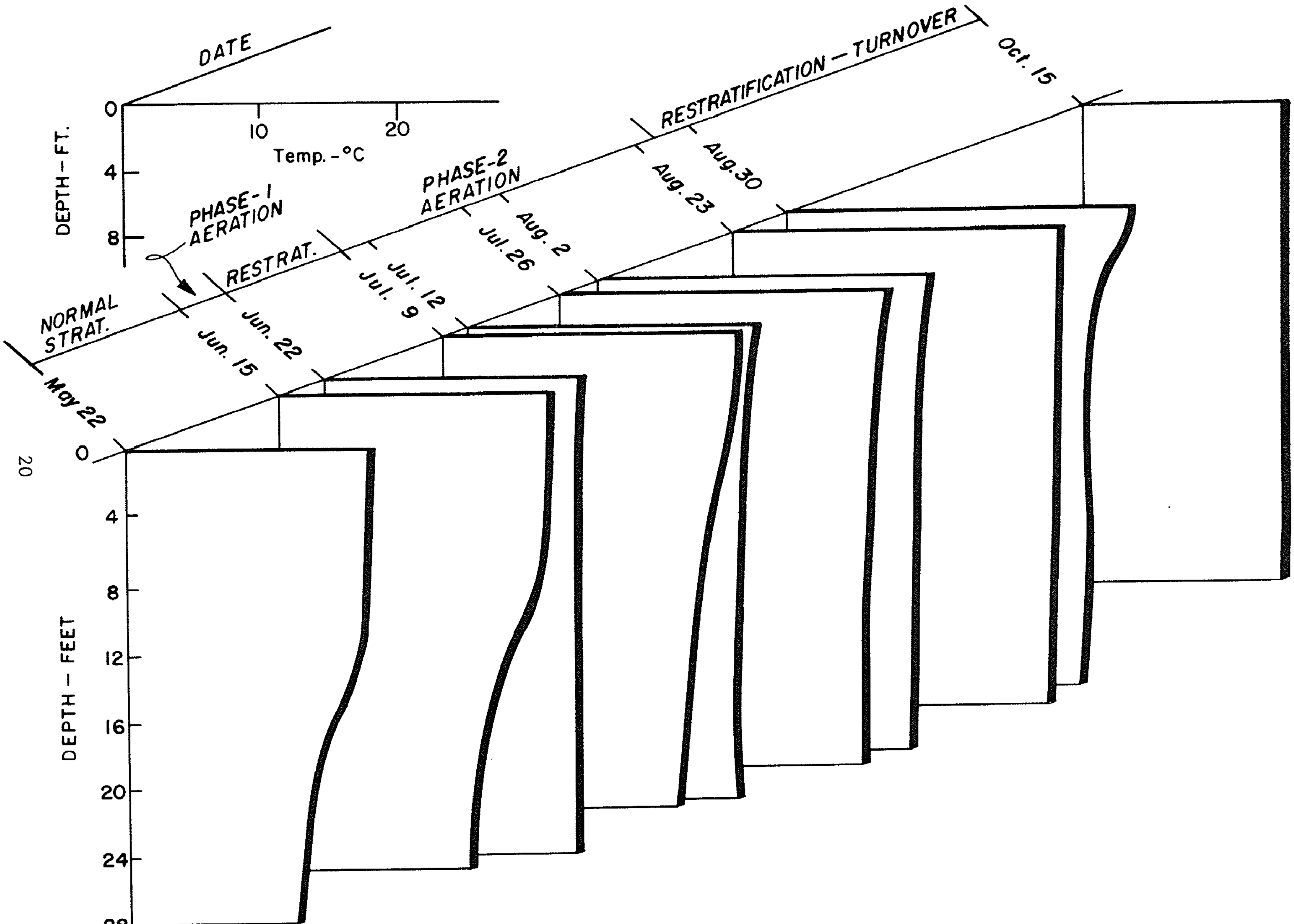


FIGURE 9 - TEMPERATURE — CHANGES

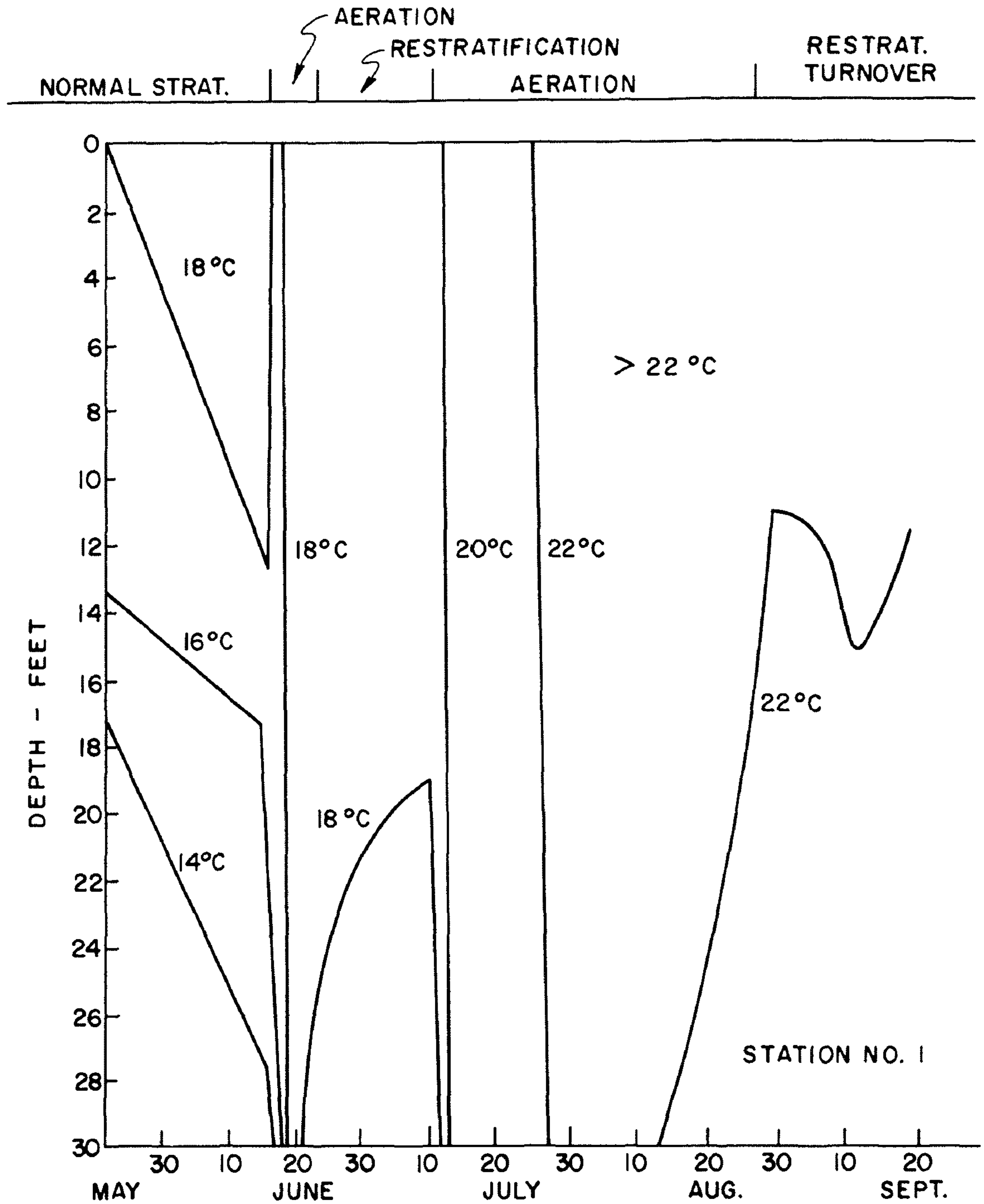


FIGURE 10 – EFFECTS OF AERATION ON TEMPERATURE

Seventeen days of restratification resulted in the hypolimnion reforming below a depth of 12 feet. The lake had zero mg/l D.O. below 12 feet (Figure 8); the thermocline had reformed; and algae continued to form thick, blue-green mats on the surface resulting in blankets of floating algae in the coves (Figures 11 and 12).

Phase IV

The second induced aeration test was started on July 10, 1969, with air being pumped at 54 cfm, creating a pressure of 22 psig in the discharge hose at the lake shore. Except for service and fuel stops, aeration was continuous until July 19 when aeration was halted for four days due to mechanical problems. Aeration was started again on July 23 and continued through August 23 without further interruption.

Monitoring of aeration effects was continued as scheduled for the first aeration test with the exception that Station 5 was included for measurement of D.O., temperature, pH, conductivity, and H_2S to allow a more accurate determination of radial aeration effects. Major chemical nutrients were measured 6 and 24 days after the start of the second aeration test.

Increases in D.O. began to appear in the mid-depths with 4.0 mg/l reaching a depth of 15 feet after only 24 hours of operation. After two days of continuous aeration, it was noted that oxygenation conditions were beginning to degenerate. The degeneration of the rate of oxygen absorption was first noticed after two days of constant cloud cover and after an intense cold rain during the second night, which caused a high discharge through the uncontrolled spillway, carrying much of the surface-floating algae downstream. The day following the rainstorm the algal mats had disappeared, there appeared to be very little plankton in the water mass, and fish began to stress. Anaerobic conditions continued to become worse and fish began to die even though aeration was continuous. Induced aeration was continued in order to satisfy the oxygen demand more quickly so that restocking could be done without undue loss of time.

After the algae died, a tremendous oxygen demand was established as a result of the decomposing organic material. Continued aeration could not immediately satisfy the oxygen demand. During the four-day period, when the compressor was stopped for repair, the organic material in suspension began to settle to the bottom and D.O. in the surface waters began to improve. However, when aeration was started the second time on July 23, circulation of water mixed the bottom organic material back into the water mass and caused a temporary loss of oxygen until the oxygen demand became satisfied. This phenomenon was found to have occurred in aeration studies in a small lake near Stockholm and is discussed by Bernhardt, 1967 (15).

By July 27, the oxygen demand had begun to become satisfied and had increased to 7.0 to 8.0 mg/l D.O. at the surface with 4.0 mg/l reaching a depth of 22 feet (Figure 8). The decision was made to restock the lake with rainbow trout at this time. Approximately one-third of the normal concentration of catchable-size trout was restocked on July 29, of which about two-thirds survived. The one-third loss of restocked fish apparently was caused by

Figure 11 - Algal Mats in Coves

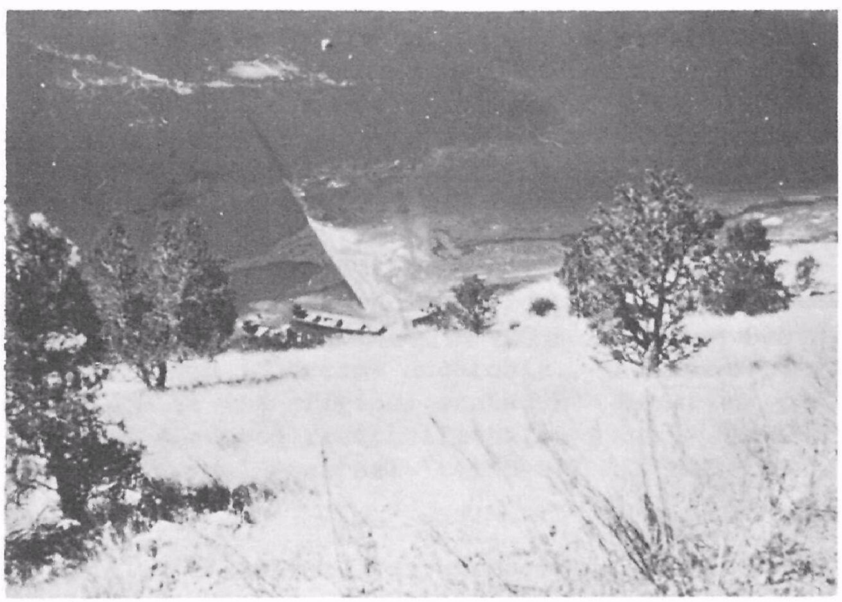


Figure 12 - Floating Algal Scum Near Aerator

the unavoidable shocking of the fish with the quick change in temperature. The lake was about 24°C, and the water in the transport truck was approximately 18°C. Within two days after restocking, the D.O. in the surface waters began to degrade again. This degradation was apparently a result of the decaying dead fish on the bottom disrupting the delicate balance of aerobic-anaerobic conditions, causing the lake to return to an anaerobic environment.

