JOURNAL OF THE TENNESSEE ACADEMY OF SCIENCE
VOLUME 50, NUMBER 1, JANUARY 1975

SOME CHEMICAL AND PHYSICAL ASPECTS OF CENTER HILL RESERVOIR, TENNESSEE

ARNOLD GNILKA
Biologist in Civil-Environmental Division, Duke Power Company
Charlotte, North Carolina

ABSTRACT

Temperature and oxygen profiles and surface and bottom analyses for silica, total iron, pH, phenolphthalein and methyl orange alkalinities, specific conductance, turbidity, and nitrate nitrogen were made in Center Hill Reservoir from April, 1966, through April, 1967. Results indicated that surface waters, as compared to bottom waters, maintained lower levels of total iron, nitrate nitrogen, pH, and turbidity during summer. Phenolphthalein and methyl orange alkalinities exhibited atypical late-summer peaks which were attributed to the inflow of water from Great Falls Reservoir. Specific conductance and silica data varied considerably during the study. Oxygen and temperature profiles revealed late summer oxygen depletion occurring first in the upper portions of the reservoir and later in the lower portions. Center Hill Reservoir was, therefore, an oligotrophic lake despite the climograde oxygen curve; oxygen depletion was probably attributed to allochthonous materials.

INTRODUCTION

This investigation was initiated to study selected physical and chemical relationships at Center Hill Reservoir, Tennessee. These relationships are well documented for natural lakes and are exhaustively detailed by Hutchinson (1957); however, little comparable work exists for reservoirs. Published limnological studies of Tennessee reservoirs have largely been limited to the TVA system, in particular, to Norris Lake. Dendy (1945) and Eschmeyer (1950) gathered oxygen and temperature data and correlated them with fish distribution. Wiebe (1938, 1939a, 1939b, 1940, 1941) investigated the nature of density currents and oxygen and temperature relationships. Dendy and Stroud (1949) demonstrated the effects of Fontana Reservoir on temperature and oxygen distribution in smaller downstream reservoirs. Wunderlich (1971) worked extensively with changes in physical and chemical parameters, especially temperature and oxygen in various TVA reservoirs. Center Hill Reservoir has been the subject of few limnological studies. Nichols (1962) and Netsch and Turner (1964) gathered oxygen and temperature data, and the Tennessee Game and Fish Commission has carried out occasional oxygen and temperature studies in conjunction with its fisheries program.

Center Hill Reservoir, impounded by the U. S. Army Corps of Engineers in 1949, is situated in DeKalb, Putnam, Smith, and Warren Counties, Tennessee. The dam, located at mile 26.6 of the Caney Fork River, forms a typical headwater reservoir with steep sides, many small coves, and a low rate of flow (MacKenthun, *et al.*, 1964). At maximum elevation the reservoir contains 2.58 x 10^9 m^3 of water, a surface area of 9.3 x 10^3 hectares, and a maximum depth of 54.3 m. The reservoir drains 5.7 x 10^5 hectares of mixed farm and forest lands. The Caney Fork River, impounded by Great Falls Dam, and Falling Water River are the principal influent rivers.

METHODS

Two permanent mid-channel sampling stations were established on the reservoir: station 1 at Hurricane Bridge, 13.7 km above the dam; and station 2 at Sligo Bridge, 35.5 km above the dam.

Oxygen and temperature readings were taken *in situ* with a YSI Model 51 oxygen and temperature meter at 0.6 m intervals from the surface to a depth of 29.6 m. Water samples were collected with a 3.1-liter Kemmerer sampler at the surface and at the 29.6-m depth and transferred to 1-gallon plastic bottles for transport to the laboratory. Samples were analyzed within 6 hours after the last sample was collected. Specific conductance was measured with an Industrial Model RC-7p conductivity bridge and turbidity with a Hellige Turbidimeter. Phenolphthalein and methyl orange alkalinities, total iron, and silica were measured according to to Standard Methods (Amer. Publ. Health Assoc., *et al.*, 1960). Nitrate nitrogen was determined by the phenoldisulfonic acid method (Swingle, 1964).

RESULTS AND DISCUSSION

Total alkalinity, as described by Ellis, et al. (1946), is the sum of hydroxide, normal carbonate, and bicarbonate ions expressed as mg liter^{-1} of calcium carbonate.

