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MECHANISMS OF DISSOLVED OXYGEN DEPLETION IN THE THERMOCLINE OF CENTER HILL RESERVOIR, TENNESSEE

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ABSTRACT

A six month preliminary study was conducted from June through November, 1973, to determine possible mechanisms of dissolved oxygen depletion in the thermocline of Center Hill Reservoir, Tennessee.

Water samples were collected from ten streams flowing into the reservoir and at six locations in the main channel of the reservoir on a bimonthly basis. The water samples collected were used to determine general chemical and physical parameters.

Statistical correlation studies of the data gives a good indication of the location of nutrient input from feeder streams in the reservoir main body. However, studies of phytoplankton productivity parameters of the epilimnion and parameters representing dissolved oxygen depletion in the thermocline indicate little or no significant correlation.

INTRODUCTION

Dissolved oxygen depletion in the thermocline and in the hypolimnion of large storage impoundments (reservoirs) has been one of great interest to biologists for many years. The studies to date do show evidence of a complex interrelationship such as the concentration of nutrient flow into the reservoir, among those being phosphates, nitrates, total hardness, total alkalinity, the morphology of the reservoir and of the surrounding watershed, the flow characteristics of the reservoir, detention time, plankton production and respiration, biochemical oxygen demand (BOD), outflow or discharge, penstock location and ever increasing urbanization.

It seems evident that D.O. concentration changes greatly in large deeper stratified bodies of water, due to integration of periodic changes in nutrient levels over an entire season—a desirable time span (Hooper 1969, Neel 1963).

In the selection of nutrient ions to be used in correlation studies with suspended solids, including phytoplanktonic growth, total phosphates and nitrates are the most thought of and used. However, there are other important indices. Sulfates, chloride, potassium and dissolved solids were used by Beeton as indices of eutrophication of the St. Lawrence-Great Lakes.

Taylor (1971) showed that short water retention time affects mainstream reservoir productivity by limiting the time for phytoplankton growth. The long water retention time of 150-250 days of the storage impoundments is most productive. Center Hill would be considered to have a long retention time, since it has a retention time of 140-150 days (Brown, 1974, personal communication).

Churchill and Nicholas (1966), Churchill (1958) found D.O. depletion of the thermocline in Boone Reservoir resulting from several important factors: (1) strong thermal stratification intensified by a density underflow of cold water into the reservoir, (2) phytoplankton in the warm epilimnion, (3) zooplankton at depths which reflected lowest D.O. concentration (in the thermocline depths) and (4) reaeration in the open river between South Holston Reservoir and Boone Reservoir that results in relatively high D.O. concentrations entering the pool. These "animals" graze on the phytoplankton present. The quantity of oxygen used by the zooplankters in respiration exceeds that produced by phytoplanktonic photosynthesis in that depth zone (20-40 ft. or 6-12m) where zooplankton concentrations are relatively high.

In the late summer months of 1972, the thermocline of Center Hill Reservoir showed marked D.O. depletion, more than the hypolimnion. The greatest depletion was at approximately 12m (Austin, 1974).

In this study, it was hypothesized that the D.O. depletion in the thermocline of Center Hill is due partially to: (1) nutrient inflow from the feeder streams enhancing epilimnial productivity represented by suspended solids, and (2) organic matter precipitating or sinking from the epilimnial stratum of the reservoir producing a biochemical oxygen demand in the thermocline.

MATERIALS AND METHODS

Ten tributaries (feeder streams) flowing into Center Hill were selected as representative nutrient supplies for correlation studies to phytoplankton growth in the main channel of the reservoir. The ten feeder streams as shown on Figure 1 are sampling sites 1-10.

Fig. 1: *Diagrammatic Map of Center Hill Reservoir, Tennessee. Numbers indicate sample site locations.*

There were six reservoir or main channel sampling sites chosen for water sampling. They are sites 11-16 as shown on Figure 1. All reservoir sampling sites were in mid-channel or as nearly so by visual sighting.

The study period was from June 23 to November 19, 1973. Samples were collected on a bimonthly basis, when possible, to better observe changes.