Aeration was continued until August 26 with a gradual increase in D.O. in the surface waters reaching 6.0 mg/l at depths of 10 feet and 2.0 mg/l at 20 feet. Aeration was discontinued prior to complete oxygen saturation of the entire water mass as in the first test in order to allow enough time remaining in the summer season to remeasure the second restratification rate.

Phase V

Aeration was stopped on August 26, and the lake was allowed to partially restratify before normal fall "turnover" (Figure 9). The normal fall "turnover" occurred in Lake Roberts during the first week of October with D.O. reaching concentrations of 7.0 to 5.0 mg/l throughout the water mass by October 15.

Dissolved oxygen and temperature profiles were monitored on August 27, 29, and 30; September 10; and October 15 during the restratification and "turnover" period. Chemical restratification during Phase V reached a maximum around September 10 with 4.0 mg/l D.O. at a depth of 10 feet and less than 1.0 mg/l below that depth. The temperature profiles indicated only slight restratification in the upper 8 feet of the lake (Figure 9). By October 15, the normal seasonal "turnover" was complete and the lake had become well mixed to an isothermal condition at a temperature of 14.2°C and with 8.0 mg/l D.O. to depths of 30 feet.

Chemical samples were collected at Stations 1, 2, and 3 after the "turnover" period for comparison with the previous four phases of study (Appendix Table 1). Analyses of these samples indicated the lake had become well mixed chemically as a result of the seasonal "turnover."

Lake Roberts was restocked in mid-October with approximately 17,000 fingerling and 8,000 catchable-size rainbow trout without adverse effects.

SECTION VI

DISCUSSION

Literature, reporting reservoir destratification and induced aeration in small lakes, indicates little research has been done to characterize the changes in major chemical nutrients resulting from induced aeration. Primary evaluations of the magnitude of changes in selected chemical parameters in epilimnion and hypolimnion waters, resulting from induced air mixing and introduction of dissolved oxygen, were specific goals of the research conducted by the Robert S. Kerr Water Research Center.

In addition to measuring chemical parameters, evaluations of energy requirements and oxygenation efficiency to maintain the lake in a well-mixed isothermal state were also studied. Energy requirements and oxygenation efficiency were then compared to previous studies to determine the system's potential as a water quality management tool.

A host of chemical parameters was measured during each of the five phases of operation (Appendix Tables 1 and 2). Pertinent parameters tabulated in Appendix 1 are illustrated graphically and discussed in this section. Several parameters were not measured throughout all phases of the study when it was found that they were not significantly affected by aeration.

At the beginning of aeration, the lake was in a strongly stratified condition with D.O. in the epilimnion in a super-saturated state as a result of photosynthetic activity of algae (Figure 13). It became obvious after seven days of aeration that the stratified condition had been destroyed and super-saturated epilimnion water had mixed with the anaerobic hypolimnion waters, creating a well-mixed water mass with 100% oxygen saturation on the bottom. During the second phase of the study when restratification was allowed, the lake restratified again forming an anaerobic environment in the hypolimnion and a super-saturated epilimnion. During the second aeration phase, an algae die-off occurred resulting in an almost complete loss of oxygen as a result of mixing the decaying organic material precipitated by the dead algae. This condition was partially overcome by continued aeration, and the lake was restocked at an inopportune time before restoration was complete. The death of part of the restocked fish upset the balance of the lake once again and it became anaerobic. Continued aeration finally restored the lake to near its original state, and aeration was halted to allow measurements of a second restratification phase. Monitoring was continued through the normal seasonal "turnover" for comparison of restratification conditions.

Measurements of pH also illustrate very remarkably the effects of mixing by aeration. The pH returned to high values in the bottom and low values at the surface during restratification and quickly responded to mixing during the second aeration test (Figure 14). It was noted that during the second aeration test when the algae died and the lake became anaerobic, the pH typically dropped to values below 8.0 throughout the water mass. During

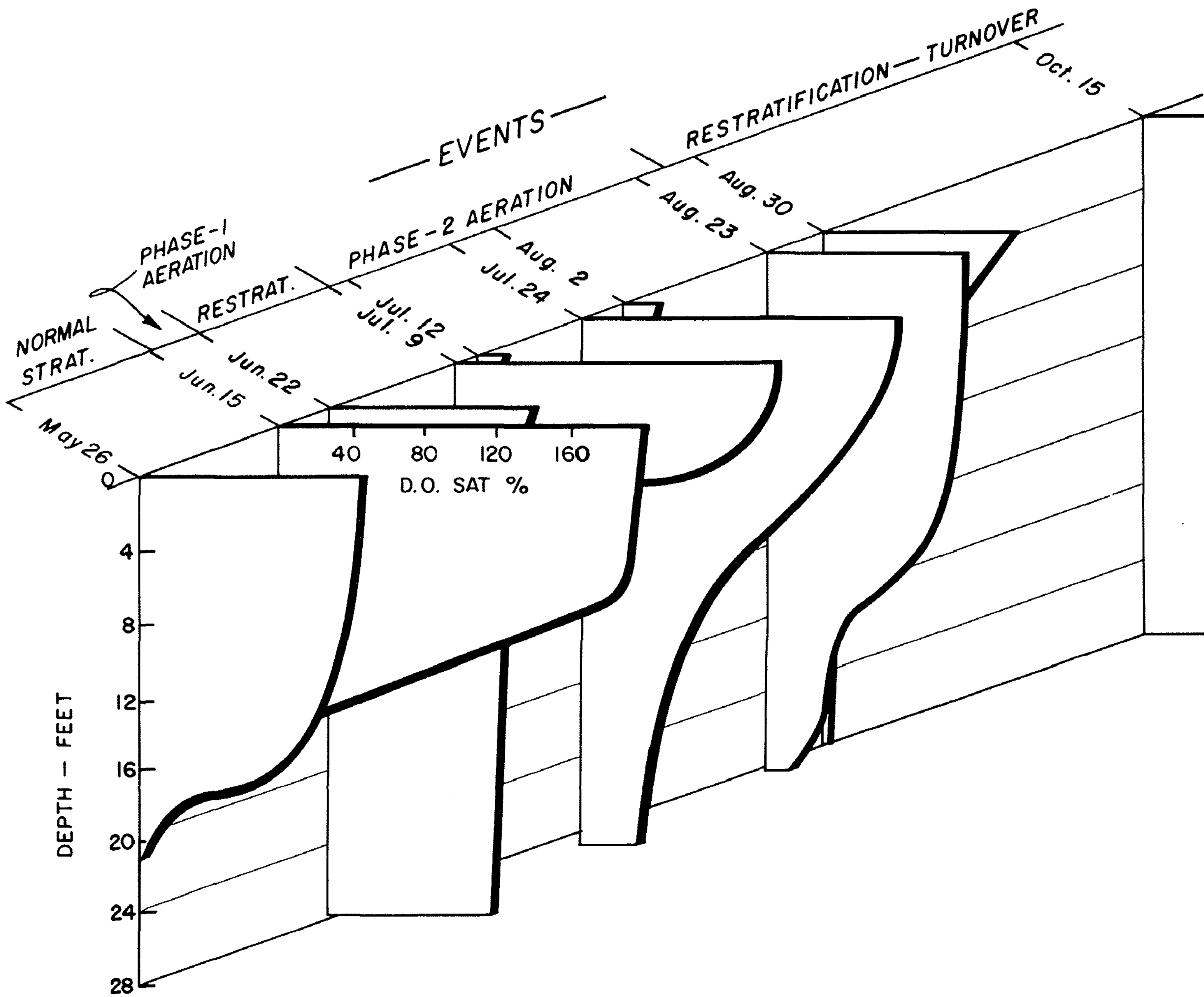


FIGURE 13 - AVERAGE DISSOLVED OXYGEN SATURATION

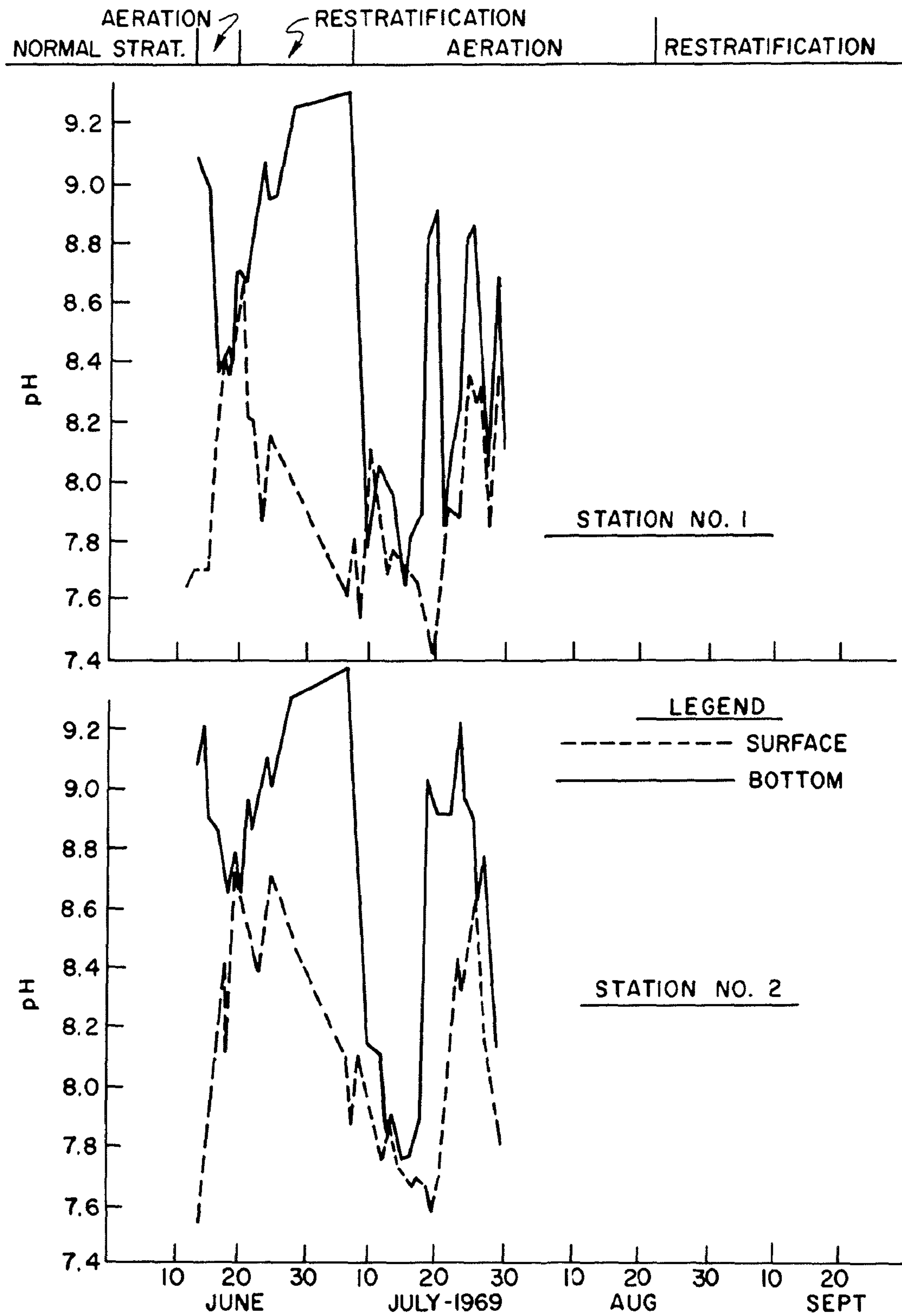


FIGURE 14 — EFFECTS ON pH

the 4 1/2 day compressor-repair period, pH showed a quick response to restratification as particulate matter held in suspension by aeration began to settle to the bottom.

