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Stephen B. Smith
U.S. Fish and Wildlife Service

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EFFECTS OF WATER RELEASED FROM STRATIFIED AND UNSTRATIFIED RESERVOIRS ON THE DOWNSTREAM WATER QUALITY

STEPHEN B. SMITH
Multi-Outlet Reservoir Studies
U.S. Fish and Wildlife Service
Arkadelphia, Arkansas 71923

ABSTRACT

Water quality samples were collected from the Little River system in Pine Creek Lake, Oklahoma, and Gillham Lake, Arkansas, and their associated tailwaters during the winter (reservoirs unstratified) and summer (reservoirs stratified) of 1980. Downstream water quality was not affected by reservoir water releases while the reservoirs were unstratified. When the reservoirs were stratified water quality in the tailwaters was dependent on the release depth of the water. The practice of flushing out a tailwater following an extended low flow period should be examined on a site by site basis. Anoxic water released from a reservoir may contain high amounts of certain chemicals that may be detrimental to downstream aquatic life.

INTRODUCTION

Water released from a reservoir may alter downstream physicochemical conditions, depending on the quality of the water at the release depth, quantity of water released, and time of year (Neel, Limnology of North America, Univ. Wisconsin Press. Pages 575-593, 1963; Pfitzer, Trans. N. Am. Wildl. Conf. 19:271-282, 1954). The quality of water released during prolonged periods of low flow is important, particularly during the growing season (May through October), when water quality may be poor in the hypolimnion of the reservoir or in slow moving water in pools of the tailwater. Physicochemical characteristics in the tailwater influence the character and densities of aquatic life downstream.

Water quality data were collected from Pine Creek Lake and tailwater, Oklahoma; Gillham Lake and tailwater, Arkansas; and the Glover River, Oklahoma, an unimpounded stream in the Little River drainage. Samples were taken when the reservoirs were not stratified, and during summer stratification, to determine the effects of reservoir water releases on the physicochemical characteristics of the tailwaters.

STUDY AREA

The Little River system has two main stem reservoirs and five major tributaries, four of which have reservoirs (Figure). Pine Creek Lake, the upstream impoundment on the Little River, is a multipurpose flood control reservoir of the U. S. Corps of Engineers in southeast Oklahoma. The surface area is 2023 hectares (ha) and mean and maximum depths are 4.8 and 23 m, at conservation pool elevation (135.2 m above mean sea level). The dam gate tower has multi-level intakes at elevations 128.9 and 123.7 m to maintain low flow. A warmwater discharge up to 10.5 m^3/sec can be manipulated through these low flow gates. Two slide gates at elevation 117 m control the discharge from 10.5 to 226.5 m^3/sec.

Gillham Lake is a multi-purpose flood control reservoir of the U. S. Corps of Engineers on the Cossatot River in southwest Arkansas. At conservation pool elevation (153.0 m above msl), the lake has a surface area of 554 ha and mean and maximum depths of 7.3 and 21.3 m. Multi-level intakes within the gate tower are located at elevations 148.4 and 143.8 m. The warmwater discharge from the multi-level intakes can be maintained at 0.8 m^3/sec during low flow or increased to 4.2 m^3/sec. Reservoir discharge from 4.2 to 84.9 m^3/sec is controlled by two slide gates at elevation 133.2 m.

The Little River was sampled in Pine Creek Lake and at locations downstream to the headwaters of Millwood Lake, near the confluence of the Cossatot River, 165.4 km downstream from Pine Creek Dam. The Cossatot River was sampled in Gillham Lake, and at locations downstream to its confluence with the Little River, 75.6 km below Gillham Dam (Figure). Tailwaters below Pine Creek and Gillham lakes were maintained by warmwater low flow releases of 1.6 and 0.8 m^3/sec, respectively, in 1980.