Water samples were collected by hand dipping or with a 12 Volt D.C. electric pump. The pump was used to collect water samples from a depth of 2m for epilimnial water and 12m for thermocline water.

Dissolved oxygen (D.O.) and temperature readings were taken at each depth with a YSI meter (Model 54, sensitive to 0.05 mg/1 on a D.O. scale of 0-20, and ± 1.0% on the temp. scale).

After all samples were collected, they were transferred to a cold storage chamber and stored at 4° C.

The stream chemical and physical parameters tested, such as phosphates and nitrates, were used to illustrate sources of nutrient input for the reservoir and observe the correlation it has with epilimnial productivity (suspended solids) at 2m depth and possible causes for the D.O. depletion in the thermocline at 12m depth. The chemical parameters were analyzed by the Water Quality Laboratory of the Department of Public Health in Nashville, Tennessee.

RESULTS AND DISCUSSION

Falling Water River Embayment (Site 15), the fifth reservoir site, exemplifies the general results of all the reservoir sampling stations; having high suspended solids in the epilimnion while the D.O. in the thermocline decreases. In Figure 2 the suspended solids in the epilimnion ranged from a low of 5.5 mg/1 to a high of 32.0 mg/1 in late July. Since the Falling Water River Embayment receives water from several large tributaries including the Falling Water River influent, it is likely that much higher nutrient input results and is utilized by the phytoplankton.

The statistical analysis is a positive and negative correlation between two sets of data. The figure p, in parenthesis, is the probability that the null hypothesis ($r=0$) is true. The null hypothesis states that there is no correlation between the two sets of data. The n is the number of observations in the sample.

One of the most significant findings was the very high positive correlation (0.972, $p<0.01$, $n=9$) between the surface temperature of the feeder streams and the temperature of the epilimnial water (2m), on a "delayed basis". A delayed basis suggests that the data observed from the streams on June 23 sampling period would be correlated with the data observed in

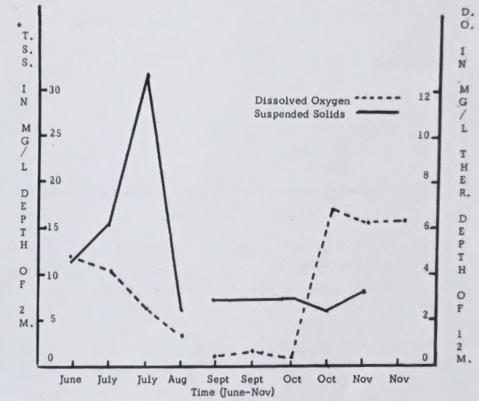

Fig. 2: *(Falling Water River Embayment) Epilimnial suspended solids vs. thermocline D.O. *Total suspended solids.*

the epilimnial (2m) samples collected on July 15 or the following sampling date. The flow time of 2 weeks for the streams seem reasonable since the average flow time of the reservoir is 150 days (Brown, 1974, personal communication). For example, the reservoir is 64 miles long, and the average length of all the streams is 4.1 miles from sampling point in the stream to sampling point in the reservoir. Therefore, 4/64 of 150 days is approximately 9 days—the average stream flow dynamics. That would leave from four to five days for growth response from phytoplankton. Also, the flow time of 2 weeks seems possible in that the concentrations of nutrients in the stream waters correlate significantly with the reservoir epilimnion. As the nutrients increase in the streams, concentrations of nutrients in the reservoir at 2m show appreciable increase, after a 2 week period. This is to account for the flow time of the streams or in the case of the reservoir samples, the time allowed for suspended solids precipitation into the thermocline. Subsequently, this would tend to show that the stream waters along with various nutrients were entering the main reservoir at that depth or at least stratifying there and supplying phytoplankton necessary nutrients for growth. As shown on Figure 3, the temperature of the streams plotted against the reservoir epilimnial waters (2m) of 2 weeks later are very close indeed.

The correlation analyses on data collected in the reservoir epilimnion on the same sampling period gave significant results.