Hydrogen Sulfide increased significantly in the bottom near the mud-water interface as the lake stratified during early June (Figure 15). However, when aeration began, H_2S disappeared in the water mass by the second day. During the first two days, it was very evident from the repugnant odor that H_2S was being vented to the atmosphere as the bubbles of the air plume were rupturing at the water surface (Figures 16 and 17). As the lake was allowed to restratify, H_2S began to increase in the bottom waters again. When the second phase of aeration began, H_2S was reduced as before; however, before it was completely dissipated, the lake became anaerobic and H_2S remained until anaerobic conditions were finally overcome at the end of July.

During the initial aeration period, while H_2S was being vented, there were no visual adverse effects of H_2S toxicity to fish. As a matter of fact, while H_2S was venting to the atmosphere, fish were congregating in the air plume. Releasing air at the greatest depth near the bottom may prove to be a very economical technique of removing high concentrations of H_2S in small lakes.

The effects of induced aeration on ammonia nitrogen (NH_3-N) were very similar to that of the H_2S (Figure 18). High bottom concentrations were reduced during initial aeration as pH rose to 8.6, then NH_3-N redeveloped during restratification. During the second aeration phase, NH_3-N in the bottom was reduced while concentrations in the surface were increased until the lake became well mixed. Even as anaerobic conditions developed, NH_3-N was continually reduced through time as aeration proceeded. Apparently, the NH_3-N was vented to the atmosphere through the air plume similar to H_2S, since the pH remained above 8.0, and nitrite nitrogen (NO_2-N) and nitrate nitrogen (NO_3-N) did not increase indicating no conversion of NH_3-N to those forms.

Total Kjeldahl nitrogen reacted inversely to NH_3-N (Figure 19). During stratification prior to aeration, Kjeldahl nitrogen concentrations were higher in the surface waters than in the deeper anaerobic waters. This phenomenon could have been a result of higher nitrogen content in the cell structure of the dense population of algae which was released from the cells through chemical reactions in the testing procedures, since the samples were not filtered prior to analysis. As the lake became mixed during the first aeration phase, the concentration of Kjeldahl nitrogen in both the surface and bottom waters became slightly reduced and well mixed. During the restratification period, concentrations again increased in both the surface and bottom waters, with the surface concentrations becoming slightly higher as in previous normal stratification. When aeration started a second time, mixing occurred quickly; however, the concentrations of Kjeldahl nitrogen did not drop as sharply as in the first test, but gradually declined with continued aeration. The initial higher mixed condition is reasonable since there was more organic material in suspension at the start of the second aeration test. As aeration continued, the anaerobic environment was continually suppressed allowing lower conversion of bottom organic nitrogen by the biota.