Data from Watts Bar and Norris reservoirs (TVA Fish and Wildlife Branch 1964 and 1965, respectively) suggested that Ca^{++} and Mg^{++} were the most prevalent cations; the same condition was assumed at Center Hill Reservoir. Therefore, the relationships among the cations, pH, and alkalinity were essentially caused by Ca^{++}, and to a lesser extent by Mg^{++}, interacting with carbon dioxide and carbonate.

Total alkalinity of Center Hill (Table 1) increased in the surface and bottom waters at both stations from June through the first week in November. Apparently carbonate, in the form of calcium carbonate, was redissolved as it entered the carbon dioxide-rich hypolimnion. However, the concomitant drop in alkalinity in the epilimnion, normally associated with this phenomenon, did not occur. The increased alkalinity of Center Hill can best be explained by the addition of bicarbonates from Great Falls Reservoir. The cooler water released from Great Falls flowed between the epilimnion-metalimnion interface of Center Hill. Transport of bicarbonates to the epilimnion and hypolimnion could then take place.

Additional evidence for an external source of bicarbonate was indicated by phenolphthalein alkalinity (first detected June 15, 1966; last detected September 28, 1966). During July and August when phenolphthalein alkalinity was highest and, presumably, carbonate was being precipitated in the surface water, a slight drop in total alkalinity occurred with a concomitant rise in alkalinity of the bottom waters. Gradually the alkalinity in the surface water increased after the initial drop and attained a concentration similar to that of the hypolimnion. Alkalinity gradually declined in surface and bottom waters at both stations from November, 1966, until the end of the study.

TABLE 1: *Selected Water Chemistry Analyses for Stations 1 and 2 for 1966 and 1967 in Center Hill Reservoir, Tennessee*

		DATE											
Station	Depth	April 17	May 14	May 21	June 1	July 27	Aug. 25	Oct. 31	Nov. 7	Nov. 14	Dec. 19	March 10	March 23
1	Surface	31.5	45.0	45.9	45.9	52.5	57.0	60.5	61.6	60.5	57.2	48.0	41.3
	Bottom	39.6	45.0	44.1	47.7	57.2	60.5	61.6	66.0	60.5	62.7	43.2	46.0
2	Surface	23.4	42.3	45.9	45.9	59.2	64.7	66.0	71.5	69.3	59.4	33.6	32.6
	Bottom	25.2	44.1	46.8	42.3	59.3	64.9	71.5	71.5	59.4	64.9	41.3	31.7
PHENOLPHTHALEIN ALKALINITY (mg liter⁻¹ as CaCo₃)													
1	Surface	0	0	0	0	4.4	3.3	0	0	0	0	0	0
	Bottom	0	0	0	0	0	0	0	0	0	0	0	0
2	Surface	0	0	0	0	3.3	2.2	0	0	0	0	0	0
	Bottom	0	0	0	0	1.1	0	0	0	0	0	0	0
TURBIDITY (mg liter⁻¹ as SiO₂)													
1	Surface	22.5	5.5	5.0	5.0	5.0	5.0	4.7	4.7	4.7	5.5	12.0	25.5
	Bottom	12.5	6.0	6.0	5.5	6.0	6.8	7.5	11.0	12.7	6.0	8.5	8.5
2	Surface	12.5	10.0	6.0	5.0	5.0	5.0	4.7	5.5	13.5	5.5	141.0	34.0
	Bottom	15.0	8.5	8.5	5.5	5.2	14.5	22.5	22.5	36.0	18.5	15.0	27.0
TOTAL IRON (mg liter⁻¹)													
1	Surface	—	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3
	Bottom	—	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2	Surface	—	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.0	0.6
	Bottom	—	0.3	0.1	0.1	0.1	0.1	0.6	0.6	0.3	0.1	0.3	1.0
NITRATE (mg liter⁻¹ as N)													
1	Surface	0.19	0.27	0.31	0.10	0.10	0.24	0.10	0.10	0.10	0.20	0.10	0.49
	Bottom	0.62	0.27	1.24	1.11	0.10	1.57	0.49	0.31	0.19	0.22	0.33	0.66
2	Surface	0.36	0.40	0.49	0.10	0.10	0.22	0.10	0.10	0.10	0.27	1.11	1.33
	Bottom	0.37	0.31	1.15	1.02	0.10	0.84	0.36	0.27	0.19	0.36	0.31	0.80
SPECIFIC CONDUCTANCE (micromhos cm⁻¹)													
1	Surface	113.9	299.7	191.0	203.6	171.4	162.9	153.8	164.7	151.2	159.6	144.8	122.4
	Bottom	131.8	299.7	229.2	196.0	176.4	169.4	176.4	182.0	177.5	163.5	153.6	160.0
2	Surface	113.2	268.2	211.7	207.6	181.8	167.1	166.6	194.8	167.1	149.0	112.9	109.0
	Bottom	119.3	304.1	216.4	240.6	169.0	158.8	177.7	209.6	189.6	147.3	117.6	109.0

