DISSOLVED OXYGEN PROFILES AT NORRIS DAM AND IN THE BIG CREEK SECTOR OF NORRIS RESERVOIR (1937), WITH A NOTE ON THE OXYGEN DEMAND OF THE WATER (1938)[1]

A. H. WIEBE,

Biological Readjustment Division,
Department of Forestry Relations (T.V.A.)

INTRODUCTION

A limnological study of Norris Reservoir was begun by the author early in August, 1937. It became apparent immediately that the vertical distribution of dissolved oxygen along with that of some other chemical constituents in the lower and deeper sections of the reservoir was quite different from that usually found in lakes that become stratified during the summer. Thermal stratification, however, occurred in the usual manner. It is the object of this paper to report, briefly, on the vertical distribution of dissolved oxygen (D. O.) in the Big Creek Sector of Norris Reservoir. Originally Big Creek was a tributary of the Clinch River, entering the latter approximately three miles above the present location of Norris Dam. The flooded section of Big Creek is approximately fifteen miles long (depends on elevation of lake surface). The length of the original channel that is flooded by the reservoir would be considerably more than fifteen miles. The approximate depth of the water at the various stations may be obtained from Figures 1–5.

DATA

The atypical stratification with respect to D.O. was due to the presence of a stratum of water low in D.O. in between two strata of relatively well areated water.

Figures 1–5 illustrate the condition with respect to D.O. at Norris Dam and at six stations on Big Creek. In all charts the values for Norris Dam are at the left margin of the chart; the numerals 1–7 at the top of each chart refer to stations on Big Creek. The numbers on the face of the chart represent values for D.O. in parts per million (p.p.m.). Dates of observation are indicated on the charts.

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[1] Published by permission of the Tennessee Valley Authority.

Figure 1 shows the existence of a relatively thin stratum of well areated water at the surface. This is followed by a still thinner sheet of water in which the D.O. diminishes rapidly. Then follows a layer of stagnant water having less than 1.0 p.p.m. of D.O. At Stations 5 and 6, this stagnant water extends from a depth of 25 ft. to the bottom, thus forming a pool. At Stations 1 and 2 and 4, it is wedge-shaped in a side view and does not extend to the bottom. It should be noted that the stratum of stagnant water becomes thinner towards the lower end of the reservoir. This decrease in thickness is due to an increase in the cross-section of the reservoir. Between #1 on Big Creek and Norris Dam, the stagnant water (less than 1.0 p.p.m.) disappears completely. This is shown by the presence of 1.95 p.p.m. of D.O. at 40 feet. The chart shows that the stagnant water extends also along the bottom of the reservoir from Station 6 to Station 1 on Big Creek, but at the Dam there are still 3.7 p.p.m. D.O. at the bottom on August 16. The next point of interest in

FIGURE I

DISSOLVED OXYGEN PROFILE
NORRIS DAM AND BIG CREEK

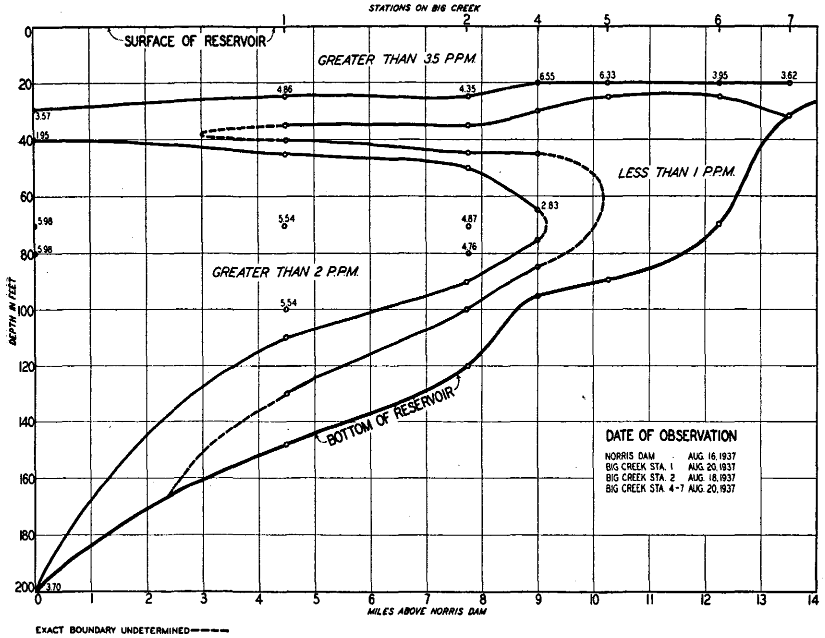


Figure 1 is the wedge of relatively well areated water extending from the dam towards the head of the reservoir and reaches #4 on Big Creek. In this wedge the D.O. reaches a maximum of 5.98 p.p.m. at the dam, 5.54 p.p.m., 4.87 p.p.m., and 2.83 p.p.m. at Nos. 1, 2 and 4, respectively. As will be pointed out later, this wedge of well areated water is a residue from the time when conditions in the reservoir were homogeneous.

