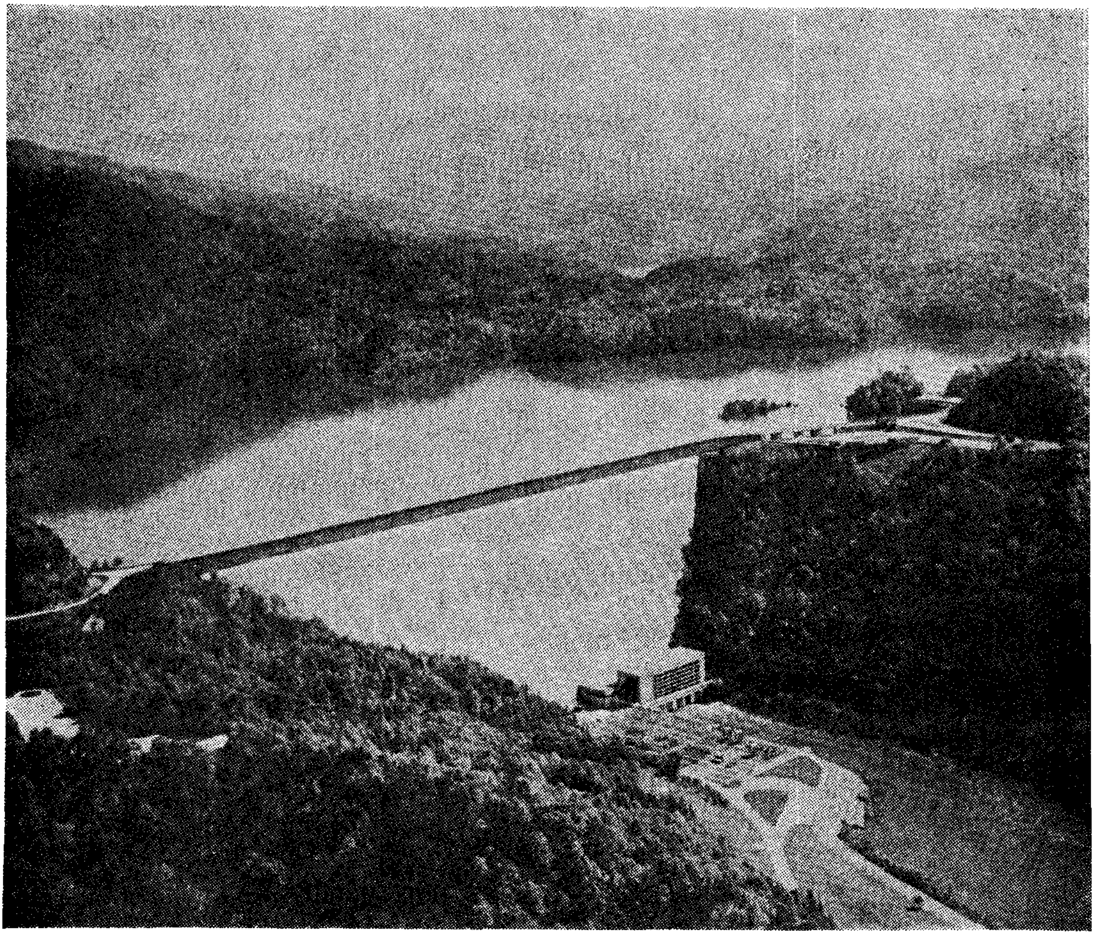
SOME INTERESTING LIMNOLOGICAL ASPECTS OF FONTANA RESERVOIR[1]



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ABSTRACT

Fontana Reservoir, located in the mountains of western North Carolina, covers 10,670 surface acres at full pool elevation of 1,710 feet. The reservoir is approximately 29 miles long, has 248 miles of shoreline, a maximum depth of 440 feet, and three influent rivers, the Nantahala, Little Tennessee, and Tuckaseigee.

[1] Contribution from Federal Aid to Fish Restoration Funds under Dingell-Johnson Project F-16-R, State of North Carolina.

Temperature and chemical profiles were taken monthly from June 1964 through December 1965 at five permanent sampling stations. It was concluded from the study that: (1) During the summer, the Nantahala River water flows below the warmer Little Tennessee and Tuckaseigee River waters; (2) Two steep temperature gradients meeting the requirements of a thermocline definition were formed in Fontana Reservoir during each annual cycle; (3) No significant variations of alkalinity nor carbon dioxide concentrations were found in the reservoir; (4) Anaerobic decomposition of sludge deposits in the Tuckaseigee River arm resulted in the formation of a stratum of anoxic water in the main reservoir; (5) The anoxic water stratum was found to reach the penstocks in October at about the time of the fall overturn; and (6) At least five percent of the total reservoir capacity is removed from fish productivity by a complete absence of oxygen.

INTRODUCTION

Fontana Reservoir, impounded by the Tennessee Valley Authority in 1944, lies in Swain and Graham Counties, North Carolina. It is bordered on the north by the Great Smoky Mountains National Park, on the west by Cheoah Reservoir, on the east by the Tuckaseigee River Valley, and on the south by the Cheoah Mountains and the Nantahala National Forest.