Turbidity

Turbidity in Center Hill ranged from 4.0 to 141.0 mg liter⁻¹ as SiO₂ (Table 1). Turbidity was generally less at station 1 than at station 2, possibly due to the settling of heavier particles in the upper reaches of the reservoir. Turbidity was lowest at both stations during periods of stratification and highest during periods of isothermy. After periods of rain turbidity generally increased.

On March 10, 1967, a spectacular increase in surface water turbidity to 141.0 mg liter⁻¹ (from 5.5 mg liter⁻¹) was observed at station 2. This increase was attributed to the warmer (9.2 C) turbid water from Great Falls Reservoir after heavy rainfall flowing over the cooler (7.0 C) Center Hill Reservoir water. On the same date, turbidity was 8.5 and 15.0 mg liter⁻¹ for the bottom waters at stations 1 and 2, respectively, and 12.0 mg liter⁻¹ for the surface water at station 1. The Great Falls water gradually spread over Center Hill and increased the surface water turbidity, but not the turbidity of the water below the intrusion layer at station 1. Ellis (1940) reported a similar situation in Elephant Butte Reservoir.

Total Iron

In natural waters iron can exist in the ferrous or ferric state; however, ferrous iron is uncommon due to its rapid oxidation to the ferric state. The surface stations exhibited low total iron concentrations (less than 0.1 mg liter⁻¹) throughout the study except an increase in March, 1967 (Table 1). This sharp increase in concentration was a reflection of unusually heavy amounts of iron-rich silt entering the reservoir. A similar relationship between turbidity and iron was reported by Brigham (1972) for Asa Creek, Illinois. The total iron concentration of the bottom waters was usually greater than that of the surface waters at both stations. During summer the iron concentration of the bottom waters remained stable at both staioms. A rapid increase in total iron of bottom water at station 2 was detected in October when destratification occurred and the lake circulated freely.

Nitrate Nitrogen

In all its forms nitrogen is utilized by the plankton and is usually present in low concentrations in the trophogenic zone. During periods of circulation, nitrate is evenly distributed from the surface of the bottom of the reservoir (Armitage, 1962). With the onset of stratification, the nitrate is usually removed from he epilimnion primarily by phytoplankton.

At station 1, lower nitrate levels (Table 1) during the summer and autumn coincided with a maximum oxygen level near the surface and reflected utilization of nitrate by the plankton. Similar concentrations were detected at station 2; however, the surface water at station 2, in general, contained higher nitrate levels than that at station 1.

Specific Conductance

Specific conductance is the ability of water to convey an electrical current (Amer. Publ. Health Assoc., *et al.*, 1960). Specific conductance is affected not only by temperature and the total concentration of ions, but also by the nature of the constituent ions. The most prevalent ions in Center Hill were calcium and bicarbonate; therefore, specific conductance was positively correlated with total alkalinity. Hooper (1956) reported similar seasonal maxima and minima in alkalinity and specific conductance in Southern Michigan lakes.

Specific conductance generally followed the alkalinity curve. Some high readings in April and May, 1966 were not explained easily, but they appeared to be related to the influent waters. The relationship between alkalinity and specific conductance at both stations (Table 1) suggests that the alkalinity-associated ions most affected the specific conductance of Center Hill.