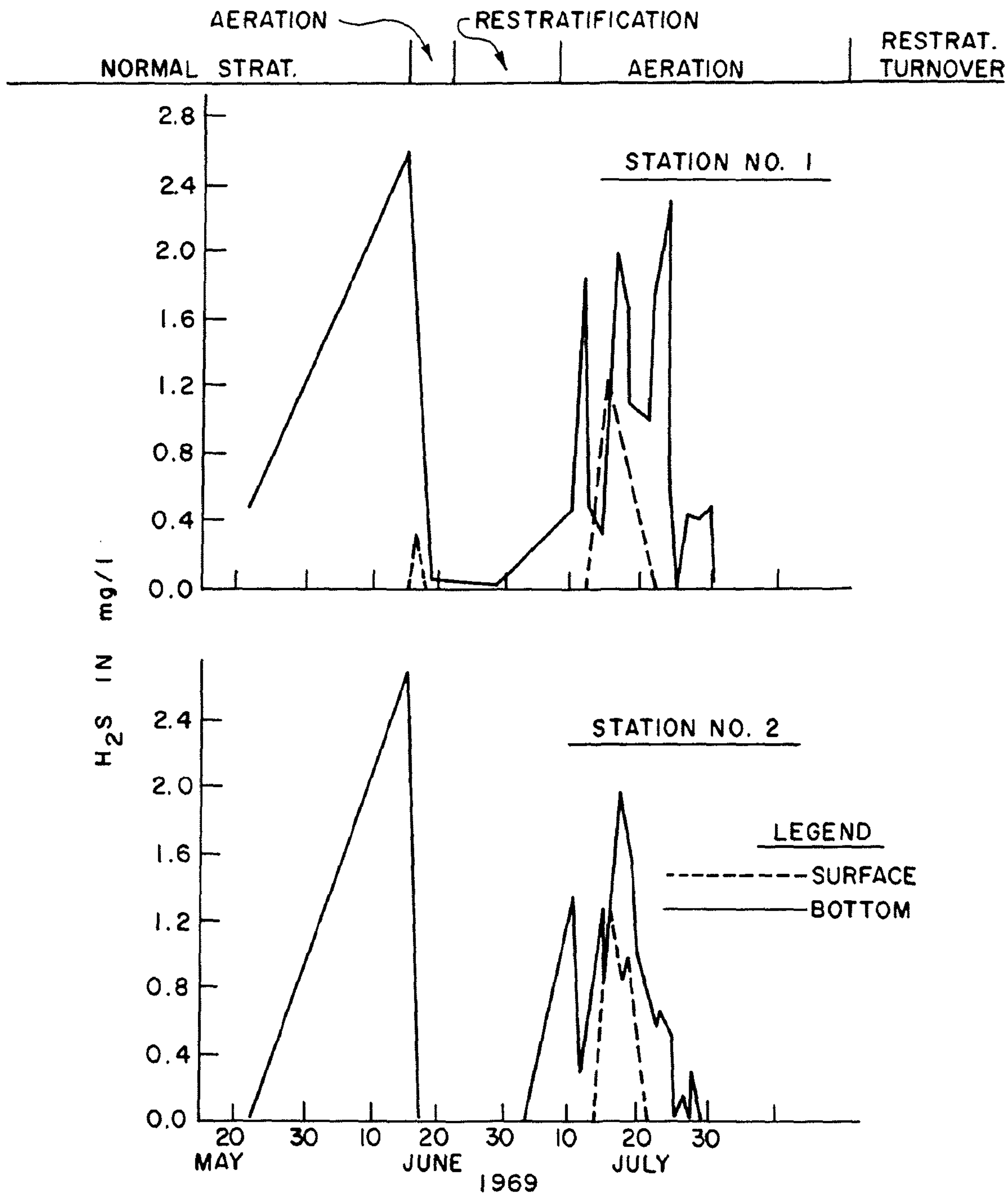


FIGURE 15 — EFFECTS ON HYDROGEN SULFIDE

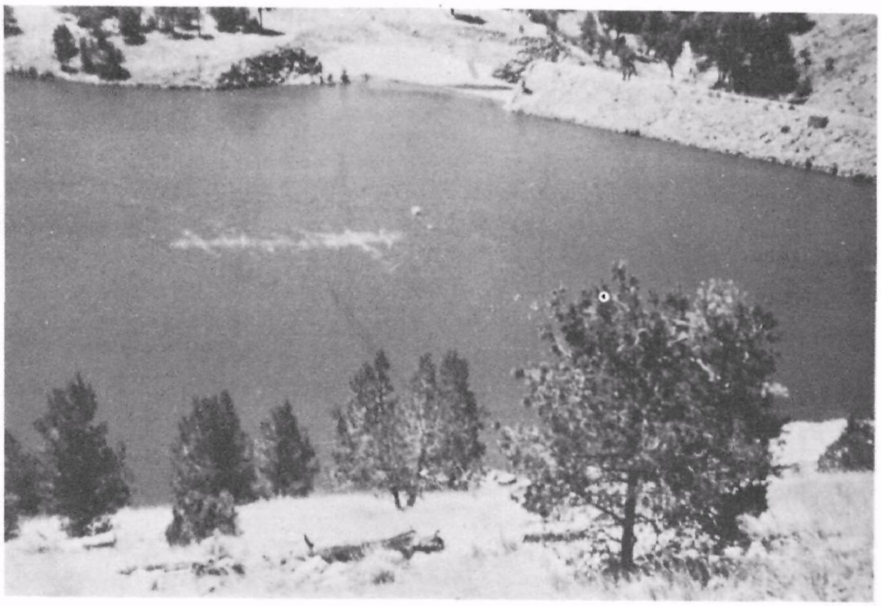


Figure 16 - Elongated Air Plume

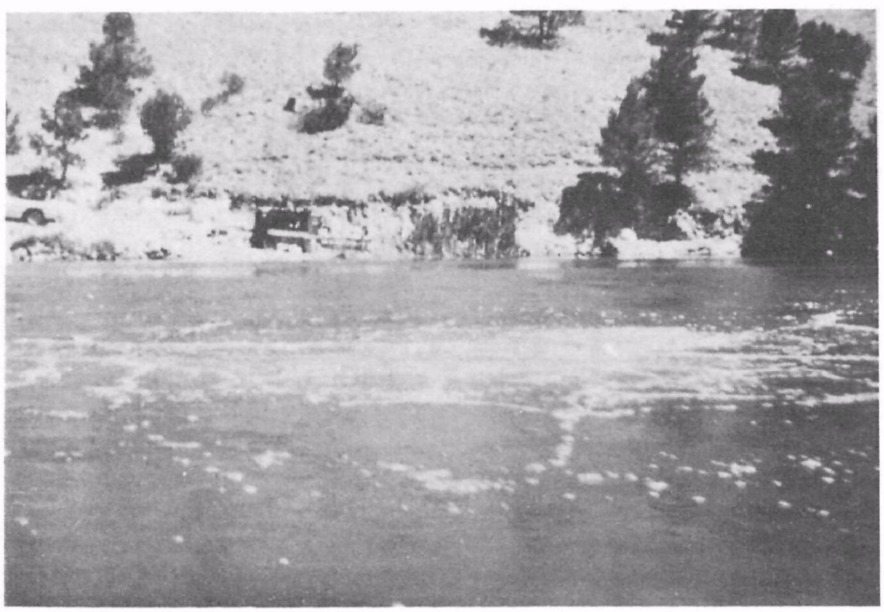


Figure 17 - Erupting Bubbles in Air Plume

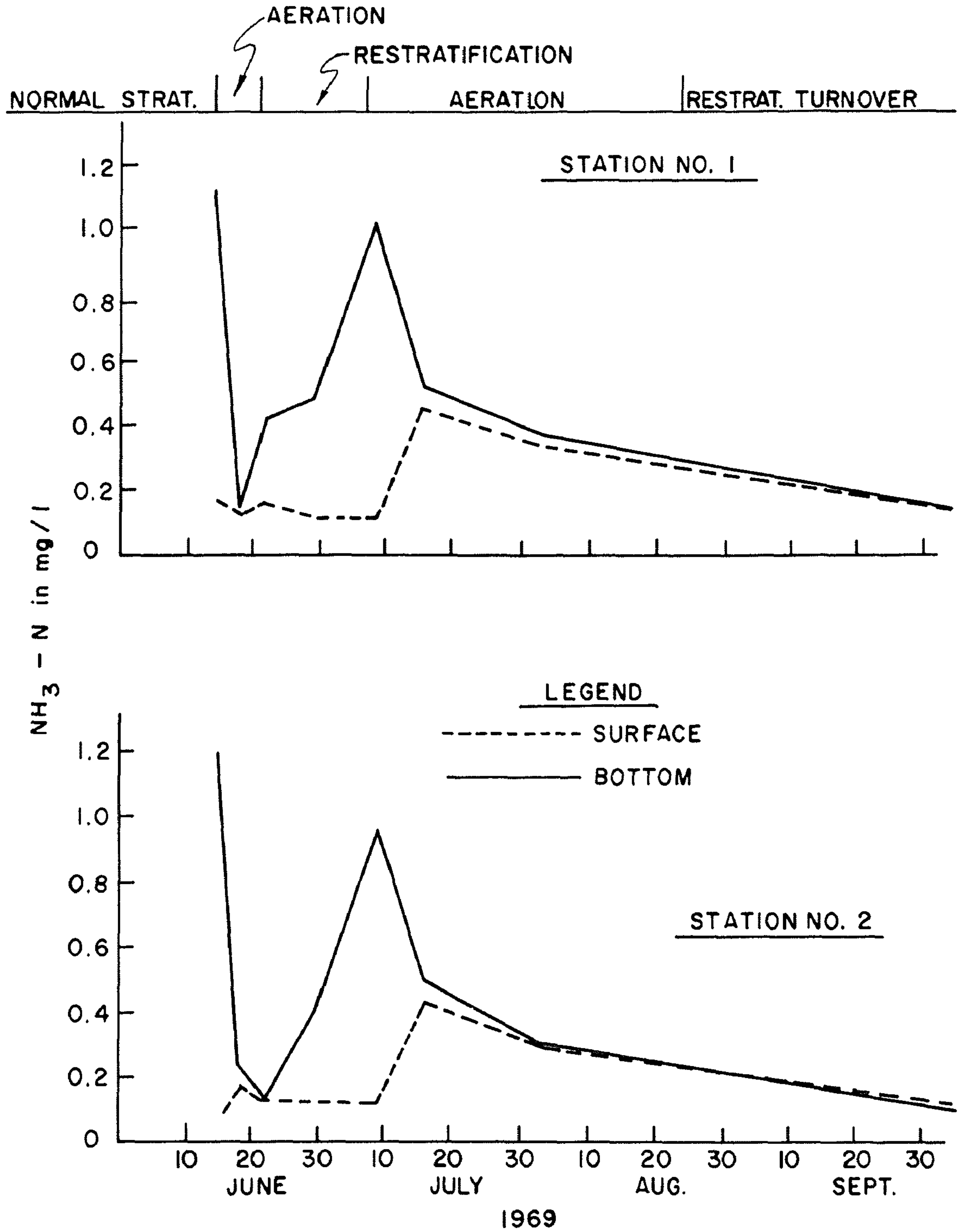


FIGURE 18 – EFFECTS ON AMMONIA NITROGEN

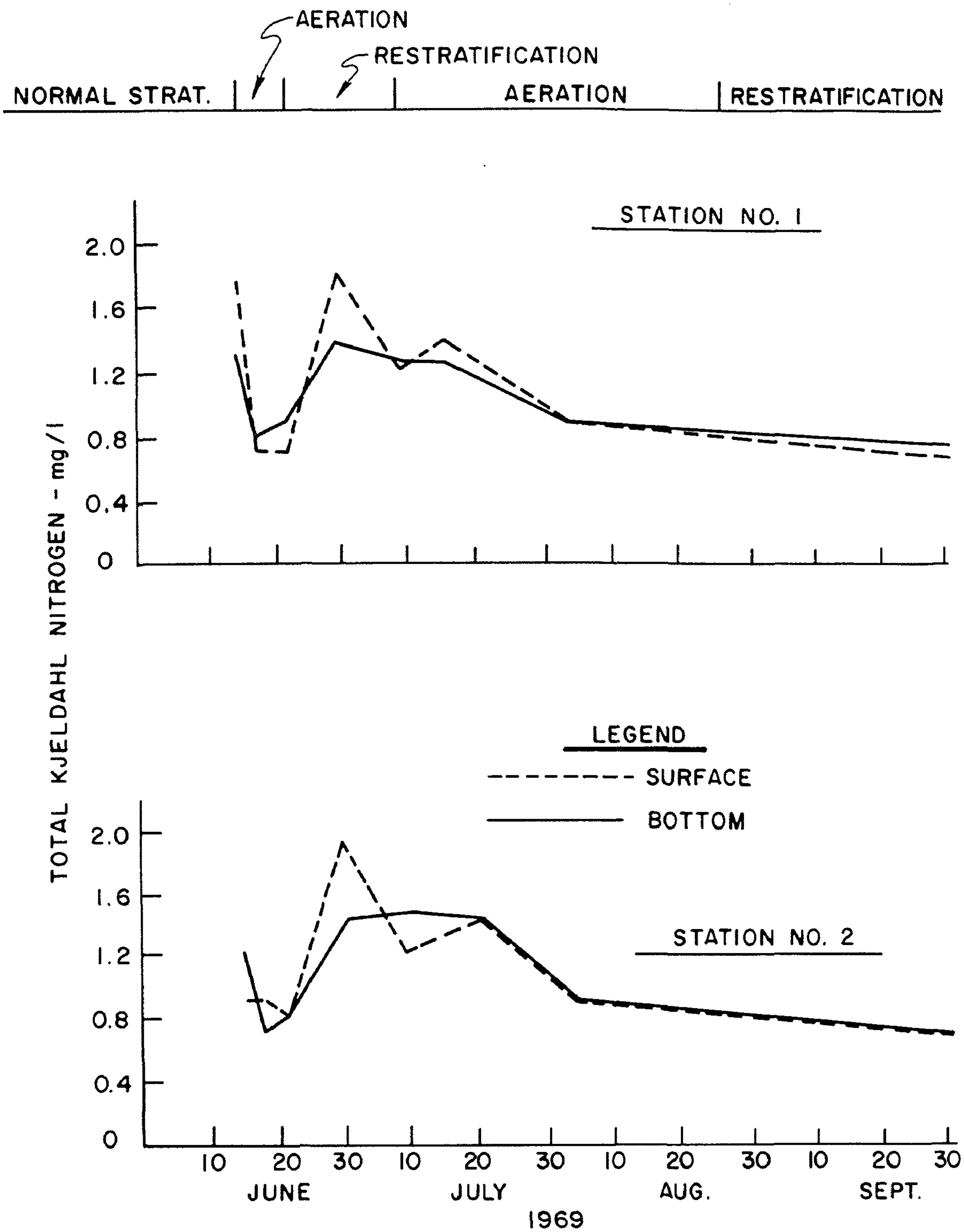


FIGURE 19 — EFFECTS ON TOTAL KJELDAHL NITROGEN

Aeration effects on total phosphate were very dramatic (Figure 20). The phosphates were strongly stratified before initial aeration, then mixed very quickly when aeration was started. When restratification was allowed, the surface waters had slightly higher total phosphate concentrations than the bottom. This occurrence apparently was a result of reduction of phosphates from algal cells in the densely populated surface samples through chemical reactions in the testing procedures. Samples were not filtered prior to analytical tests; therefore, this phenomenon cannot be supported with test data.

During the second aeration test, the phosphate concentration in the bottom waters became slightly higher than in the surface, indicating that mixing circulated the live algae throughout the water mass. After the algae die-off, there was apparently more particulate matter held in suspension in the surface waters than near the bottom due to the stronger current in the surface waters created by the aerator turbulence. Evidence of this occurrence was supported by the higher concentrations of total phosphate in the surface waters at Station 1 as compared to Station 2 as the second aeration progressed through the anaerobic period.

Ortho-phosphate reacted to aeration very similar to the total phosphates (Figure 21). Ortho-phosphate concentrations in the surface and bottom waters responded almost identically as total phosphate during the first aeration test; however, when the lake was allowed to restratify, bottom and surface concentrations returned to the normal pattern and did not exhibit an inverse separation as illustrated by total phosphates. Bottom and surface concentrations became well mixed again after 6 days of the second aeration test; but when the algae die-off occurred, surface concentrations became much higher than bottom waters. This phenomenon was particularly noticeable at Station 1 near the aerator indicating the pumping action created surface currents holding masses of organic phosphate material in suspension near the surface.

Manganese was the only other chemical parameter measured that was significantly affected by aeration (Figure 22). During normal stratification, there was a high concentration of manganese near the bottom; however, as anticipated from observations of other parameters, the bottom and surface waters quickly mixed to an intermediate concentration when aeration started. At the beginning of each aeration test, bottom and surface concentration mixed quickly; however, during the second aeration test, the mixed concentration became very low during the algae die-off. During the die-off, there was a significant increase in H_2S throughout the water mass which may have resulted in manganese reacting with the sulfate ions to form manganese sulfate in solution since free sulfate ions have been reported to remain in the water mass as H_2S is vented to the atmosphere (16). Following the algae die-off, manganese increased to maximum concentration as H_2S reached low levels through the venting operation of aeration.

In addition to colorimetric tests, analyses were conducted on an array of trace metals immediately before the first aeration and again after 3 days of continuous aeration (Appendix Table 2). In examining Table 2, it was