At spillway elevation of 1,710 feet, Fontana Reservoir has a surface area of 10,670 acres, a maximum depth of 440 feet, a maximum width of 0.6 mile, a shoreline length of 248 miles, and holds 1,444,300-acre feet. The reservoir has steep sides, many small coves, and the bottom consists of rock, gravel, silt and debris. In the normal annual operating cycle, the reservoir is drawn down during the fall and winter months to provide flood storage and refilled in the spring. The average annual fluctuation in water surface elevation approximates 130 feet.

Fontana Reservoir's watershed has a drainage area of 1,571 square miles with its principal influent streams being the Nantahala, Little Tennessee, and Tuckaseigee Rivers. Other important feeder streams include Hazel, Eagle, Forney, Sawyer, Noland, Panther and Alarka Creeks all of which are cold, clear mountain streams. The average monthly inflow into the reservoir ranges from 2,643 to 10,081 second-feet whereas the average monthly discharge from the reservoir ranges between 3,145 and 7,318 second-feet. The greatest amount of rainfall occurs in March, April, and July.

Temperature and chemical profiles were determined monthly from June 1964 through December 1965 to determine the various chemical and physical characteristics of the reservoir waters.

METHODS AND PROCEDURES

Five permanent, mid-channel sampling stations were selected at five-mile intervals throughout the main part of the reservoir. These five stations were located off Points 2, 5, 8, 14 and in the lower end of the Tuckaseigee River arm (Figure 1). During periods of suspected low dissolved oxygen content at the penstock level, additional samplings were made 100 feet up-reservoir from the dam as well as in the three major influent streams.

The monthly sampling from surface to bottom at each station included temperature, dissolved oxygen, carbon dioxide, total alkalinity, and pH. In addition, electrical conductivity readings were recorded in the June through December 1965 samples. Temperatures were taken with a Whitney resistance thermometer at two-foot intervals for the first 20 feet and at five-foot intervals thereafter. Water for chemical analyses was collected with a Foerst water sampler and analyzed according to "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes."[2] These samples were taken at five-foot intervals of depth to 40 feet, at 10-foot intervals from 40 to 100 feet, and at 20-foot intervals below 100 feet. If a stratum of low dissolved oxygen concentration was encountered, additional samples were taken to identify its exact limits.

[2] Methods were taken from "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes," Tenth Edition, American Public Health Association, et al. 1955.