The picture presented by Figure 2 is essentially the same as that shown in Figure 1. However, the following changes should be noted: (1) the stratum of stagnant water (less than 1.0 p.p.m.) now extends to the Dam at from 35 to 45 feet below the surface; (2) the stagnant water at #4 is no longer divided by the wedge of well areated water, but is present at all depths below 30 feet; (3) a decrease in the D.O. at the bottom near the Dam, and (4) a reduction in D.O. within the wedge of well-areated water.

FIGURE 2

DISSOLVED OXYGEN PROFILE
NORRIS DAM AND BIG CREEK

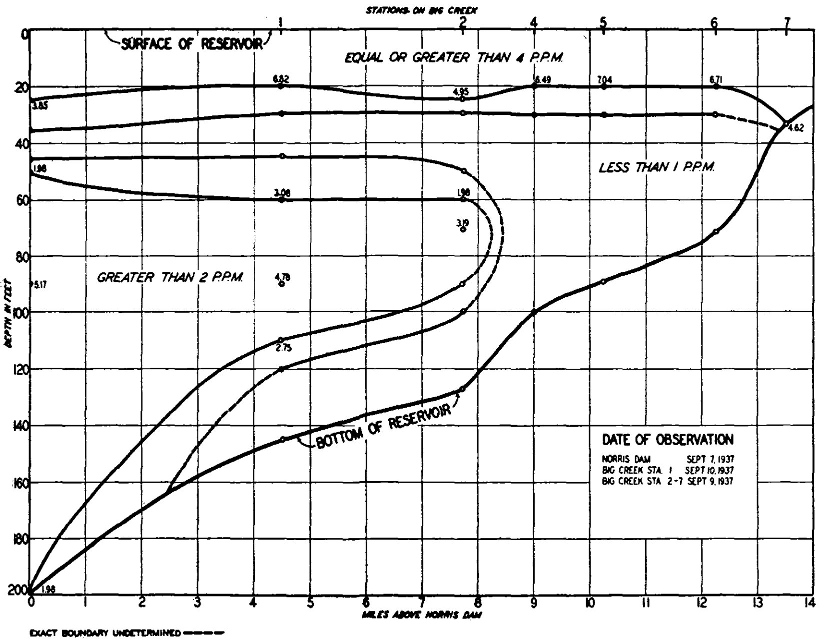
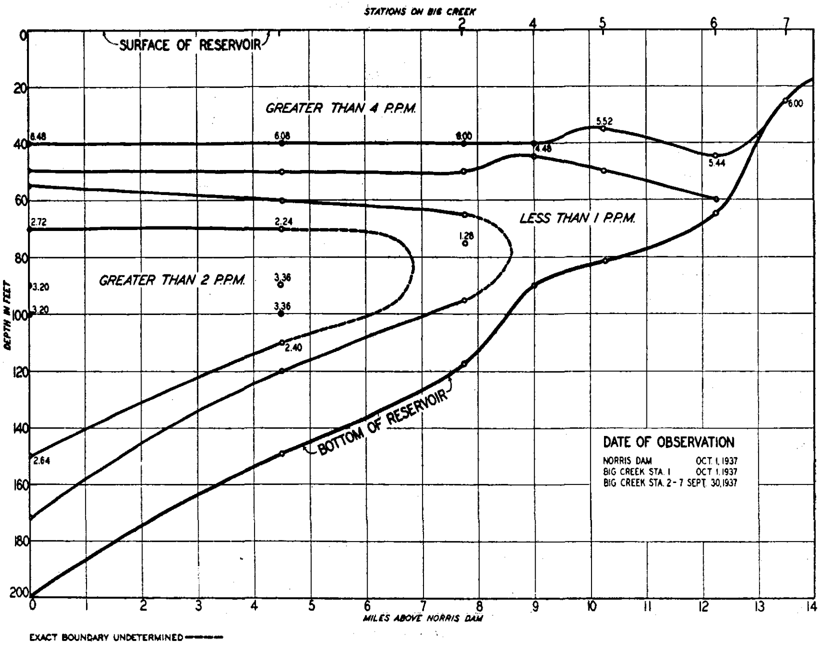


Figure 3 shows the following changes from conditions shown in Figure 2: (1) An increase in thickness of the surface stratum of well areated water, (2) the resulting lowering of the level of the stagnant water (intrusion sheet), (3) the stagnant water on the bottom extends to the Dam, and (4) a further reduction in D.O. and in thickness of the wedge of well-areated water.