Temperature

On April 17, 1966, a weak thermal stratification was evident as the lake began warming (Table 2). By May 14, the upper limit of a metalimnion had formed at 7.6 m at station 1 and 7.0 m at station 2. On the same date the winter storage water (7 C or less) was located at 27.7 m at station 1 and 24.1 m at station 2. On June 1, the upper level of the metalimnion was located at 6.0 m at both stations, while the winter storage water was detected at 29.6 m. Warming reached a peak on July 27, when surface waters were 30.1 C at station 1 and 29.4 C at station 2; the metalimnion began at 5.8 m at both stations. By August 25, cooling of the lake had begun and the metalimnion began sinking. On October 31, the metalimnion was no longer evident at stations 1 and 2. Thermal stratification was practically destroyed by November 7, and the waters were circulating freely by December 19.

TABLE 2: *Selected Temperatures (° C) for Stations 1 and 2 for 1966 and 1967 in Center Hill Reservoir, Tennessee*

		Depth (meters)								
Date	Station	Surface	2	4	6	8	10	15	20	30
April 17, 1966	1	14.1	11.0	10.2	9.9	9.7	9.1	8.4	6.9	5.8
	2	12.8	11.4	11.1	10.6	10.1	10.0	9.1	6.8	6.0
May 14, 1966	1	17.1	17.1	17.1	17.1	16.8	15.8	11.5	9.8	6.9
	2	16.0	16.1	16.1	16.1	14.7	14.0	12.8	9.1	6.5
May 21, 1966	1	21.9	19.5	18.1	16.9	15.8	14.1	12.6	9.9	6.5
	2	21.5	18.3	17.5	15.8	14.9	14.4	13.0	9.5	6.8
June 1, 1966	1	22.5	22.0	21.5	17.5	15.7	14.8	13.2	11.0	7.0
	2	21.1	21.1	20.6	17.4	16.0	15.2	15.0	10.0	7.0
July 27, 1966	1	30.1	29.7	29.5	27.0	21.8	18.0	14.1	12.1	7.8
	2	29.4	28.9	28.9	26.0	21.9	18.4	14.2	12.0	7.8
August 25, 1966	1	27.1	27.1	27.1	27.1	27.0	20.9	15.1	13.1	8.8
	2	27.1	27.1	26.8	26.8	24.6	23.1	15.9	13.1	8.9
October 31, 1966	1	17.1	17.2	17.2	17.2	17.2	17.2	17.0	14.7	10.2
	2	16.9	16.9	16.9	16.9	16.9	16.9	17.0	15.0	10.1
November 7, 1966	1	15.0	15.0	15.0	15.0	14.9	14.9	14.9	14.9	10.4
	2	14.9	14.9	14.8	14.7	14.7	14.6	14.5	14.4	9.9
November 14, 1966	1	14.8	14.7	14.7	14.7	14.7	14.5	14.3	14.3	10.9
	2	14.2	14.2	14.2	14.2	14.1	14.1	14.1	13.1	11.5
December 19, 1966	1	10.2	10.4	10.3	10.3	10.3	10.3	10.3	10.3	10.3
	2	9.0	9.3	9.3	9.3	9.3	9.3	9.1	8.9	8.9
March 10, 1967	1	7.1	6.9	6.5	6.5	6.1	6.1	6.1	6.1	6.1
	2	9.2	9.0	8.9	8.9	8.9	8.0	6.9	6.3	6.3
March 23, 1967	1	10.9	9.1	8.8	8.8	8.6	8.3	7.0	6.5	6.0
	2	10.1	10.1	9.8	9.6	9.1	8.9	7.8	6.0	6.3

Warm surface water detected at station 2 on March 10, 1967, came from the warmer, turbid waters of Great Falls Reservoir spreading over the cooler Center Hill waters. This condition created a temperature differential of 2.5 C at station 2, while station 1 was practically isothermal. At station 2 waters below 16.7 m did not mix with the waters above. Louder and Baker (1966) reported a similar situation in Fontana Reservoir where water from tributary streams flowed over the cooler waters in the reservoir. Density flow, as an intrusion layer, has been reported by Wiebe (1940, 1941), Lyman (1944), and Wunderlich (1971). These unusual conditions (when compared with a natural lake) mean that temperature profiles should be taken at a maximum of 10-km intervals in the upper reaches of the reservoir. Near the dam 2-km intervals between stations for a distance of 10-km should provide a better understanding of the effect of the penstock-intake on temperature profile.