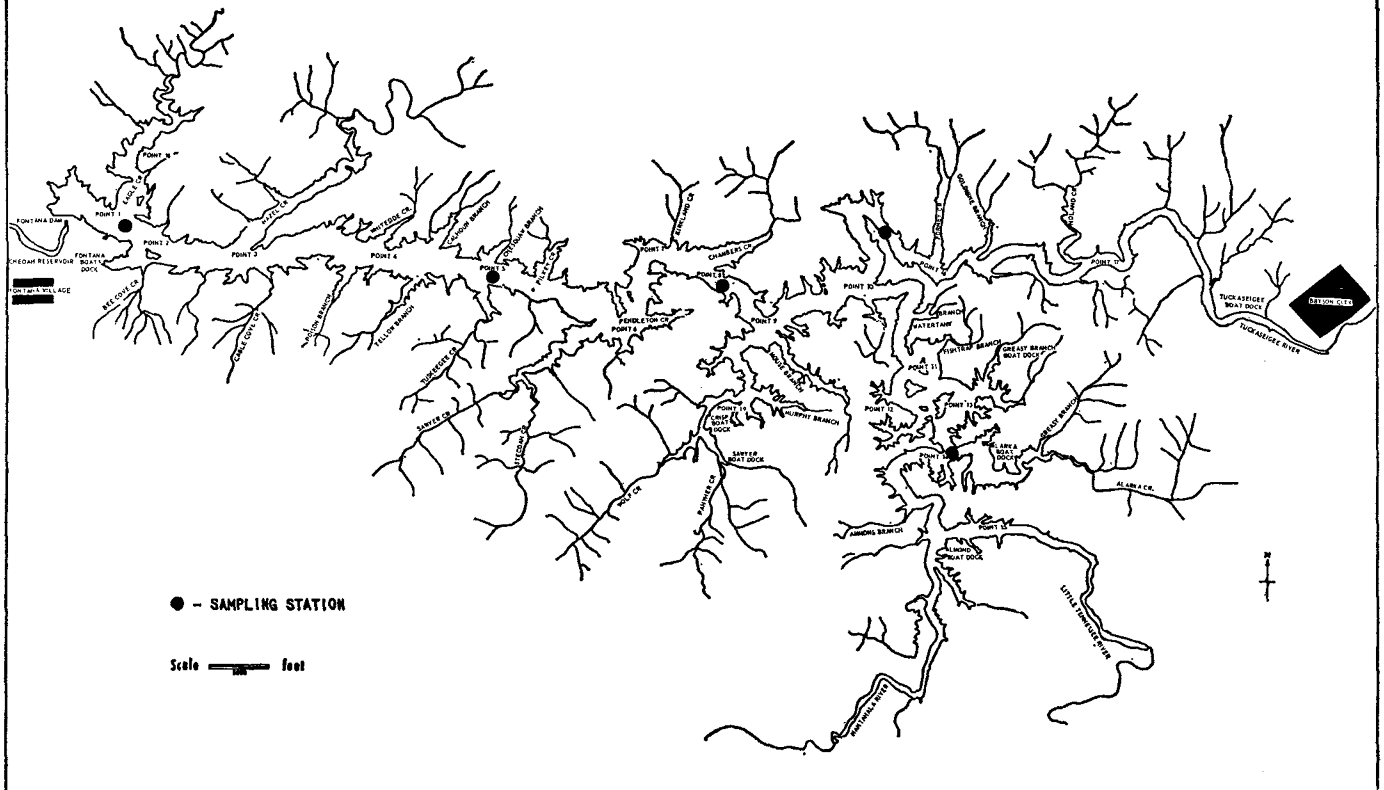

FIGURE I. Fontana Reservoir showing primary sampling locations.

RESULTS AND DISCUSSION

Temperature

The Fontana powerhouse penstock centerline is located 247 feet below spillway elevation. Water temperatures within the reservoir are strongly influenced by the location of the penstock openings, by the extreme depth of the impoundment, and by the characteristics of the three influent rivers, the Nantahala, Little Tennessee, and Tuckaseigee.

Surface water temperatures ranged between 32° F. and 82° F. during the period June, 1964 through December, 1965 (Figures 2-4). Bottom water temperatures near the dam were very stable and fluctuated less than 2° F., during the study period. During much of the summer, a temperature differential of about 40° F. was present between surface and bottom waters.

Water entering the reservoir in winter ranged generally between 32° F. and 45° F. with the Little Tennessee River contributing the colder waters. Water from the Little Tennessee watershed is influenced directly by climatic conditions whereas Nantahala River water is warmer in winter and colder in summer because of the retention and subsequent release of water stored in Nantahala Reservoir, an impoundment 15 miles above the Fontana backwater. Tuckaseigee River water tempera-

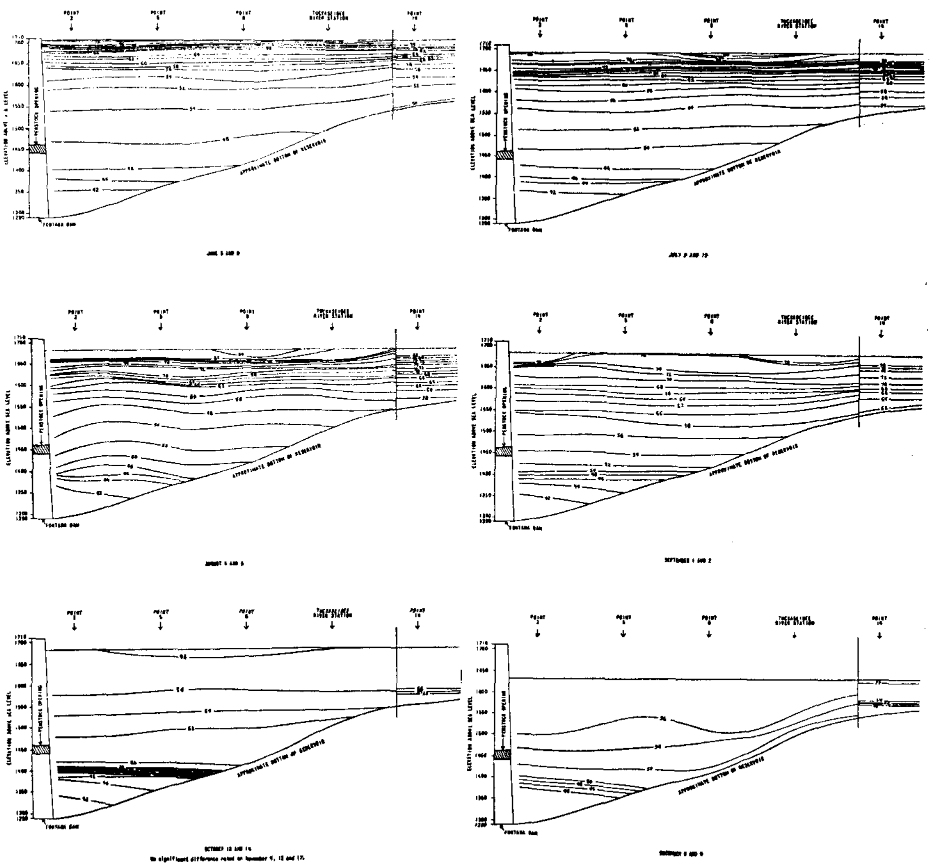

FIGURE 2. Isotherms (Degrees Fahrenheit), Fontana Reservoir, 1964.

tures were usually intermediate due probably to the effect of six headwater impoundments which are located much farther from Fontana backwater than is Nantahala Reservoir. The leveling effect of these distant reservoirs upon water temperatures reaching Fontana are less than in the Nantahala system.