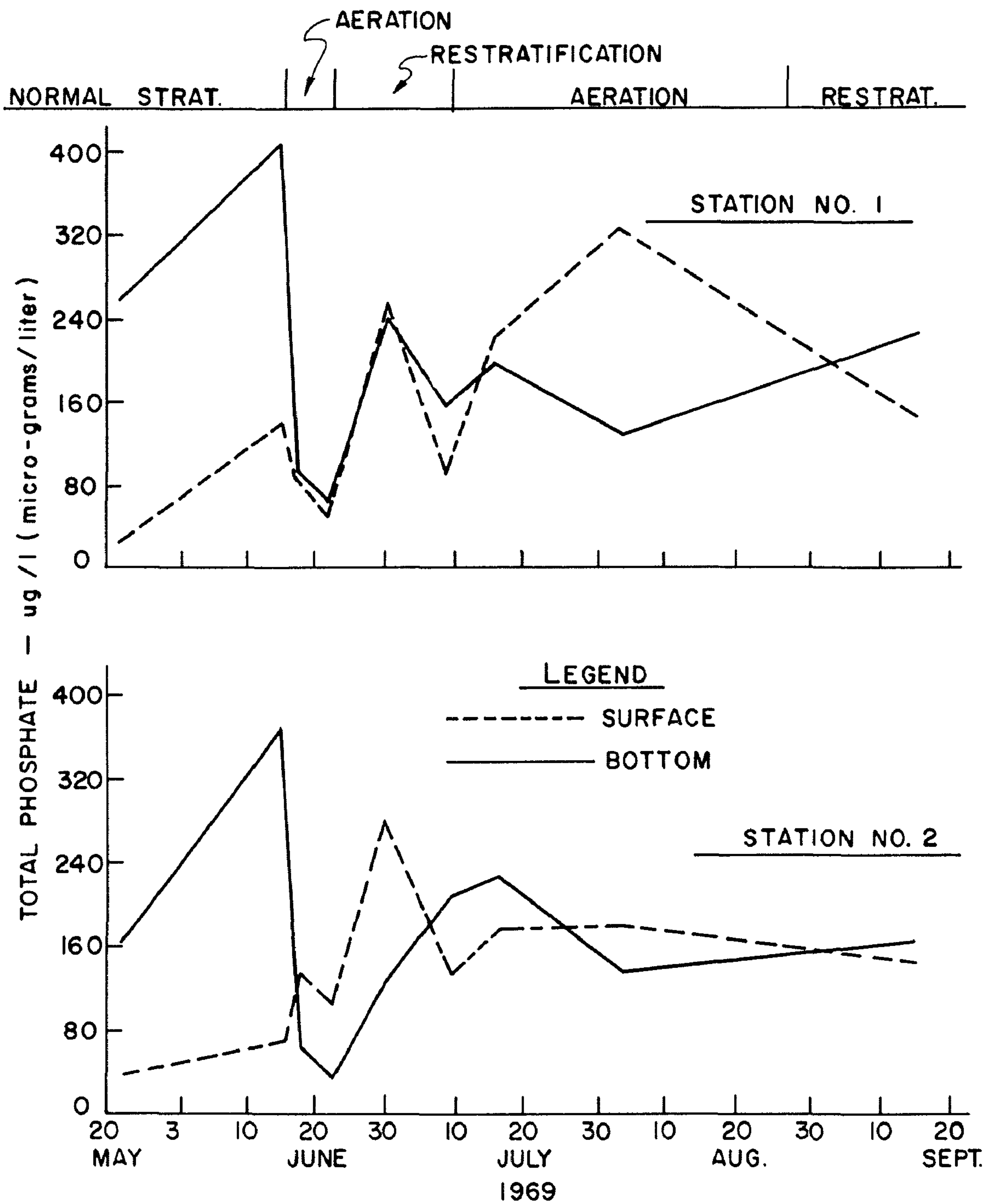


FIGURE 20— EFFECTS ON TOTAL PHOSPHATE

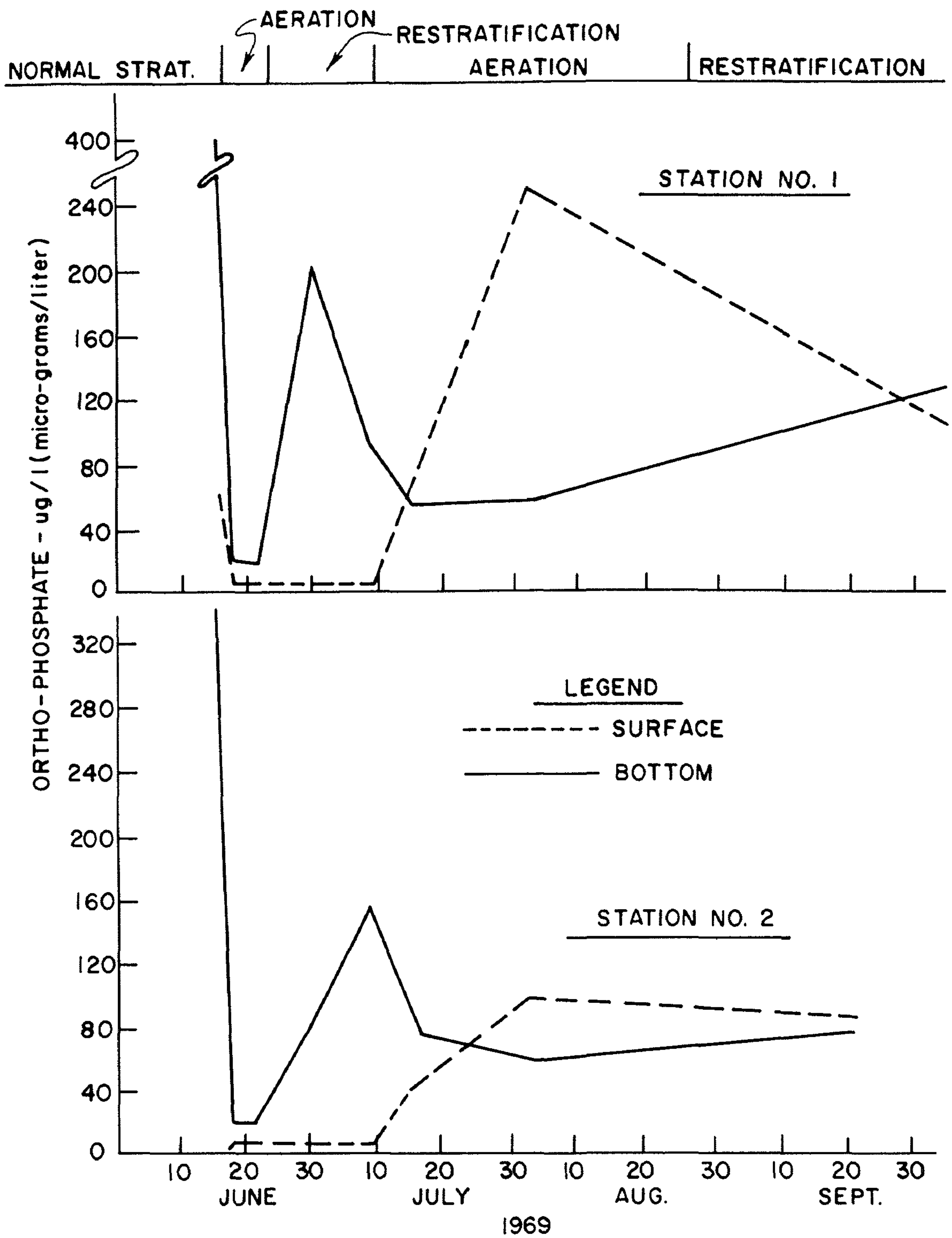


FIGURE 21 — EFFECTS ON ORTHO-PHOSPHATE

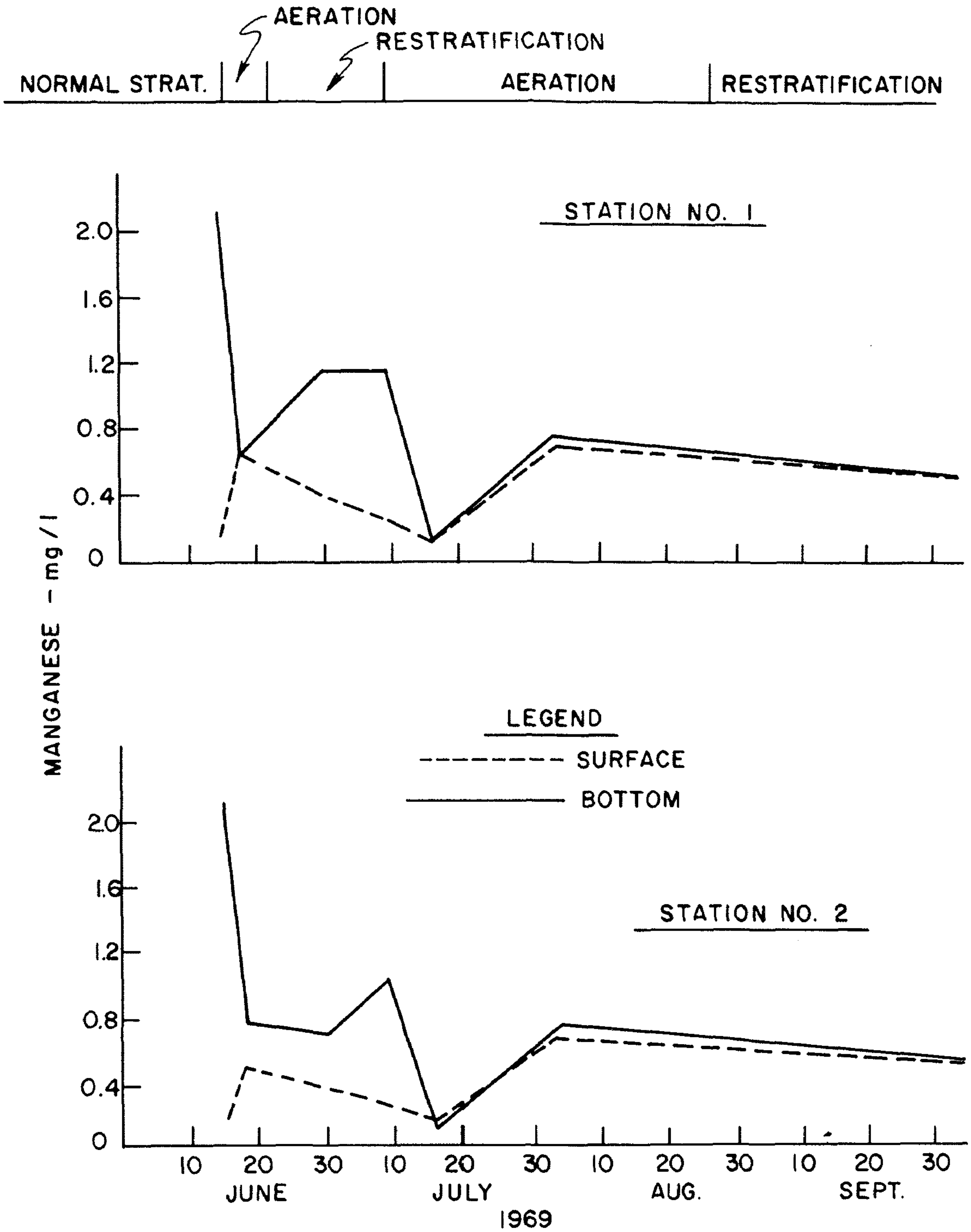


FIGURE 22 – EFFECTS ON MANGANESE

found that boron, iron, manganese, and alumnium were the only metals significantly affected by aeration. Apparently, these metals were extracted from the bottom muds by the current created along the bottom by the uplifting of water through the air plume. As these metals reached the surface, they were held in suspension for a time by the surface currents near the aerator but were not dispersed to great radial distances on the surface. (Compare data at Stations 1 and 2.)

The total pounds of D.O. in the lake volume was computed regularly throughout the study (Figure 23). The data presented support the earlier discussion regarding D.O. distribution, saturation, and reduction resulting from circulation of organic particles. Data presented illustrate there were more pounds of D.O. in the lake during normal stratification than during aeration periods (Figure 23); however, comparing these data with Figure 13, it is obvious that even though there were less pounds of D.O. in the lake during aeration, it was more equally distributed throughout the water column during the first aeration phase. The reduction in total mass of D.O. during the first aeration phase is a result of the oxygen circulation reducing organic material from the bottom muds. Comparison of Figures 13 and 23 shows that during the beginning of the first restratification period increased photosynthetic activity of the algae in the epilimnion increased the total mass of D.O. but the D.O. was confined to the epilimnion.

During the later part of the first restratification period, the lake had intensely stratified leaving a large volume of anaerobic hypolimnion and a thinner super-saturated epilimnion resulting in an overall loss in total pounds of D.O. At the start of the second phase of aeration, the total mass of D.O. began to increase, but as soon as the algae die-off began, the total mass of D.O. decreased. Circulation of the dying algae and bottom organic deposits during the second aeration test resulted in immediate utilization of D.O. When the compressor was turned off on July 19, the D.O. immediately began to increase; but when the compressor was returned to service, organic material began to circulate again and D.O. was completely lost until the oxygen demand finally became satisfied. When final restratification was allowed, D.O. was lost for a time because the D.O. added by the aerator had stopped and D.O. production by algae was slow since algae concentrations were low.

Oxygen uptake tests were performed on bottom sediments on August 13, 1969, near the end of the second aeration period. These tests were performed to determine if, in fact, organic material carried off the bottom by currents, created by aeration, was actually reducing the oxygen concentration in the lake. Sediment samples were collected from the bottom at Stations 1 and 2. These sediments were mixed with lake water of known D.O. concentration. The mixture was put in 300 ml BOD bottles and stirred while continually measuring the change in D.O. until it reached near zero (Table 2). The samples were later analyzed for total suspended solids and compared with actual suspended solids at three levels in the lake at all stations. It was noted that the D.O. in the samples was immediately reduced to near half when sediment was added to the surface lake water and was reduced to near zero rather quickly as the mixed samples were continually stirred. The water samples collected