Oxygen

The oxygen data (Table 3) revealed a slight oxygen gradient on April 17, 1966. Oxygen began decreasing in the bottom waters at station 2 by May 14 and at station 1 by May 21. On July 27, bottom waters at station 2 contained less than 1.0 mg liter⁻¹ oxygen. A positive heterograde oxygen curve had developed near 5.8 m at station 2 and between 5.8 and 9.5 m at station 1. A similar, but less extreme, oxygen condition existed at station 1 on August 25.

By October 31, the bottom waters at station 1 were devoid of oxygen, while the cooling surface waters contained uniform oxygen concentrations to a depth of 12.5 m. Mixing had started in the upper 12 meters by this time. The bottom waters contained more than 1.0 mg liter⁻¹ oxygen on November 14 at station 2 and on November 28 at station 1. There was no oxygen stratification throughout the winter. On March 23, 1967, an oxygen differential of 1.7 mg liter⁻¹ at station 1 and 1.0 mg liter⁻¹ at station 2 indicated that free circulation had ended.

Hutchinson (1957) indicated that molecular diffusion is insignificant in oxygenating a body of water, although a combination of active mixing and convective streaming are the most important physical processes causing oxygenation of natural waters. Oxygen reaches all levels of a dimictic lake only during the autumnal and vernal circulation periods (Ruttner, 1963). Once a lake is thermally stratified, rapid translocation of oxygen by physical means is confined to the upper portions of the epilimnion. The controlling factor of oxygen concentration below the wind-agitated waters and in the euphotic zone is determined by biological activities (Hutchinson, 1957). Oxygen deficits of the hypolimnion are caused primarily by oxidizable substances from dead and dying organisms, waste products, and silt (Ruttner, 1963). As they are oxidized, oxygen becomes depleted. Ellis (1940) found that oxygen became depleted first in the upper portion of the reservoir where silt had been deposited. Wiebe (1939a, and 1939b) reported that, in addition to the greater silt deposition, the higher temperature obtained in the upper shallower portions of the reservoir contributed to the oxygen depletion. The situation at Center Hill Reservoir appeared similar to those mentioned by Ellis and Wiebe.

CONCLUSIONS

During spring and fall Center Hill Reservoir exhibited a clinograde oxygen surve which is usually associated with a eutrophic lake. However, the oxygen curve at Center Hill was primarily due to allochthonous materials rather than materials originating in the reservoir. The positive heterograde oxygen curve present during July and August was probably due to photosynthesis (Ruttner, 1963), a conclusion further substantiated by the presence of phenolphthalein alkalinity during the same period.

The oxygen and temperature data indicated the existence of density currents in Center Hill Reservoir, but the data were insufficient to support definite conclusions about their occurrence, size, and origins. Great Falls Reservoir was suspected as the source of most of the density currents, as well as a source of allochthonous materials. Additional sampling points on Center Hill Reservoir and at least one sampling point on Great Falls Reservoir should be established to study adequately the density currents.

Results revealed distinct differences between conditions at stations 1 and 2. Generally, both physical and chemical changes occurred first and were most abrupt and extensive at station 2. Such differences between the stations were probably due to (1) the upstream position of station 2, (2) the greater volume of water per unit of bottom area at station 1, and (3) samples at station 2 were taken nearer the mud surface of the reservoir.

TABLE 3: *Selected Oxygen Values (MG Liter^{-1}) for Stations 1 and 2 for 1966 and 1967 in Center Hill Reservoir, Tennessee*