Fontana Reservoir water ranges generally between 40° F. and 50° F. during January, February, and March except for periods when cold weather may lower the surface temperature. As the inflowing waters become warmer in April, they spread over the surface of the colder winter-storage water. The transition between winter-storage water and summer-storage water is at about the 50° F. isotherm. Tuckaseigee and Little Tennessee Rivers contributed to the upper portion of the summer-storage pool. Nantahala River, however, remained cold because of stored winter water from Nantahala Reservoir and flowed beneath the warmer surface waters from the other two rivers.

During May, a thermocline began forming in the impoundment headwaters at about the 20-foot depth. Temperature differential was at its peak in July and August when as much as 3.6° F. change was meas-

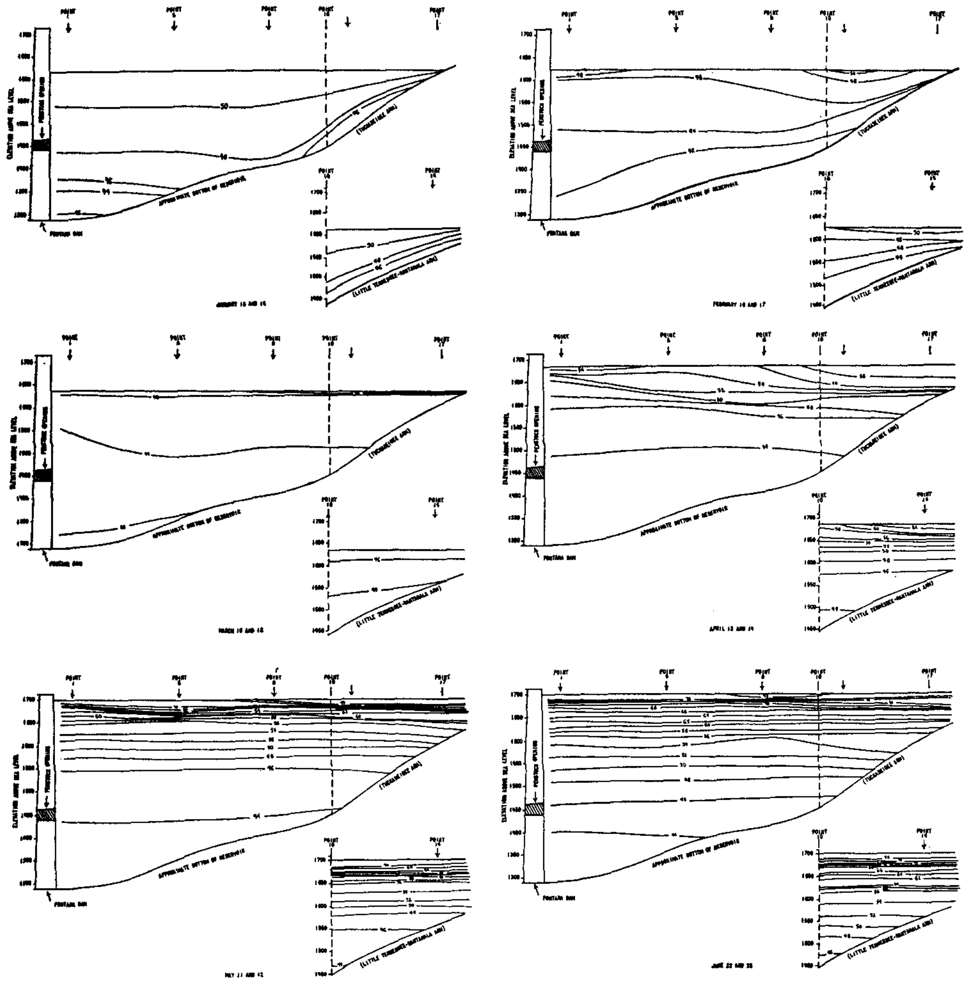

FIGURE 3. Isotherms (Degree Fahrenheit), Fontana Reservoir, 1965.

ured at depth intervals of one foot. The isotherms within and beneath the thermocline then gradually spread apart as the warm influent waters infiltrated the reservoir and the summer-storage layer grew thicker. At this stage there seemed to be three major strata within the reservoir.

The first strata, equivalent to an epilemnion, comprised warm surface water which was warmed by exposure to the sun and to summer temperatures. This layer extended to the thermocline and contained temperatures generally above 70° F.