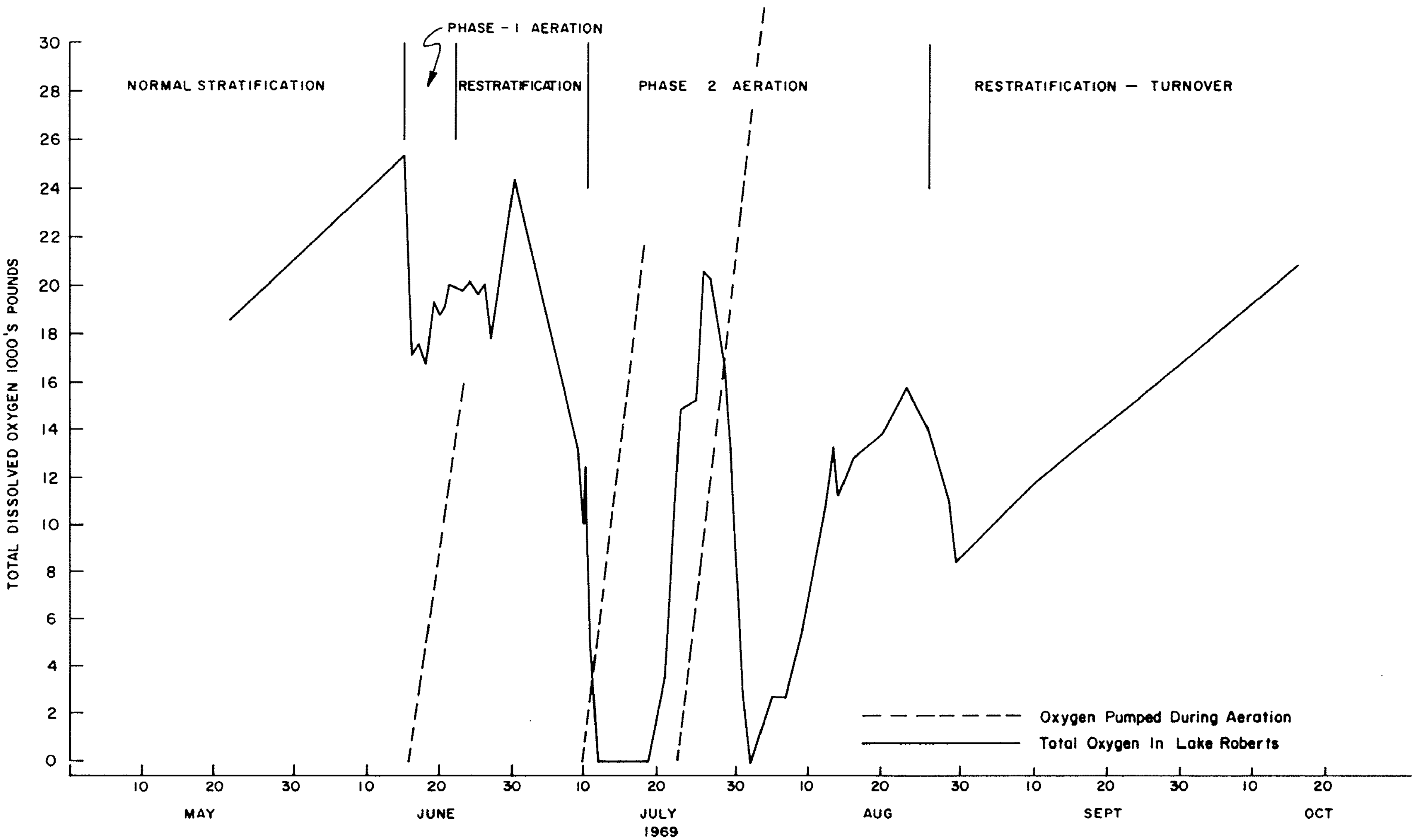


FIGURE 23 - AERATION EFFECTS ON DISSOLVED OXYGEN

TABLE II

DISSOLVED OXYGEN UPTAKE TEST

Station #1			Station #2		
Time (Min.)	D.O. mg/l	D.O. X10^{-2} mg/l/gm TSS	Time (Min.)	D.O. mg/l	D.O. X10^{-2} mg/l/gm TSS
7:58 PM	5.8[a]	-----	10:58 PM	6.0[a]	----
8:00 "	3.2[b]	64.5	11:00 "	2.8[b]	41.8
8:15 "	3.0	60.5	11:15 "	1.85	27.6
8:30 "	1.65	33.3	11:30 "	1.35	20.1
8:45 "	1.3	26.2	11:45 "	1.05	15.7
9:00 "	1.1	22.2	12:00 M	0.8	11.9
9:15 "	0.9	18.1	12:15 AM	0.55	8.2
9:30 "	0.7	14.1	12:30 "	0.45	6.7
9:45 "	0.5	10.1	12:45 "	0.40	6.0
10:15 "	0.15	3.0			

[a]D.O. of lake water immediately before mixing with sediment

[b]D.O. of sample immediately after mixing with sediment

NOTE: Station 1--sample contained 5048 mg/l total suspended solids (TSS); Station 2--sample contained 6704 mg/l TSS; Both samples were continually stirred during D.O. measurements.

in the lake during aeration had only 1 to 2 percent as much total suspended solids as the test samples described in Table 2. As a result of these lower percentages of Total Suspended Solids (TSS), oxygen uptake rates in the lake after the algae died and aeration continued were similar to the laboratory tests but reacted at a much slower rate.

Discussion in earlier sections pointed out that a detailed biological monitoring program and analysis of aeration effects on various biological parameters were part of the New Mexico Department of Game and Fish objectives. Therefore, no data analysis or conclusions as to biological effects are presented in this report. After normal seasonal "turnover" had occurred in the lake and physical parameters had returned to normal for the fall months, a profile of plankton distribution was collected at Stations 1 and 5 by the Water Quality Control Research Program personnel (Appendix Table 3). These data can be used as a base for analyses of data collected by the State of New Mexico, since their sampling program did not start until seasonal stratification had occurred and was not continued through the seasonal "turnover" period.

Analyses of the actual pounds of D.O. pumped versus the pounds of D.O. actually in the lake at specific times illustrate some startling facts. During the first phase of induced aeration, 15,900 pounds of oxygen was pumped in a period of 144 hours with approximately 9,400 horsepower resulting in a pumping efficiency of 1.7 pounds of D.O. per horsepower-hour of expended energy. Immediately prior to the start of the first induced aeration phase, there was 25,300 pounds of D.O. in the lake. During the first 50 hours of compressor operation, there was an additional 5,500 pounds of oxygen pumped into the lake. However, after 50 hours of pumping, the lake contained only 21,600 pounds resulting in a net loss of 9,200 pounds. Even though there was an actual loss in D.O., all induced aeration effects were not negative. The hypolimnion, prior to induced aeration, was void of D.O. below 15 feet. After 50 hours of compressor operation, there was 3,700 pounds of D.O. in the water layer below 15 feet uniformly distributed at a concentration of 5.6 ppm to the bottom. By the end of the first aeration phase, 4,600 pounds of D.O. had been diffused into the hypolimnion resulting in a uniformly distributed concentration of 6.6 mg/l D.O. to the bottom.

The oxygenation efficiency of the first induced aeration test was calculated similarly to other studies (5,11). Calculations of oxygenation efficiency for the total water mass were negative; however, calculations for the volume below a depth of 15 feet showed that 1.2 pounds of D.O. per horsepower-hour were added during the first 50 hours of compressor operation. By the end of the first aeration test (144 hours), the oxygenation efficiency in this layer had declined to 0.5 pounds of D.O. per horsepower-hour.

During the second induced aeration test, before the compressor was stopped for repair, the lake lost all of its D.O. even though 20,300 pounds of D.O. were pumped. After the compressor was repaired, another 31,500 pounds were pumped and D.O. was lost again. Obviously, the organic demand was greatly increased by circulation of organic material precipitated by the decaying algae, resulting in an oxygen demand greater than the capacity of the aeration system.

The intensity of thermal stratification has been used for many years by limnologists as an arbitrary measure of the stability of a lake (17). Previous researchers have proposed the use of stability changes as a method of calculating destratification performance (5,18,19). Stability computed in work units can be described as the minimum energy required to mix a body of water until it is completely isothermal. The ratio of stability to total mechanical energy input expressed in percentage, has been used as an index of performance (destratification efficiency) for various reservoir aeration devices.

The stability of Lake Roberts was computed regularly throughout the study for comparison with other similar studies (Figure 24). Data illustrated in Figures 9 and 24 show that the lake became thermally destratified in a very short period of time, indicating a relatively high destratification efficiency. However, high destratification efficiency should not be interpreted as indicating a high rate of oxygenation efficiency as illustrated by previous discussion of problems encountered in incorporating D.O. throughout the water mass.

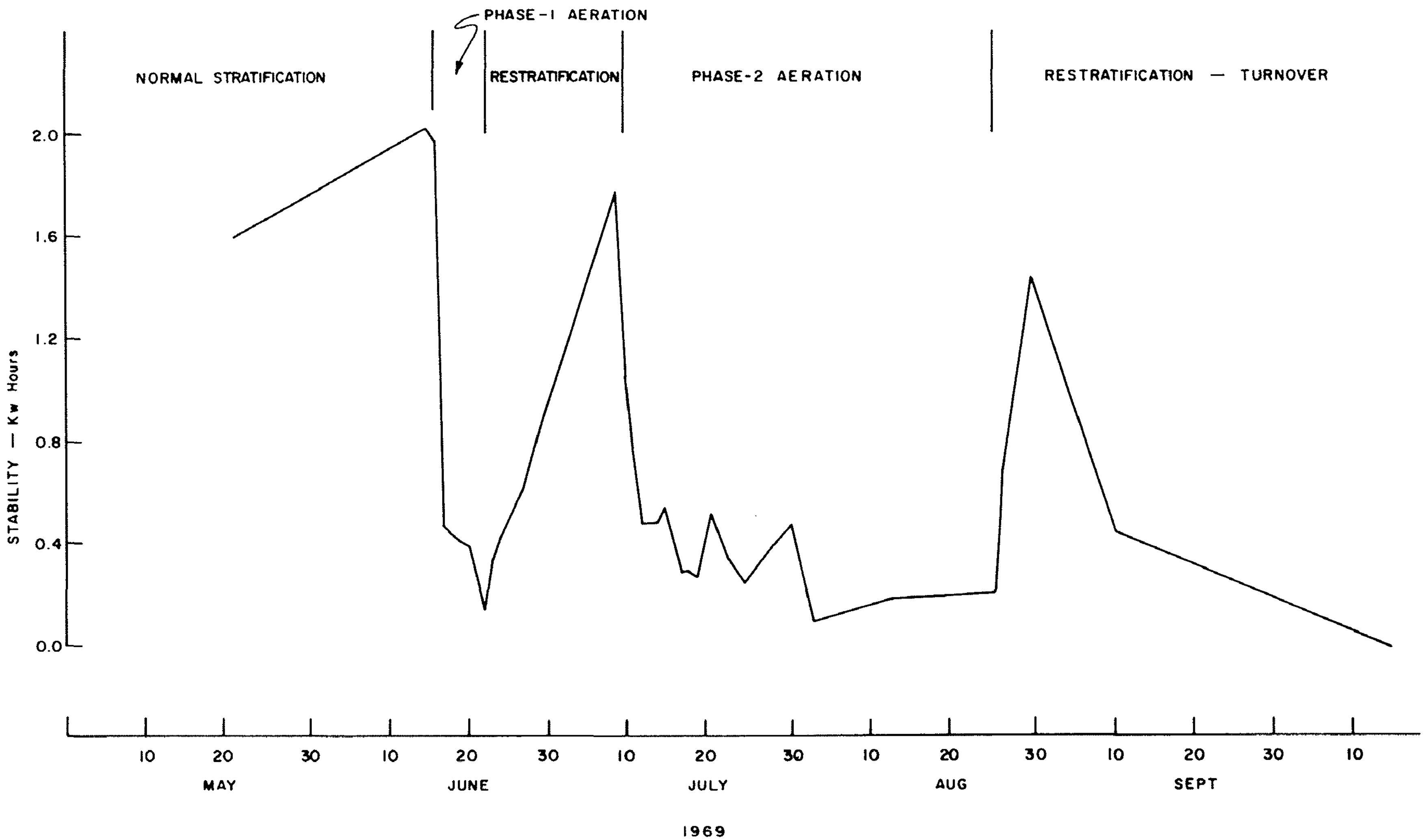


FIGURE 24 - AERATION EFFECTS ON STABILITY

Comparison of the destratification efficiency with data reported by Bernhart (5) showed that the efficiency of the system tested in Lake Roberts during initial aeration was very near that of Boltz Lake which has similar physical characteristics (Table 3). However, computations show there is a gradual decrease in destratification efficiency as induced aeration is continued. This decrease indicates that when stratification is initially overcome and the lake becomes isothermal, power should be reduced accordingly to maintain a destratified condition at a minimal input of energy. Continued induced aeration at the initial energy input rates results in a progressive waste of energy reducing destratification efficiency.