		Depth (meters)								
Date	Station	Surface	2	4	6	8	10	15	20	30
April 17, 1966	1	9.7	9.5	8.8	8.6	8.3	8.3	8.0	7.3	7.1
	2	10.4	9.6	10.0	9.6	9.5	9.5	8.8	7.5	7.4
May 14, 1966	1	8.6	8.6	8.6	8.6	8.5	8.7	7.8	7.8	6.9
	2	8.2	8.1	8.1	8.0	7.9	7.9	7.5	6.5	5.5
May 21, 1966	1	5.9	6.4	6.6	6.2	5.4	5.3	5.0	5.1	4.0
	2	6.4	7.0	6.8	5.9	5.4	5.3	5.3	4.6	3.4
June 1, 1966	1	5.5	5.6	5.7	5.8	5.0	4.6	4.4	4.4	3.4
	2	5.5	5.4	5.4	5.5	5.0	4.7	4.0	3.8	2.3
July 27, 1966	1	7.9	7.8	7.8	11.4	10.9	7.8	3.4	4.2	2.8
	2	8.0	8.1	8.1	9.8	7.4	6.7	3.2	3.2	0.8
August 25, 1966	1	8.4	8.4	8.4	8.3	11.1	8.5	3.4	4.1	2.7
	2	8.3	8.3	8.3	8.2	6.8	6.8	3.0	3.1	0.2
October 31, 1966	1	7.4	6.9	6.8	6.8	6.8	6.8	6.6	0.4	0.0
	2	7.5	7.3	7.0	7.0	7.0	7.0	6.9	4.9	0.0
November 14, 1966	1	8.6	7.9	7.5	7.5	7.5	7.5	7.3	7.3	0.3
	2	8.0	7.4	7.3	7.2	7.2	7.2	6.4	5.9	6.0
December 19, 1966	1	9.6	9.7	10.0	10.0	10.0	10.0	10.1	10.1	9.4
	2	11.4	10.8	10.8	10.8	10.8	10.8	12.4	10.8	10.5
March 10, 1967	1	11.2	11.3	11.3	11.0	10.4	10.4	10.4	10.4	10.4
	2	10.6	11.3	11.3	10.7	10.7	10.4	9.7	9.4	9.4
March 23, 1967	1	10.4	10.2	9.8	9.8	9.4	9.4	9.2	8.8	8.7
	2	10.5	10.4	10.4	10.4	10.4	10.4	10.3	9.6	9.5

ACKNOWLEDGMENTS

Special thanks are extended to Dr. D. H. Stern for suggesting the problem and Dr. D. D. Moss for his advice and guidance during the research for a MS degree at Tennessee Technological University, Cookeville, Tennessee. I extend appreciation to Mr. J. Little, Tennessee Game and Fish Commission, for placing data at my disposal and to the personnel of the U. S. Army Corps of Engineers and Tennessee Valley Authority for supplying operational data from Center Hill and Great Falls Reservoirs. I thank Drs. A. R. Brigham, W. U. Brigham, D. L. Bunting, and D. R. Nelson for reviewing the manuscript.

LITERATURE CITED

American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1960. Standard methods for the examination of water and wastewater, 11th ed. Amer. Publ. Health Assoc., Washington, D.C. 626 pp.

Armitage, K. B. 1962. A comparative limnological survey of Leavenworth County and Nemaha County state lakes. Univ. Kansas Sci. Bull. 43:611-644.

Brigham, A. R. 1972. Physico-chemical limnology and periphyton in a warm-water stream receiving wastewater treatment plant effluent. Univ. Illinois Water Res. Cent., Res. Rep. No. 59, 83 pp.

Dendy, J. S. 1945. Fish distribution, Norris Reservoir, Tennessee, 1943. II. Depth distribution of fish in relation to environmental factors, Norris Reservoir. J. Tennessee Acad. Sci. 20:114-135.

Dendy, J. S., and R. H. Stroud. 1949. The dominating influence of Fontana Reservoir on temperature and dissolved oxygen in the Little Tennessee River and its impoundments. J. Tennessee Acad. Sci. 24:41-51.

Ellis, M. M. 1940. Water conditions affecting aquatic life in Elephant Butte Reservoir. Bull. Bur. Fish. 49:257-304.

Ellis, M. M., B. A. Westfall, and M. D. Ellis. 1946. Determination of water quality U. S. Dept. Interior, Fish Wildl. Serv., Rept. No. 9:1-122.

Eschmeyer, R. W. 1950. Fish and fishing in TVA impoundments. Tennessee Dept. Conserv., Nashville. 28 pp.

Hooper, F. F. 1956. Some chemical and morphometric characteristics of southern Michigan lakes. Pap. Michigan Acad. Sci., Arts, Letters 41:109-130.