The second layer extended from the thermocline downward to the winter-storage water. This layer contained most of the waters received during spring and summer which seemed to enter beneath the thermocline and gradually followed the winter-storage water downward until the top of the winter-storage layer reached the penstock level in **August.**

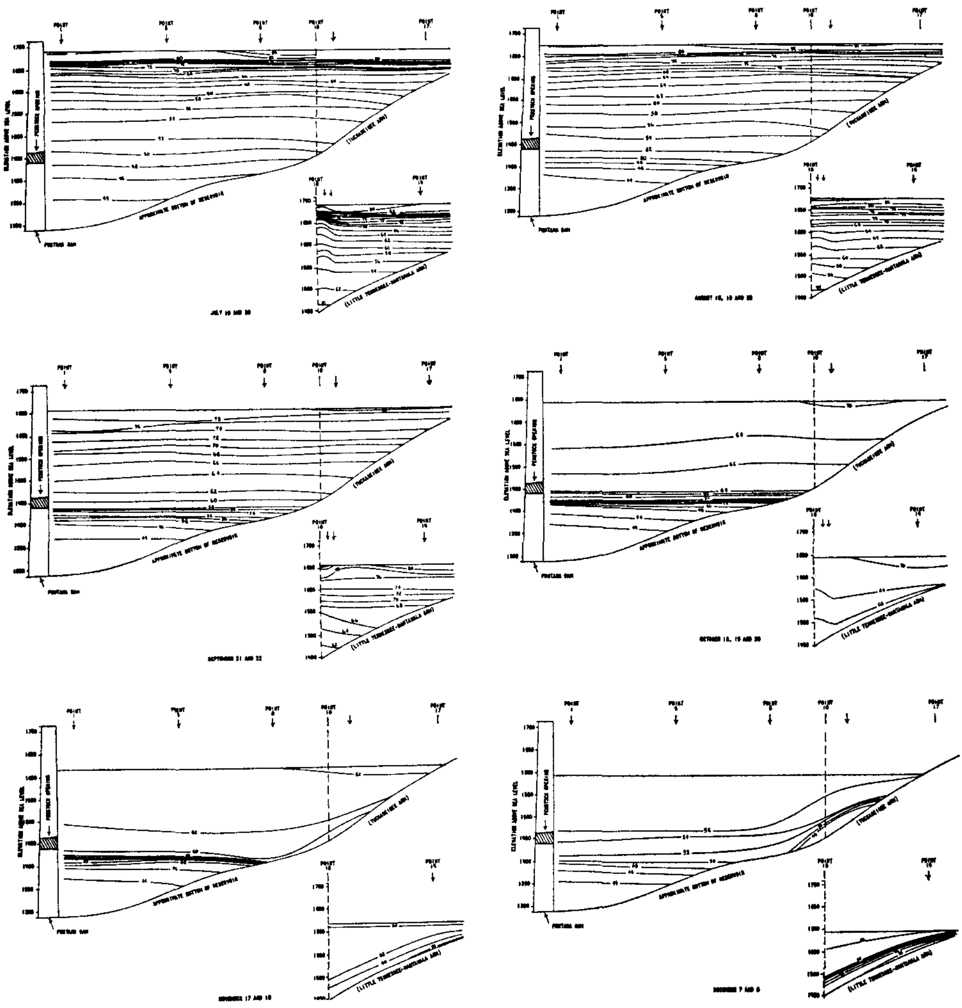

FIGURE 4. Isotherm (Degree Fahrenheit), Fontana Reservoir, 1965.

The third layer was composed of winter-storage water which was the principal effluent until August. After August, the only winter-storage water left was below the penstock level where it remained relatively stable until it was broken up by infiltrating winter water in December (Figures 2-4).

As summer progressed, the top layer grew warmer but did not thicken appreciably beyond 30 feet. Isotherms within the middle layer were gradually pushed downward as the warmer influent entered this layer. The lower portion of the middle layer started through the penstocks in August and continued until the fall overturn.

An interesting feature was the formation of a thermocline just below the penstock elevation during September and October. As the cool water of spring was drawn through the turbines and replaced by progressively warmer water, the temperature gradient between these waters and the top of the winter-storage water became much sharper with a maximum temperature differential of 7° F. over five-foot intervals of depth. This thermocline was not broken up during the fall overturn but remained intact until dispersed by cold inflow from mountain streams during mid-winter.

Hydrogen-Ion Concentration

The pH range in Fontana Reservoir during the period of study was 5.8 to 7.2. The strata above the thermocline usually showed higher pH values while lower pH values were roughly correlated with low dissolved oxygen concentrations.

Carbon Dioxide and Total Alkalinity

Carbon dioxide and total alkalinity concentrations showed no significant changes during the 19-month study period. Carbon dioxide ranged from trace readings to 30 ppm. Samples from the anoxic layer of water contained concentrations similar to other depths except those taken near the bottom.

Total alkalinity ranged between 0.0 and 40.0 ppm during the study. The infrequent readings over 30 ppm were from bottom water samples. Although no significant trends were discernable within the main body of the reservoir, influent waters of the Tuckaseigee River averaged 25 ppm total alkalinity during July through October 1965 while Nantahala River and Little Tennessee River waters exhibited concentrations of 14 and 15 ppm, respectively.

Conductivity

The conductivity of water samples from Fontana Reservoir were taken to obtain a possible clue to the conditions causing anoxia at mid-water depths. No significant correlation (R = –0.195) was obtained from 27 samples collected at intervals from surface to bottom comparing conductivity with dissolved oxygen concentrations. A comparison with carbon dioxide concentrations was also nonsignificant (R = –0.149).