At the end of the first restratification test, the lake had not returned to its former stable condition but had reached approximately 90 percent of the stability at the beginning of the first aeration test. The second aeration test was conducted at an induced aeration rate of 54 cfm of air input compared to 100 cfm in the first test. Comparing the first 74 hours of each test shows that the destratification efficiency of the second test was almost twice that of the first test, again indicating an excess of energy used in the first test.

TABLE III

COMPARISON OF VARIOUS DESTRATIFICATION EFFICIENCIES[5]

Lake (1)	Stability: Before Aeration Kw-hr (2)	Stability: After Destratification Kw-hr (3)	Stability Decrease Kw-hr (4)	Approximate Total Energy Used Kw-hr (5)	Energy Used Per Unit Lake Volume Kw-hr/acre-ft. (6)	Destratification Efficiency (Column 4÷5) Percent (7)
Lake Roberts	2.02[a]	0.47[a]	1.55[a]	1120[a]	1.1[a]	0.14[a]
70 acres	2.02[b]	0.38[b]	1.64[b]	3630[b]	3.7[b]	0.04[b]
980 acre-ft.	2.02[c]	0.14[c]	1.88[c]	6980[c]	7.1[c]	0.03[c]
Max. depth, 30ft.	1.78[d]	0.49[d]	1.29[d]	1930[d]	2.0[d]	0.07[d]
Boltz Lake 96 acres 2400 acre-ft. Max. depth, 60ft.	44.4[e]	11.8[e]	32.6-13=19.6[f]	14300[e]	5.9[e]	0.14[e]
Lake Wohlford 130 acres 2500 acre-ft. Max. Depth, 50ft.	14.7[g]	1.1[g]	13.6[g]	2910[g]	1.2[g]	0.47[g]
Wahnback Reservoir 530 acres 33740 acre-ft. Max. depth, 141ft.	400[g]	0[g]	400[g]	104,800[g]	3.1[g]	0.38[g]

[a] Aeration Phase No. 1, after 23 hours at 100 cfm
[b] Aeration Phase No. 1, after 74 hours at 100 cfm
[c] Aeration Phase No. 1, after 144 hours and maximum accumulation of free oxygen at 100 cfm
[d] Aeration Phase No. 2, after 74 hours aeration at 54 cfm
[e] Using mechanical pump to lift bottom water to surface
[f] Stability decreased because of natural particle circulation
[g] Blowing in air on the bottom of the lake and discharging aerated water below hypolimnion

SECTION VII

ACKNOWLEDGMENTS

Sincere appreciation is expressed to the State of New Mexico and the Department of Game and Fish for their cooperation and participation in conducting this experiment on one of their trout-fishery lakes. Public relations and manpower effort provided by the research unit of the New Mexico Game and Fish Department allowed this research, which significantly added to the technology of reservoir destratification through induced aeration.

Special appreciation is expressed to Officers J. E. Syling, Dean Smith, and Robert Trippeer of the New Mexico State Police, whose diving service made possible safe installation of the air distribution system on the bottom of Lake Roberts.

Appreciation is expressed to the Kennacott Mining Corporation of Bayard, New Mexico, for the loan of an air compressor and air hose for the duration of the project. Without this valuable contribution, the study would have been difficult to complete.

SECTION VIII

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APPENDIX

TABLE I

AERATION CHANGES IN CHEMICAL PARAMETERS

Sta.	Date	Depth Feet	pH	Cond. umho/cm	Cl mg/l	SO4 mg/l	Total Solids mg/l	TD Solids mg/l	T-PO4 mg/l	Ortho PO4 mg/l
1	5-22-69	0	8.4	359	3.0	27.5	245	240	0.031	---
1	5-22-69	15	8.4	359	3.0	27.5	249	244	0.024	---
1	5-22-69	29	7.5	380	3.0	23.5	280	274	0.260	---
2	5-22-69	0	8.5	359	3.2	27.0	245	241	0.038	---
2	5-22-69	10	8.5	360	2.7	27.0	246	241	0.029	---
2	5-22-69	23	7.6	370	3.0	25.5	270	264	0.163	---
3	5-22-69	0	8.4	360	3.0	27.0	244	239	0.032	---
3	5-22-69	5	8.5	360	3.0	28.0	248	243	0.037	---
3	5-22-69	10	8.3	360	3.2	26.5	239	233	0.042	---
1	6-15-69	0	9.05	240	3.0	21.0	---	---	0.140	0.063
1	6-15-69	15	8.7	305	3.0	18.0	---	---	0.060	0.051
1	6-15-69	29	7.7	425	3.0	8.0	---	---	0.407	0.396
2	6-15-69	0	9.1	250	3.0	8.0	---	---	0.068	0.003
2	6-15-69	10	9.0	265	3.0	19.0	---	---	0.046	0.021
2	6-15-69	24	7.4	410	3.0	12.0	---	---	0.367	0.342
3	6-15-69	0	9.3	245	3.0	18.0	---	---	0.056	0.012
3	6-15-69	5	8.8	290	3.0	14.0	---	---	0.025	0.015
3	6-15-69	10	8.0	320	3.0	13.0	---	---	0.100	0.063
1	6-18-69	0	9.0	300	3.0	27.0	---	---	0.086	0.007
1	6-18-69	15	8.3	325	3.0	27.0	---	---	0.086	0.006
1	6-18-69	29	7.7	365	3.0	27.0	---	---	0.093	0.022
2	6-18-69	0	9.2	265	4.0	28.0	---	---	0.130	0.012
2	6-18-69	12	8.6	290	3.0	26.0	---	---	0.073	0.011
2	6-18-69	24	7.6	360	4.0	26.0	---	---	0.066	0.019
3	6-18-69	0	---	---	4.0	29.0	---	---	0.071	0.004
3	6-18-69	10	---	---	4.0	27.0	---	---	0.097	0.011
1	6-22-69	0	8.65	305	3.0	26.0	---	---	0.057	0.008
1	6-22-69	15	8.65	315	3.0	28.0	---	---	0.067	0.008
1	6-22-69	29	8.65	310	3.0	31.0	---	---	0.065	0.017
2	6-22-69	0	8.65	305	4.0	28.0	---	---	0.105	0.006
2	6-22-69	12	8.65	315	3.0	28.0	---	---	0.047	0.008
2	6-22-69	23	8.65	305	3.0	28.0	---	---	0.036	0.020
3	6-22-69	0	8.81	305	4.0	27.0	---	---	0.056	0.006
3	6-22-69	10	8.65	310	4.0	27.0	---	---	0.051	0.008

TABLE I--Continued

NH_3-N mg/1	T-Nitrogen mg/1	NO_2-N mg/1	NO_3-N mg/1	H_2S mg/1	Fe mg/1	Mn mg/1	Cn mg/1	Ca mg/1	Mg mg/1
---	---	---	---	0	---	---	---	56.0	9.9
---	---	---	---	0	---	---	---	56.0	9.5
---	---	---	---	0.5[1]	---	---	---	58.5	9.7
---	---	---	---	0	---	---	---	55.5	9.6
---	---	---	---	0	---	---	---	56.0	9.7
---	---	---	---	0	---	---	---	56.5	9.7
---	---	---	---	0	---	---	---	53.5	9.5
---	---	---	---	0	---	---	---	55.5	9.7
---	---	---	---	0	---	---	---	56.5	9.5
0.17	1.8	<.03	<.03	0	.26	.14	---	---	---
0.15	0.5	<.03	<.03	0.05	.23	.22	---	---	---
1.11	1.3	<.03	<.03	2.60	.19	2.13	---	---	---
.09	0.9	<.03	<.03	0.00	.23	.15	---	---	---
.09	0.8	<.03	<.03	0.10	.22	.16	---	---	---
1.20	1.2	<.03	<.03	2.65	.16	2.10	---	---	---
0.08	0.8	<.03	<.03	0.15	.18	.15	---	---	---
0.10	0.7	<.03	<.03	0.10	.22	.18	---	---	---
0.24	0.4	<.03	<.03	0.00	.24	.50	---	---	---
0.16	0.7	<.03	<.03	0.35	.20	.67	<.02	---	---
0.18	0.8	<.03	<.03	---	.31	.67	<.02	---	---
0.16	0.8	<.03	<.03	1.80	.22	.68	<.02	---	---
0.18	0.9	<.03	<.03	0	.21	.48	<.02	---	---
0.13	0.7	<.03	<.03	0.1	.21	.62	<.02	---	---
0.25	0.7	<.03	<.03	1.75	.23	.76	<.02	---	---
0.07	0.8	<.03	<.03	0.02	.18	.52	<.02	---	---
0.07	0.7	<.03	<.03	0.02	.23	.50	<.02	---	---
0.17	0.7	<.03	<.03	0	---	---	---	---	---
0.15	0.7	<.03	<.03	0	---	---	---	---	---
0.42	0.9	<.03	<.03	0	---	---	---	---	---
0.14	0.8	<.03	<.03	0	---	---	---	---	---
0.18	0.8	<.03	<.03	0	---	---	---	---	---
0.14	0.8	<.03	<.03	0	---	---	---	---	---
0.13	0.5	<.03	<.03	0	---	---	---	---	---
0. 08	0.6	<.03	<.03	0	---	---	---	---	---

[1]Hack Test

TABLE I--Continued

Sta.	Date	Depth Feet	pH	Cond. umho/cm	SO_4 mg/l	Total Solids mg/l	TD Solids mg/l	T-PO4 mg/l	Ortho PO4 mg/l	NH_3-N mg/l
1	6-30-69	0	9.25	280	33	---	---	0.260	0.008	0.12
1	6-30-69	15	8.7	300	29	---	---	0.031	0.030	0.18
1	6-30-69	29	8.0	320	27	---	---	0.241	0.203	0.48
2	6-30-69	0	9.3	280	39	---	---	0.275	0.007	0.14
2	6-30-69	12	8.8	305	28	---	---	0.072	0.036	0.21
2	6-30-69	23	8.5	320	28	---	---	0.125	0.079	0.41
3	6-30-69	0	9.28	300	30	---	---	0.037	0.007	0.11
3	6-30-69	10	8.85	320	30	---	---	0.042	0.042	0.23
1	7-9-69	0	9.3	295	30	---	---	0.093	0.004	0.14
1	7-9-69	15	8.0	320	27	---	---	0.110	0.023	0.42
1	7-9-69	29	7.6	350	26	---	---	0.156	0.093	0.96
2	7-9-69	0	9.4	295	30	---	---	0.131	0.006	.14
2	7-9-69	12	8.4	320	27	---	---	0.109	0.065	.42
2	7-9-69	24	8.1	345	23	---	---	0.209	0.153	.96
3	7-9-69	0	9.4	300	29	---	---	0.089	0.009	0.15
3	7-9-69	10	8.7	320	26	---	---	0.191	0.100	0.50
1	7-16-69	0	7.95	345	25	---	---	0.223	0.055	0.46
1	7-16-69	15	7.80	345	25	---	---	0.195	0.055	0.43
1	7-16-69	29	7.75	345	26	---	---	0.195	0.055	0.53
2	7-16-69	0	7.90	345	27	---	---	0.173	0.043	0.43
2	7-16-69	20	7.95	350	25	---	---	0.182	0.053	0.44
2	7-16-69	23	7.90	355	26	---	---	0.226	0.074	0.50
3	7-16-69	0	7.9	340	25	---	---	0.207	0.038	.43
3	7-16-69	5	---	---	25	---	---	0.185	0.043	---
3	7-16-69	10	7.85	340	24	---	---	0.182	0.045	.48
1	8-3-69	0	8.1	340	23	---	---	0.325	0.250	0.34
1	8-3-69	15	8.1	335	25	200	192	0.120	0.060	0.32
1	8-3-69	29	8.1	330	25	200	189	0.130	0.056	0.38
2	8-3-69	0	8.1	320	25	---	---	0.180	0.100	0.30
2	8-3-69	12	7.9	325	24	---	---	0.130	0.055	0.33
2	8-3-69	24	7.85	325	25	199	191	0.135	0.059	0.31
3	8-3-69	0	8.1	325	24	---	---	0.160	0.072	0.30
3	8-3-69	10	8.1	325	24	196	187	0.120	0.057	0.28
1	10-15-69	0	7.7	280	---	310	300	0.143	0.080	0.12
1	10-15-69	10	8.2	280	---	255	241	0.165	0.120	0.09
1	10-15-69	29	7.9	300	---	268	247	0.226	0.140	0.11
2	10-15-69	0	7.7	290	---	265	247	0.145	0.075	0.09
2	10-15-69	12	7.8	300	---	267	254	0.160	0.076	0.09
2	10-15-69	24	7.85	290	---	306	285	0.167	0.086	0.07
3	10-15-69	0	7.7	290	---	299	280	0.176	0.084	0.18
3	10-15-69	10	7.7	300	---	250	229	0.199	0.082	0.09