Hutchinson, G. E. 1957. A treatise on limnology. John Wiley and Sons, New York. 1,015 pp.

Louder, D. E., and W. D. Baker. 1966. Some interesting limnological aspects of Fontana Reservoir. Presented at: Southern Div. Amer. Fish. Soc., Asheville, North Carolina. Oct. 24-26, 1966.

Lyman, F. E. 1944. Effects of a flood upon temperature and dissolved oxygen relationships in Cherokee Reservoir, Tennessee. Ecology 25:78-84.

MacKenthun, K. M., W. M. Ingram, and R. Porges. 1964. Limnological aspects of recreational lakes. U. S. Publ. Health Serv. Publ. No. 1167. 176 pp.

Netsch, N., and B. Turner. 1964. Creel census and population studies. Project F-2-R, Tennessee Game Fish Comm. 57 pp. Mimeo.

Nichols, H. M. 1962. Progress report, large impoundment investigations, seasonal oxygen and temperature profiles on impoundments for January 1, 1959, to December 31, 1959. Tennessee Game Fish Comm. 24 pp.

Ruttner, F. 1963. Fundamentals of limnology. 3rd ed. Univ. of Toronto Press, Toronto. 295 pp.

Swingle, H. S. 1964. Methods of analysis for waters, organic matter, and pond bottom soils used in fisheries research. 1963 revision, Auburn Univ. 107 pp.

Symons, J. M., S. R. Weibel, and G. G. Robeck. 1966. Influence of impoundments on water quality—A review of literature and statement of research needs. U. S. Publ. Health Serv. Publ. No. 999-WP-18, Oct. 1964, revised 1966. 78 pp.

Tennessee Valley Authority Fish and Wildlife Branch. 1965. Fertilization test in coves of Norris Reservoir, Tennessee. 8 pp.

Tennessee Valley Authority Fish and Wildlife Branch. 1964. Fish inventory data Wats Bar Reservoir, 1964. 14 pp.

Weibe, A. H. 1938. Limnological observations on Norris Reservoir with especial reference to dissolved oxygen and temperatures. Trans. 4th No. Amer. Wildl. Conf. 4:440-457.

Wiebe, A. H. 1939a. Dissolved oxygen profiles at Norris Dam and in the Big Creek sector of Norris Dam (1937) with a note on the oxygen demand of the water (1938). Ohio J. Sci. 39:27-36.

Wiebe, A. H. 1939b. Density currents in Norris Reservoir. Ecology 20:446-450.

Wiebe, A. H. 1940. The effect of density currents upon the vertical distribution of temperature and dissolved oxygen in Norris Reservoir. J. Tennessee Acad. Sci. 15:301-308.

Wiebe, A. H. 1941. Density currents in impounded water—Their significance from the standpoint of fisheries management. Trans. 6th No. Amer. Wildl. Conf. 6:256-264.

Wunderlich, W. D. 1971. The dynamics of density-stratified reservoirs. P. 219-231. In: Gordon E. Hall (ed.), Reservoir Fisheries and Limnology. Amer. Fish. Soc., Special Publ. No. 8. 511 pp.

ENTERPRISE RADIATION FOREST: PREIRRADIATION STUDY

Although much research has been done on the effects of ionizing radiation on natural ecosystems, little is known about radiation effects on the northern coniferous and deciduous forests. The U. S. Atomic Energy Commission has just published the report of a study (in the Enterprise, Wisconsin, Radiation Forest) planned to determine the impact of gamma radiation on natural northern forest communities. *The Enterprise Radiation Forest* documents a joint study project of the Forest Service, U. S. Department of Agriculture, and the AEC and supplies reference and base-line information not only for evaluating the radiation effects but also on the ecology of some important northern forest types.

Detailed studies of the physical and biological environments of the area before irradiation are reported. These include the selection of the study area, the topography, the climate, the solar radiation, the design of radiation site 1, the vegetation (lichens, ground vegetation, shrub layer, tree cover, and litter production), and the small-mammal populations. Finally, on the basis of extensive preirradiation studies, the investigators predict the effects of irradiation during one growing season on the plant communities of radiation site 1.

The book is available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22151.