Figure 4 shows: (1) A further increase in the thickness of the layer of well-areated surface water, and an additional lowering of the intrusion sheet of stagnant water, and (2) the virtual disappearance of the wedge of well-areated water with the resulting increase of the volume of stagnant water below and above this wedge.

FIGURE 3

DISSOLVED OXYGEN PROFILE
NORRIS DAM AND BIG CREEK



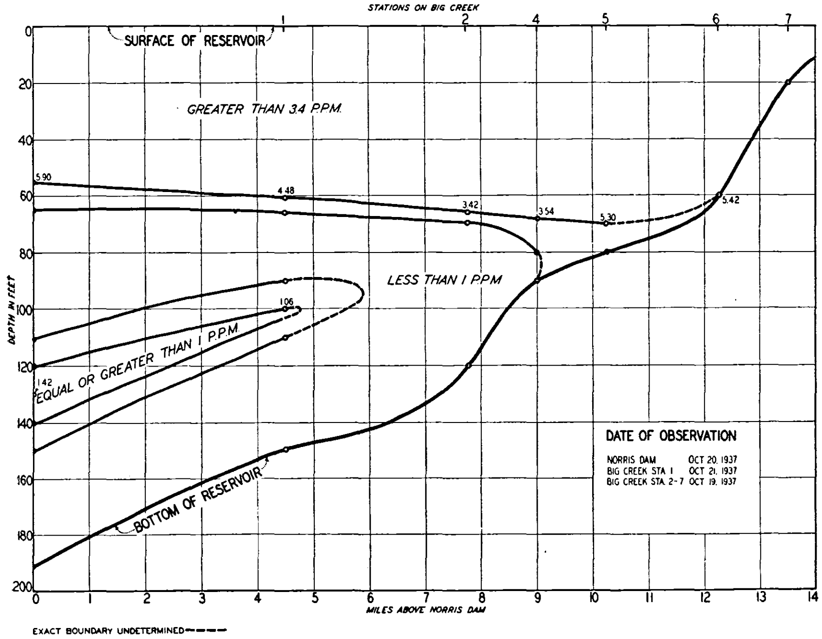
Finally, Figure 5 shows that conditions typical of lakes and reservoirs subject to stratification, namely, a well created epilimnion, a narrow zone of transition (rapid diminution in D.O.) and an oxygen poor hypolimnion.

It may be stated here without further discussion that the changes in the D.O. profiles as pointed out in the discussion of them are brought about by the following three factors: (1) Continues oxygen demand, (2) withdrawal of water at the dam, and (3) influx of fresh water spread over the surface of the reservoir.

FIGURE 4

DISSOLVED OXYGEN PROFILE

NORRIS DAM AND BIG CREEK



DISCUSSION

The following sequence of events explains the atypical stratification of the water in the deeper sections of Norris Reservoir.

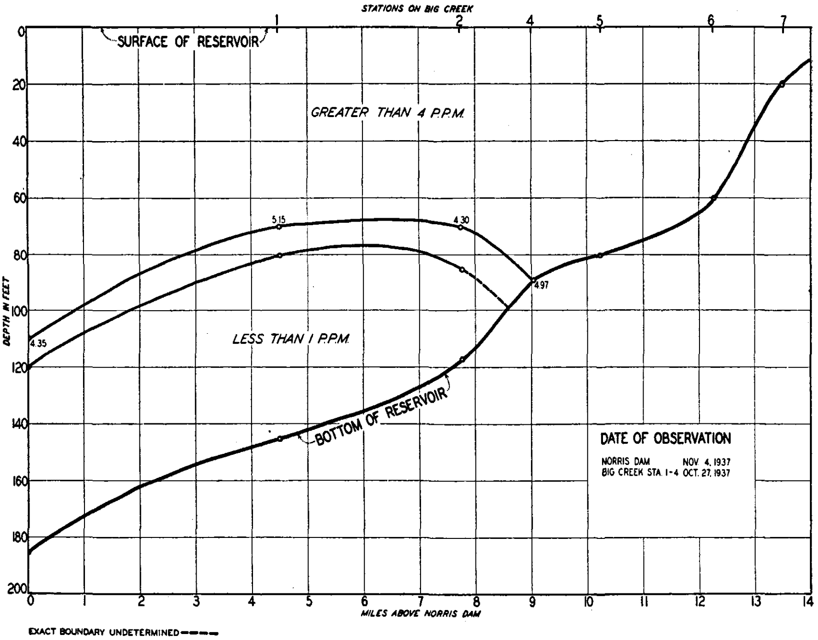
(a) During the fall and early winter as a result of the "fall turn-over" and displacement, practically all indications of stratification disappear—conditions become homogeneous.