TABLE I--Continued

Total Nitrogen mg/l	NO_2-N mg/l	NO_3-N mg/l	H_2S mg/l	Fe mg/l	Mn mg/l	Cn mg/l	COD mg/l	BOD mg/l
1.8	<.03	≤03	0	.51	.39	<.02	---	---
0.7	<.03	<.03	0	.36	.50	<.02	---	---
1.4	<.03	<.03	.3	.38	1.15	<.02	---	---
1.9	<.03	<.03	0	.66	.35	<.02	---	---
1.4	<.03	<.03	0	.34	.51	<.02	---	---
1.4	<.03	<.03	0.09	.33	.68	<.02	---	---
1.1	<.03	<.03	0	.41	.31	<.02	---	---
0.7	<.03	<.03	0	.43	.49	<.02	---	---
1.02	<.03	<.03	0	.13	.27	---	---	---
0.92	<.03	<.03	0	.13	.72	---	---	---
1.27	<.03	<.03	0.45	.18	1.15	---	---	---
1.22	<.03	<.03	0	.13	.28	---	---	---
1.01	<.03	<.03	0	.18	.52	---	---	---
1.45	<.03	<.03	1.2	.19	1.03	---	---	---
1.05	<.03	<.03	---	0.14	0.30	---	---	---
1.10	<.03	<.03	---	0.21	0.69	---	---	---
1.34	<.03	<.03	1.10	0.13	0.09	---	---	*
1.30	<.03	<.03	1.35	0.13	0.15	---	---	*
1.28	<.03	<.03	1.45	0.135	0.11	---	---	*
1.40	<.03	<.03	1.15	.15	.17	---	---	*
1.30	<.03	<.03	1.45	.15	.16	---	---	*
1.40	<.03	<.03	1.95	.12	.11	---	---	*
1.38	<.03	<.03	1.05	.15	.08	---	---	*
1.38	<.03	<.03	---	.15	.11	---	---	*
1.34	<.03	<.03	1.25	.15	.09	---	---	*
0.90	<.03	<.03	0	.06	.70	---	---	---
0.80	<.03	<.03	0	.06	.70	---	---	---
0.90	<.03	<.03	0	.04	.75	---	---	---
0.90	<.03	<.03	0	.03	.70	---	27	---
0.90	<.03	<.03	0	.04	.64	---	24	---
0.90	<.03	<.03	0.2	.13	.70	---	29	---
0.80	<.03	<.03	---	.08	.64	---	---	---
1.00	<.03	<.03	---	.08	.67	---	---	---
0.6	---	<.03	---	0.10	0.46	---	---	5.1
0.7	---	<.03	---	0.08	0.46	---	---	6.6
0.7	---	<.03	---	0.20	0.46	---	---	6.4
0.6	---	<.03	---	0.08	0.48	---	---	7.1
0.6	---	<.03	---	0.15	0.47	---	---	6.3
0.6	---	<.03	---	0.05	0.48	---	---	4.3
0.6	---	<.03	---	0.08	0.46	---	---	12.0
0.7	---	<.03	---	0.10	0.47	---	---	6.5

*Dilutions too low, less than 4 mg/l BOD at all Stations

TABLE II

AERATION EFFECTS ON TRACE METALS

Sta.	Date	Depth Ft.	Zn ug/l	Cd ug/l	B ug/l	Fe ug/l	Mo ug/l	Sn ug/l	Mn ug/l	CU ug/l	Ag ug/l	Ni ug/l	Al ug/l	Pb ug/l	Cr ug/l	Ba ug/l	Sr ug/l
1	5-22-69	0	<60	<20	<20	10	<20	<60	60	<10	<10	<20	<10	<60	<20	<10	34
1	5-22-69	15	<60	<20	34	40	<20	<60	160	10	<10	<20	60	<60	<20	<10	80
1	5-22-69	29	<60	<20	46	20	<20	<60	1040	10	<10	<20	32	<60	<20	22	72
2	5-22-69	0	<60	<20	<20	14	<20	<60	84	10	<10	<20	<10	<60	<20	<10	38
2	5-22-69	10	<60	<20	20	22	<20	<60	108	<10	<10	<20	32	<60	<20	<10	48
2	5-22-69	23	<60	<20	64	20	<20	<60	620	10	<10	<20	36	<60	<20	22	104
3	5-22-69	0	<60	<20	20	14	<20	<60	100	20	<10	<20	17	<60	<20	<10	38
3	5-22-69	5	<60	<20	40	16	<20	<60	100	26	<10	<20	<10	<60	<20	<10	44
3	5-22-69	10	<60	<20	54	32	<20	<60	190	15	<10	<20	76	<60	<20	22	84
1	6-18-69	0	<60	<20	180	130	<20	<60	620	<10	<10	<20	170	<60	<20	<10	85
1	6-18-69	15	<60	<20	100	110	<20	<60	560	<10	<10	<20	145	<60	<20	<10	85
1	6-18-69	29	<60	<20	120	110	<20	<60	580	<10	<10	<20	145	<60	<20	<10	80
2	6-18-69	0	<60	<20	120	80	<20	<60	460	<10	<10	<20	80	<60	<20	<10	60
2	6-18-69	10	<60	<20	130	100	<20	<60	420	<10	<10	<20	100	<60	<20	<10	60
2	6-18-69	24	<60	<20	90	120	<20	<60	480	<10	<10	<20	160	<60	<20	<10	70
3	6-18-69	0	<60	<20	120	90	<20	<60	420	<10	<10	<20	90	<60	<20	<10	70
3	6-18-69	10	<60	<20	85	110	<20	<60	420	<10	<10	<20	130	<60	<20	<10	60

TABLE III

PLANKTON ANALYSIS

Organisms Collected October 15, 1969	Sta.#1 Surface	Sta.#1 15'	Sta.#1 30'	Sta.#5 Surface	Sta.#5 Bottom
Number of Kinds	18	18	21	16	20
Number/Milliliter	1646	1876	1845	1820	1816
Chlorophyta-green					
Ankistrodesmus sp.	28	28	28	57	28
Bascicladia sp.	--	--	28	--	--
Chlamydomonas sp.	28	57	57	85	57
Gonatozygon sp.	--	--	28	--	--
Oocystis sp.	57	28	28	57	28
Planktospheria sp.	28	28	--	57	28
Polyblepharides sp.	57	228	114	114	142
Polytomella sp.	28	114	114	114	199
Spirogyra sp.	199	142	114	85	285
Rhizoclonium sp.	--	57	57	85	28
Chrysophyta-yellow-brown					
Amphora sp.	28	--	--	--	28
Epithemia sp.	--	--	28	--	28
Fragilaria sp.	85	28	85	--	--
Mallomonas sp.	57	28	28	85	57
Navicula sp.	--	--	28	--	28
Nitzschia sp.	--	28	--	--	--
Synedra sp.	--	--	--	28	--
Tribonema sp.	256	199	256	114	199
Uroglenopsis sp.	28	57	--	57	28
Melosira sp.	--	28	28	--	28
Cyanophyta-blue-green					
Oscillatoria sp.	28	--	57	85	28
Euglenophyta-euglenoid					
Euglena sp.	--	--	28	--	--
Lepocinclis sp.	--	--	--	--	28
Rhabdomonas sp.	28	57	85	57	57
Trachelomonas sp.	28	--	28	--	--
Pyrrophyta-dinoflagellates					
Ceratium sp.	627	684	598	712	484
Protozoa-single-celled animal					
Strombidium sp.	28	28	28	28	28
Rotatoria-wheeled-animacules					
Asplanchna sp.	--	57	--	--	--
Trichocera sp.	28	--	--	--	--

NOTE: Two strip count at 10x10x2 power with conversion factor equaling number individuals counted times 28.5=No./Ml.

TABLE III

PLANKTON ANALYSIS

Organisms Collected October 15, 1969	Sta.#1 Surface	Sta.#1 15'	Sta.#1 30'	Sta.#5 Surface	Sta.#5 Bottom
Number of Kinds	18	18	21	16	20
Number/Milliliter	1646	1876	1845	1820	1816
Chlorophyta-green					
Ankistrodesmus sp.	28	28	28	57	28
Bascicladia sp.	--	--	28	--	--
Chlamydomonas sp.	28	57	57	85	57
Gonatozygon sp.	--	--	28	--	--
Oocystis sp.	57	28	28	57	28
Planktospheria sp.	28	28	--	57	28
Polyblepharides sp.	57	228	114	114	142
Polytomella sp.	28	114	114	114	199
Spirogyra sp.	199	142	114	85	285
Rhizoclonium sp.	--	57	57	85	28
Chrysophyta-yellow-brown					
Amphora sp.	28	--	--	--	28
Epithemia sp.	--	--	28	--	28
Fragilaria sp.	85	28	85	--	--
Mallomonas sp.	57	28	28	85	57
Navicula sp.	--	--	28	--	28
Nitzschia sp.	--	28	--	--	--
Synedra sp.	--	--	--	28	--
Tribonema sp.	256	199	256	114	199
Uroglenopsis sp.	28	57	--	57	28
Melosira sp.	--	28	28	--	28
Cyanophyta-blue-green					
Oscillatoria sp.	28	--	57	85	28
Euglenophyta-euglenoid					
Euglena sp.	--	--	28	--	--
Lepocinclis sp.	--	--	--	--	28
Rhabdomonas sp.	28	57	85	57	57
Trachelomonas sp.	28	--	28	--	--
Pyrrophyta-dinoflagellates					
Ceratium sp.	627	684	598	712	484
Protozoa-single-celled animal					
Strombidium sp.	28	28	28	28	28
Rotatoria-wheeled-animacules					
Asplanchna sp.	--	57	--	--	--
Trichocera sp.	28	--	--	--	--

NOTE: Two strip count at 10x10x2 power with conversion factor equaling number individuals counted times 28.5=No./Ml.

1 Accession Number	2 Subject Field & Group	SELECTED WATER RESOURCES ABSTRACTS
	05G	INPUT TRANSACTION FORM

5 Organization

Environmental Protection Agency, Water Quality Office
Robert S. Kerr Water Research Center
Ada, Oklahoma

6 Title

INDUCED AERATION OF SMALL MOUNTAIN LAKES,

10 Author(s)

Leach, Lowell E, and
Harlin, Curtis C., Jr.

16 Project Designation

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21 Note

22 Citation

23 Descriptors (Starred First)

*Water quality control, *Aeration, Impoundments, Stratification, Water circulation, Oxygenation, Economic efficiency

25 Identifiers (Starred First)

*Destratification, Nutrient suppression

27 Abstract

Summer stratification in small mountain trout-fishery lakes restricts trout habitat to the thin layer of surface water. As atmospheric temperatures increase during later summer months, the epilimnion waters reach temperatures intolerable for trout. A technique of managing trout-fishery lakes, through introduction of compressed air, was studied at Lake Roberts in southern New Mexico during the summer of 1969. Research was conducted to determine the feasibility of induced aeration to control nutrient stratification and dissipation of high-bottom concentrations of hydrogen sulfide. The oxygenation efficiency of the induced aeration system was evaluated, and futher research required for optimum development of the systems as management tools for trout-fishery lakes is discussed.

Abstractor Lowell E. Leach

Institution Robert S. Kerr Water Research Center, Environmental Protection Agency,

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