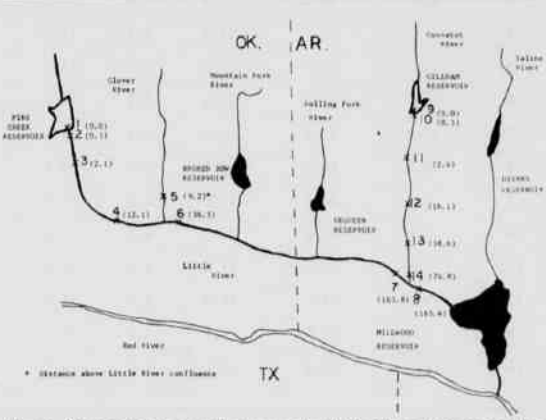

Figure. Water quality sample sites on the Little River system; number in parenthesis is downstream distance from the dams (km).

METHODS

Water samples were collected in February (reservoirs unstratified) and August (reservoirs stratified) 1980. Water temperatures, specific conductance, dissolved oxygen, alkalinity, and pH were measured at selected depths in the reservoirs and in the rivers. Additional water samples for determinations of total iron, total manganese, and ammonia nitrogen were preserved with dilute sulfuric acid and returned for analysis by the Chemistry Department of Ouachita Baptist University.

Particulate matter was analyzed from 10 ℓ sample of surface water. Coarse particulate matter was that portion retained after filtration of the 10 ℓ sample through an 80-μm mesh net. A 950 mℓ sample of filtrate was filtered through a pre-ashed and preweighed glass fiber filter paper to obtain fine particulate matter. This filtrate was retained and about 500 mℓ was dried at 105 °C to determine total dissolved solids (TDS). Filter papers with coarse and fine particulate matter were dried at 60 °C for 24 h, desiccated, and reweighed. Inorganic portions of the particulate matter (total inorganic matter, TIM) were determined by ashing the filter papers at 550 °C for 20 minutes. Organic portions (total organic matter, TOM) were determined by subtracting inorganic matter from total particulate matter. Results were expressed as milligrams per liter.

Not all water quality measurements were taken at or near minimum flow conditions, due to releases from the various reservoirs. The Little River samples near the Cossatot River confluence in February were collected when Pine Creek and DeQueen Lakes were releasing water near minimum flow. However, release from Broken Bow Lake, Oklahoma, was high due to power generation. In August, some Little River sampling stations were measured when 14.2 m^3/sec was being released from Pine Creek Lake to flush out the tailwater.

RESULTS

In February, concentrations of total iron, total manganese, and TIM were higher in the Little River than in the Glover River, and these higher concentrations persisted below the confluence of the two rivers. Ammonia nitrogen was higher below their confluence than upstream in the Little River (Stations 2-4) or in the Glover River (Station 5). All other characteristics measured in February from the Little and Glover rivers were similar (Table 1).

Cossatot River temperatures in February increased as distance downstream increased, probably as a function of time of day when samples were collected. All other characteristics measured in the Cossatot River were within the ranges of sampling and analytical error. Conductivity and TIM were higher and temperature and dissolved oxygen lower in the Little River near the Cossatot River confluence than in the Cossatot River. These Little River characteristics were probably influenced by water from Broken Bow Lake during the February sampling period (Table 1).

Pine Creek and Gillham lakes were not stratified in February, and no concentration of ions within the water column was apparent. Mean concentrations of TOM were similar for the two tailwaters but slightly higher than that for the unimpounded Glover River. Mean TDS and conductance in the Little and Glover rivers were similar but higher than measured in the Cossatot River (Table 2). Higher mean TIM in the Cossatot River than in Gillham Lake was possibly due to the suspension of substrate particles in the tailwater from higher than minimum flow discharge before the samples were taken. Other physicochemical variables sampled in February from the Little, Cossatot, and Glover rivers were similar, and no significant variation between the rivers was apparent.

In August, the hypolimnion in Pine Creek Lake began 2 m below the lake surface, 4.6 m above the upper low flow intake gate. Comparisons of the physicochemical characteristics from the Little River

Table 1. Water quality characteristics from the Little, Glover, and Cossatot rivers, February 1980.