(b) The reservoir is subject to a continuous draw-down. The discharge gates are near the bottom.

(c) Field observations show that bottom stagnation begins first towards the head of the reservoir. In Big Creek, this stagnation occurs first at a point between stations 6 and 7. There are two reasons why this stagnation sets in here earlier and proceeds at a faster rate than at #2, for instance: (1) Because of the lesser depth of the water at #6 and #7, the bottom temperatures there are higher than at #2; (2) Another and more important factor in the depletion of D.O. in the upper reaches of the reservoir is the silt carried in by the tributaries, especially after heavy rains. This silt is not all inorganic material, but may contain a considerable amount of organic matter plus the bacteria[2] that exist on this organic matter. When the incoming water hits the backwater at the head of the reservoir, materials suspended in the water begin to settle out. But whether on the bottom or suspended in the water, the silt, as defined above, has an appreciable D.O. demand. The water in the lower and deeper sections of the reservoir carries only a small part of the silt load carried by the water at the head of the reservoir. Hence the oxygen

FIGURE 5

DISSOLVED OXYGEN PROFILE
NORRIS DAM AND BIG CREEK



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[2] Whitney, L. V., 1937. Microstratification of the Waters of Inland Lakes in Summer. Science, Vol. 85, No. 2200.

demand is greatly reduced. Table I is offered to prove the difference in D.O. demand in the upper and lower sections of the reservoir. Table II affords additional proof of the high D.O. demand of the water at the head of the reservoir. Furthermore, it suggests that the demand is largely the result of biological activities.

Birge and Juday[3] (1911) report several cases where a diminution of D.O. occurred within a stratum of well areated water. They ascribed this diminution in D.O. to biological process. (1) Abundant plankton growth occurs within the upper strata of water. (2) The subsequent death of these planktons cause them to sink toward the bottom. However, they begin to decompose before their descent is completed and thus cause a depletion in D.O. within a region that would otherwise be characterized by a high D.O. This explanation holds for the depletion of D.O. in the shallower, upper portions of Norris

TABLE I

Shows the D.O. present when samples were collected on May 25, 1938, and the amount left after seven and fifteen days of incubation at Stations 2 and 7a. (7a is about 0.5 miles below the No. 7 shown in Figures 1 to 5.) The samples were kept in the dark on the laboratory boat and were subject to variations in temperature. Hence the values in the table are not comparable to B.O.D. values of the sanitary engineer.

STATION	#7a			#2		
Depth, Ft.	Initial D.O.	D.O. After 7 Days	D.O. After 15 Days	Initial D.O.	D.O. After 7 Days	D.O. After 15 Days
1	9.7 p.p.m.	2.8 p.p.m.	0.0 p.p.m.			
10	9.1	2.1	0.3	10.5 p.p.m.	9.1 p.p.m.	6.2 p.p.m.
20	8.7	0.56	0.0	10.6	9.1	6.2
30				10.5	8.5	5.7
35	8.4	0.7				
45	7.1	0.0	0.0			
50	4.9	0.0	0.0	9.3	8.5	5.7
55	3.5[1]	0.0	0.1 (?)			
80				7.8	7.1	5.7
100				7.0	6.3	5.3
120				6.6	6.0	4.1
138				5.7[2]	5.2	4.1

[1] Bottom. [2] Bottom.

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[3] Birge, A. E. and Juday, C., 1911, The Dissolved Gasses of the Water and their Biological Significance. No. XXII; Wis. Geo. and Nat. Hist. Sur.

Reservoir if we consider not only the plankton but also the organic matter carried in with the silt and the bacterial fauna of the silt complex. However, to account for the stratum of stagnant water at from 35 to 45 feet, (see Tables I and II again) at station #2 we need an additional factor. Density or subsurface currents as pointed out below would seem to serve this purpose.