In another comparison involving 74 samples from within the layer of reduced dissolved oxygen concentrations, a correlation was drawn between the conductivity and dissolved oxygen concentrations of less than 3.0 ppm. A highly significant correlation (R = 0.28) was obtained.

Dissolved Oxygen

Dissolved oxygen concentrations in Fontana Reservoir were generally more than 6 ppm during January except in strata below the penstock openings where residual waters contained low concentrations. Water samples collected during February, March, and April yielded dissolved oxygen concentrations between 7 and 15 ppm throughout the reservoir. The normal reduction of oxygen in bottom waters began during May (Figure 6).

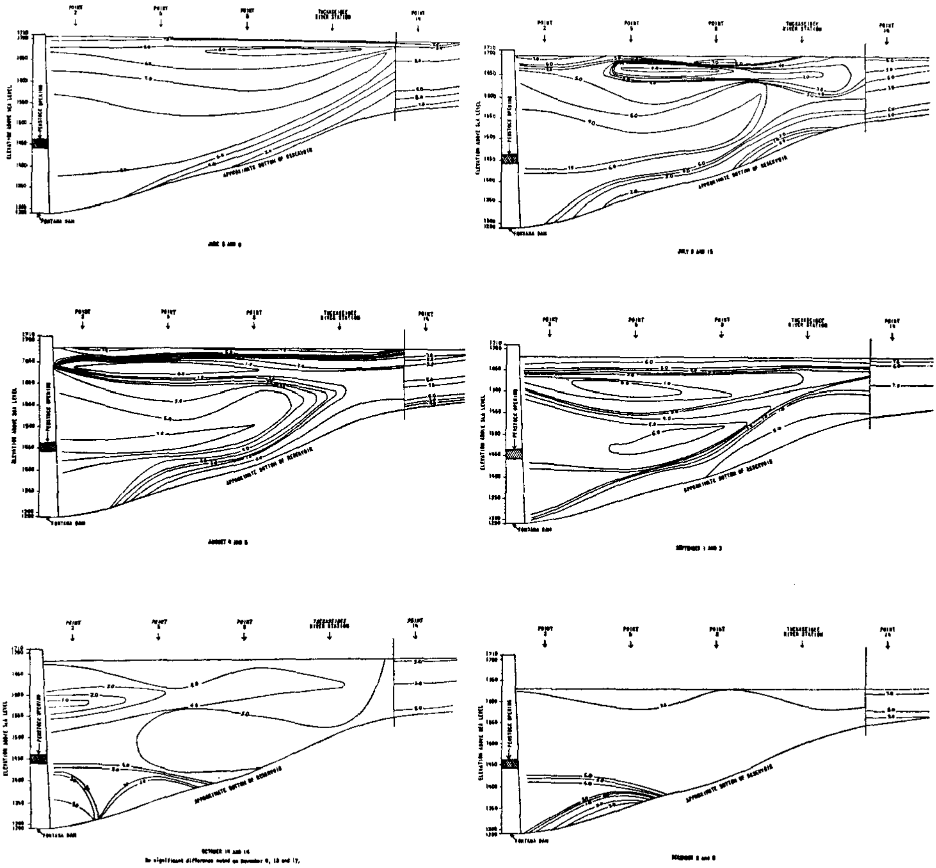

FIGURE 5. Distribution of dissolved oxygen, Fontana Reservoir, 1964.

The formation of a layer of water containing progressively small concentrations of dissolved oxygen began in May in the Tuckaseigee arm of the reservoir. Anoxia was evident in bottom waters in June and by August 20, only the surface strata to the 30-foot depth contained dissolved oxygen (Figures 5-7). The layer spread from the Tuckaseigee arm through the main body of the reservoir at about the 50-foot depth until the entire reservoir contained a continuously thickening layer of anoxic water which separated the upper strata from the lower strata. Surface waters and water below the anoxic layer contained dissolved oxygen concentrations ranging from 1 to 7 ppm. The layer beneath the anoxic stratum received continuous recruitment of high quality water from the Nantahala-Little Tennessee arm while at the other end of the reservoir this same layer was being withdrawn through the penstocks.

As the summer season progressed, the surface elevation of the reservoir was lowered by drawoff and the anoxic layer thickened as it was wedged deeper within the confines of the steep banks. A layer containing less than 3.0 ppm reached the penstock level on October 9, 1964 but was reaerated above 3.0 ppm dissolved oxygen within 300 yards downstream in the tailwater. In 1964 and 1965 the fall overturn occurred before the anoxic layer reached the penstocks.