Total solids concentrations and light transparency

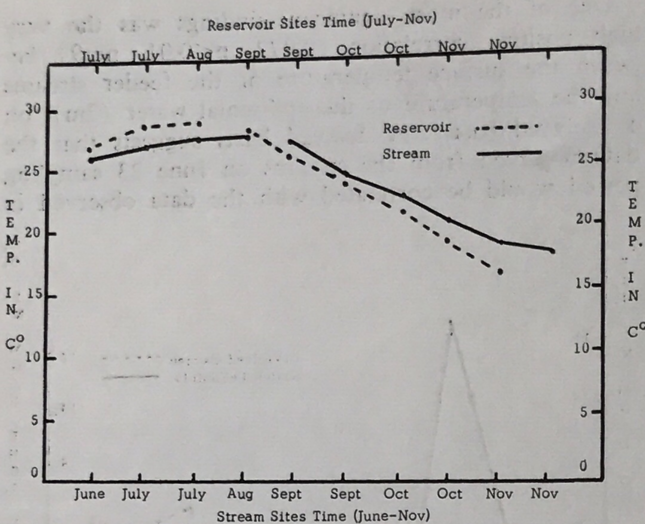

Fig. 3: *Main stream surface temperature plotted against mean reservoir epilimnial temperature. Study period June-November 1973.*

by Secchi disk resulted in a significant negative correlation (−0.85, $p<0.01$, n=9). These results would be expected since the total solids in the water would inhibit light transparency.

Also, the light transparency as measured by Secchi disk and total hardness gave a significant negative correlation (−0.91, $p<0.05$, n=7), indicating possibly that the light transparency decreased as total hardness concentration increased. This would also indicate increased phytoplankton, utilizing bicarbonates for photosynthesis.

Hoping to show that the depletion of D.O. in the thermocline is due to bacterial oxidation of dead or dormant phytoplankton precipitating from the epilimnion, correlations were established on a "delayed basis" to help verify this hypothesis.

Suspended solids concentrations from the epilimnion correlated to D.O. in the thermocline showed no significant correlation (−0.23, $p>0.05$, n=9). If the suspended solids, representing phytoplankton, precipitated to the thermocline over the given 2 week period of time, then the D.O. was not significantly depleted by the settling out effect.

Suspended solids concentrations in the epilimnion correlated to the BOD values of water samples from the thermocline gave no significant correlation (−0.095, $p>0.05$, n=7), indicating the suspended solids are not producing a BOD. The validity of the BOD values is questionable due to possible over saturation of oxygen prior to incubation.

A test was conducted to see if air was entering the BOD bottles around the stoppers by incubating 20 BOD samples uncovered and 20 BOD samples covered with rubber bandage cots. All 40 BOD samples were incubated for 28 days. No significant difference, by T-test analysis, was found between the uncovered and covered BOD samples. Then it was realized that over saturation of oxygen could be occurring in oxygenating the BOD samples prior to incubation.

SUMMARY

Results of the correlation studies indicate that the productivity, i.e. reflected in the total suspended solids, and other selected parameters in the epilimnial water (2m depth), is directly correlated to selected parameters of the feeder streams (surface—0.3m depth) observed two weeks earlier. The two week lag period was selected to allow time for stream flow from stream sample sites into the reservoir sample area. Since stream waters were assumed to be moving into the reservoir main body and stratifying in the epilimnion (2m depth), the following correlation between feeder streams and epilimnial waters was considered significant: temperature of the stream waters (surface—0.3m depth) correlated to the reservoir epilimnial (2m depth) water temperature, which gave (0.97, $p<0.01$, n=9).

The relationship between epilimnial (2m depth) productivity, i.e. total suspended solids and the D.O. concentration in the thermocline (12m depth), was correlated on a two week lagged basis as mentioned above. The lag period in this instance is used to allow time for precipitation of suspended solids to the thermocline from the epilimnion. These studies show no significant correlations, (0.095, $p>0.05$, n=7), between epilimnial (2m depth) suspended solids and BOD in the thermocline (12m depth).

From all indications, a major cause of dissolved oxygen depletion is not from one source, but rather a combination of factors acting singly or most likely in combination. These may include zooplankton respiration, fish respiration, bacterial oxidation, oxidation of various ions entering the reservoir such as ferrous and manganous, lack of light penetration to provide oxygen via photosynthesis and lack of circulation between the epilimnial and thermocline waters.

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