(d) Because of the facts mentioned under (a) and (c), we find at some time during the spring or summer that the water in the lower part of the reservoir has a relatively high D.O. content at all depths while in the upper portions of the reservoir there exists a surface stratum of well areated water with a stratum of stagnant water underneath it. That such a condition prevailed in Big Creek during the early summer of 1937 is suggested by Figure 1 and is proven by 1938 observations.

TABLE II

Shows D.O. values for samples collected at Big Creek No. 8 on June 28, 1938. At the same time three sets of samples were placed in a dark compartment on the laboratory boat and tested for D.O. as indicated in columns 2 to 4. One set of these samples (column 4) had formalin added as a preservative. All incubated samples were subject to changes in temperature.

Depth, Feet	Initial D.O. 6/28/38	D.O. Left 7/12/38	D.O. Left 7/29/38	7/29/38 D.O. Left in Preserved Samples[1]
1............	8.8 p.p.m.	3.1 p.p.m.	0.00 p.p.m.	6.0
5............	8.1	2.7	0.00	6.0
10............	7.2	2.4	0.48 ?	5.8
15............	4.9	0.5	0.00	3.6
20............	3.1	0.5	0.00	2.4
25............	2.0	0.05	0.00	1.32
29 (b)..........	1.4	0.00	0.00	0.9

[1] NOTE: It is possible that not enough preservative had been added. Still there is a marked difference in D.O. values in columns 3 and 4.

(e) Under the influence of the draw-down at the dam, the entire mass of water may tend to move towards the dam at a uniform rate at all depths. However, if appreciable differences in density exist, the velocity may not be uniform. The fact that on August 16, 1937, the surface temperature (T.) at the dam was 86° F. and the bottom T. 48.25° F., a difference of 37.75° F., suggests the possibility of a density gradient due to differences in T. from surface to bottom. (The difference in the surface T. and bottom T. at any given time is a function of the depth of the water.)

The discharge at the dam occurs near the bottom. Thus the colder and heavier water near the outlet will be removed first. This would set up a tendency for all the colder and heavier water to move towards the dam. Under these conditions subsurface or density currents may develop. If these currents have the proper velocity under the prevailing differences in density so as not to lose their identity by diffusion (velocity too low) or by mixing because of turbulence (velocity too high); then it is possible to have the condition found in Norris Reservoir (Figures 1–4), namely, the intrusion of a stratum of stagnant water into a region of water of much higher D.O. content but of the same density as indicated by T.

That such subsurface currents existed is suggested not only by the D.O. but by temperatures as well. For instance, the stagnation zone at #6 on August 20, 1937, extended over the T. range of 78° F.–54.75° F. The so-called intrusion sheet of stagnant water at #2 on the same date covered the T. range of 72.25° F.–59.75° F. Thus the temperature range of the stagnant water (intrusion sheet) at #2 was within the T. range of the stagnant bottom water at #6. The condition just mentioned was general throughout the entire reservoir in 1937.

The data on D.O. and T. would seem to establish the identity of the stagnant bottom water at the head of the reservoir with that occurring at from 35 to 40 feet in the lower sections of the reservoir and suggest the possibility of density currents.

Additional proof that density currents are responsible for the peculiar distribution of D.O. in Norris Reservoir in 1937 have been obtained in 1938. In Big Creek, we have traced a stratum of water of low methylo range alkalinity from the head of the reservoir to #2, a distance of approximately 8 miles. The minimum alkalinity in this stratum occurred at a depth of 40 to 45 feet. This stratum of water moved toward the lower end of the reservoir and in a side view had the form of a wedge. The wedge shape is produced by spreading due to an increase in the cross-section of the reservoir. Again in the Clinch River sector, we have traced several subsurface strata of silt laden waters. One of these strata was followed for a distance of 20 miles. The maximum density, as determined by turbidity measurements, of this stratum occurred at a depth of from 55 to 65 feet. Under these conditions, the surface water to a depth of 25 feet may be absolutely clear. The same thing is true, only in a lesser degree, of the water below the stratum of very turbid water.

CONCLUSION

The atypical distribution of D.O. in Norris Reservoir in general and in the Big Creek Sector in particular as represented in Figures 1 to 5, is due to two factors: (1) the high biological oxygen demand of the water at the head of the reservoir causing stagnation within the hypolimnion, (2) Density currents carrying this stagnant water toward the dam at its characteristic density and temperature level.

ACKNOWLEDGMENTS

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