The overturn mixed the reservoir to the penstock level and the

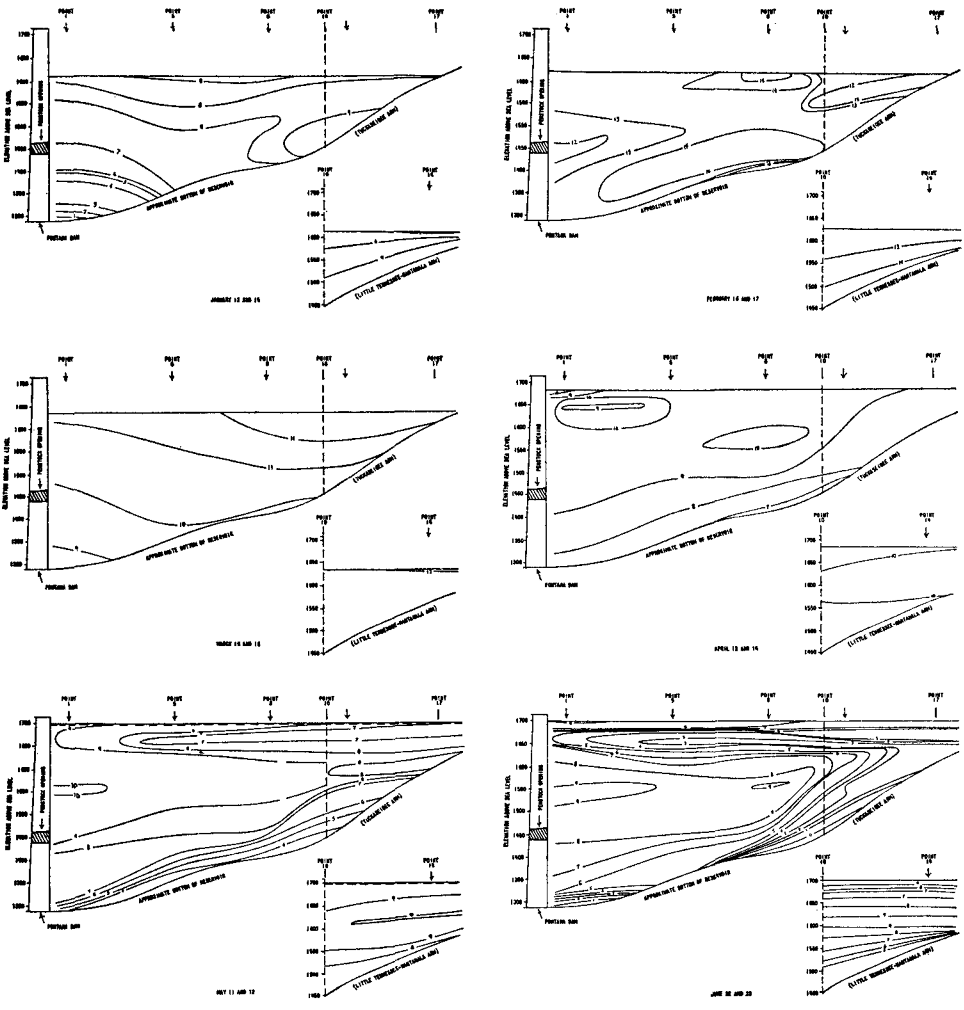

FIGURE 6. Distribution of dissolved oxygen, Fontana Reservoir, 1965.

anoxic layer was lost. Dissolved oxygen concentrations in the strata above the penstocks increased gradually throughout the winter. Concentrations below the penstocks remained static until February when the identity of the winter water was lost through infiltrations of cold water.

Municipal and perhaps some industrial pollutants in the Tuckaseigee River caused formation of sludge deposits in the Tuckaseigee arm of the reservoir during winter months. As the water warmed in spring, anoxic conditions developed on the bottom and anaerobic decomposition of the sludge took place. Gasses from the decomposition process caused floating sludge mats to form during April 1964 and 1965. The hydrolytic and rapidly oxidizable products formed by the anaerobic process created a very high oxygen demand which rapidly removed oxygen from the water. Oxygen was replaced in surface waters by algal photosynthesis and wind action. These factors were not effective beneath the thermocline, however, and any oxygen production below 30 feet was quickly tied up by hydrogen sulfide gas which was present in the anoxic layer.

The total effects of these conditions upon the fishery of Fontana Reservoir have not been determined. It is probable that the vertical movement of fishes is limited by the anoxic layer. Fishes might well become trapped below the layer and be forced to remain there until the fall overturn as the hydrogen sulfide in the strata as well as the anoxic condition is toxic. For all practical purposes fishes trapped below the anoxic strata are unavailable to the fishery for a period of about three months.

Another effect of considerable magnitude is the loss in productivity of the water from the Tuckaseigee River for a three-month period. All the water in the Tuckaseigee arm, except the upper 30 feet, is devoid of oxygen for about three months. Since the Tuckaseigee River represents about one-sixth of the total volume entering the reservoir, at least five percent of the total reservoir capacity is removed from the fishery by a complete absence of oxygen. The total loss of productivity can only be estimated but probably approaches 25 percent since the reservoir's most productive period is affected.

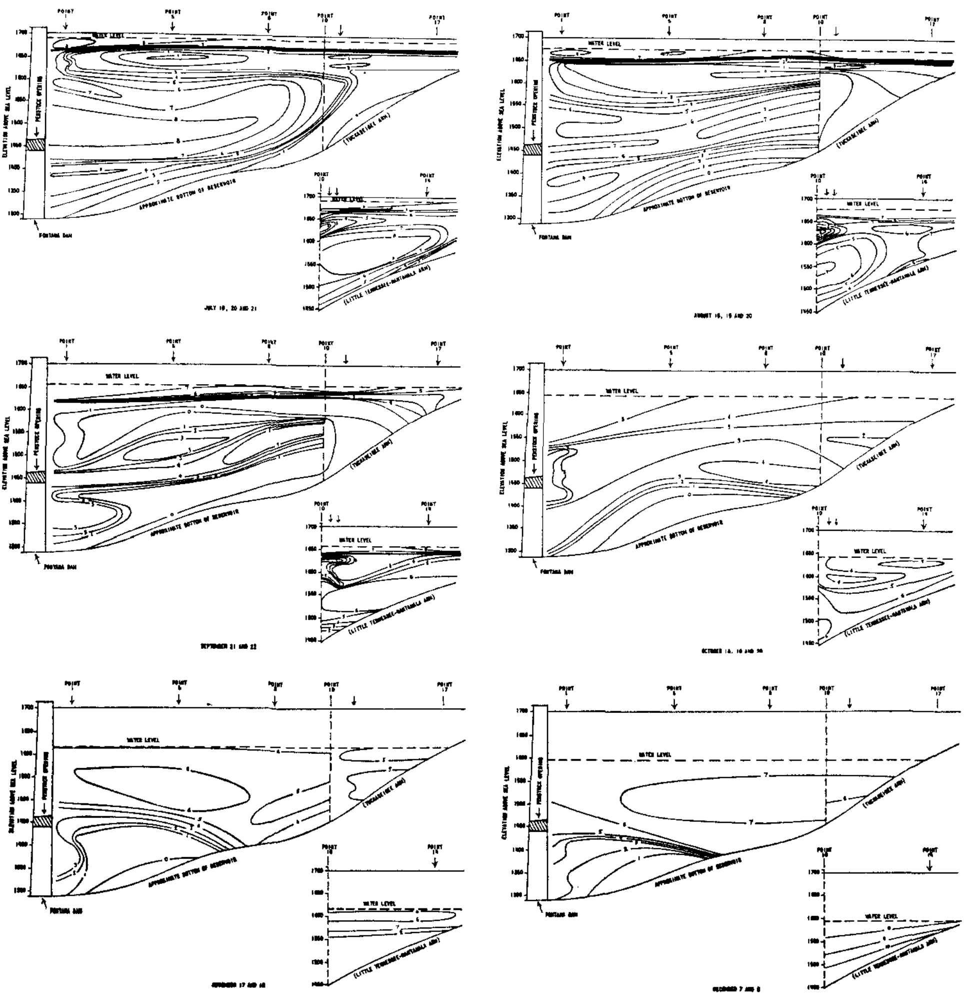

FIGURE 7. Distribution of dissolved oxygen, Fontana Reservoir, 1965.

CONCLUSIONS

1. Influent waters from the Nantahala River are warmer in winter and cooler in summer than the other streams flowing into Fontana Reservoir.
2. During the summer, Nantahala River water flows below the warmer Little Tennessee and Tuckaseigee River waters.
3. Two steep temperature gradients meeting the requirements of a thermocline definition were formed in Fontana Reservoir during each annual cycle.
4. No significant variations of alkalinity nor carbon dioxide concentrations were found in the reservoir.
5. Within a mid-water strata of reduced dissolved oxygen concentrations, a highly significant positive correlation was obtained between conductivity and dissolved oxygen concentrations.
6. Anaerobic decomposition of sludge deposits in the Tuckaseigee River arm resulted in the formation of a stratum of anoxic water in the main reservoir.
7. The anoxic water strata was found to reach the penstocks in October at about the time of the fall overturn.
8. At least five percent of the total reservoir capacity is removed from fish productivity by a complete absence of oxygen. The total productivity loss due to low water quality may approach 25 percent.

DISTRIBUTION AND ABUNDANCE OF THE CENTRARCHIDS IN THE RECENT DELTA OF THE MISSISSIPPI RIVER[1]

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ABSTRACT

Distribution and abundance of eight centrarchid fishes were studied on Delta National Wildlife Refuge from August, 1963 through January, 1965.

Gear used to collect the fish included rotenone, gill nets, trammel nets, bag seine, minnow seine and electric shocker. Standing crop samples were conducted using rotenone and block-off nets.

Salinity was a major factor which limited distribution of centrarchids on the refuge. Pond depth and turbidity were also factors affecting distribution and abundance. Oxygen, carbon dioxide, pH and alkalinity were found to be within suitable levels for fishes during sampling periods.

Spotted sunfish had the most diversified distribution of any centrarchid. Largemouth bass preferred the clearer, deeper waters. Warmouth occurred in more turbid waters than other centrarchids.

Centrarchids averaged 32.79 per cent of the total standing crop of fishes in area 1, 23.54 per cent in area 2 and 4.44 per cent in area 3. Centrarchidae represented the second largest family in number of species and first in poundage of fishes occurring on the study area. Redear sunfish, warmouth, spotted sunfish, black crappie and largemouth bass were the most abundant centrarchids in descending order.

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