Sites[1]	Temperature (°C)	Conductivity (μmhos/cm)	Dissolved oxygen (mg/1)	pH	Alkalinity (mg/1 as $CaCO_3$)	Total iron (mg/1)	Total manganese (mg/1)	Ammonia nitrogen (mg/1)	Total organic matter (mg/1)	Total inorganic matter (mg/1)	Total dissolved solids (mg/1)
1	6.5	61.0	10.2	6.2	21.5	0.4	0.1	0.20	1.30	3.86	12.7
2	9.0	41.0	11.8	6.2	10.9	0.6	0.1	0.30	2.13	3.80	39.8
3	6.0	49.0	11.9	5.8	10.5	0.5	0.1	0.20	0.97	3.74	44.6
4	5.8	53.0	11.3	5.8	16.5	0.8	0.2	0.20	2.26	3.94	55.6
5	7.0	48.0	12.3	6.2	16.5	0.4	0.0	0.20	1.04	3.16	49.0
6	7.0	52.0	12.2	5.8	20.7	0.9	0.2	0.70	1.29	4.34	31.6
7	10.5	55.0	9.2	5.9	19.0	-	-	0.40	1.79	4.96	31.0
8	10.1	48.0	9.2	5.8	19.8	-	-	0.40	1.59	5.34	48.3
9	7.0	34.0	10.0	6.0	8.2	-	-	0.02	1.96	4.05	35.3
10	8.0	40.0	11.5	6.2	7.8	-	-	0.00	1.44	3.60	34.9
11	7.5	41.0	11.8	5.8	12.0	-	-	0.07	1.75	3.20	36.5
12	7.0	32.0	10.8	5.8	15.0	-	-	0.03	1.29	2.45	40.6
13	9.0	32.0	11.4	5.7	34.1	-	-	0.04	1.47	3.37	39.0
14	13.0	39.0	10.4	5.6	15.5	-	-	0.03	1.75	3.72	36.0

[1] See Figure to site locations.

in August were also complicated by increased discharge before and during the collection of the water samples. However, because rainfall was low before sampling, downstream water came primarily from the reservoir. Temperature, TIM, and TDS increased with increased distance downstream from Pine Creek Lake (Table 3). Total inorganic matter increased following the increased reservoir release. Dissolved oxygen, total iron, total manganese, and TOM all decreased with increased distance below the reservoir. Measurements of total iron and manganese at Station 6 were higher after the reservoir discharge increased. Low stream flow in the Glover River, due to the dry conditions in August, resulted in lower dissolved oxygen and TIM and higher conductance in the Glover River than in the Little River. Other variables measured in August from the Little and Glover rivers were similar, and no trends were evident (Table 3).

The hypolimnion in Gillham Lake began 6 m below the lake surface, 1.4 m below the upper low flow intake gate. In August, TDS and conductivity increaed with increasing distance downstream from Gillham Reservoir. Low rainfall near the Cossatot River resulted in lack of dilution and a high evaporation rate (ca. 0.8 cm/day), causing an increase in the ionic strength, which along with geochemical interactions of the water were probably responsible for the higher downstream TDS and conductance. TIM increased near Station 12 on the Cossatot River, then decreased farther downstream. Temperature, TOM, and TDS increased, and the dissolved oxygen, TIM, and conductance decreased below the confluence of the Little and Cossatot rivers. Other variables measured in the Cossatot and Little rivers near their confluence were similar (Table 3).

Physicochemical characteristics differed more within and between the rivers in August than in February. Mean concentrations of TOM, TIM, TDS, and conductance were all higher in the Little River than in the Cossatot River. Mean TOM and TDS in the Glover River were similar to those in the Little River, but mean TIM was 50% lower in the Glover River (Table 2).

Table 2. Mean water quality characteristics of selected variables during February (F) and August (A) 1980.

	Total organic matter (mg/ℓ)		Total inorganic matter (mg/ℓ)		Total dissolved solids (mg/ℓ)		Conductance (µmhos/cm)	
	F	A	F	A	F	A	F	A
Gillham Lake	1.96	0.44	1.44	3.62	35	35	34	33
Cossatot River	1.55	1.44	3.27	3.37	37	37	37	33
Pine Creek Lake	2.10	1.84	3.86	0.35*	13*	41	61	76
Little River	1.66	1.63	3.38	4.87	43	66	49	76
Glover River	1.04	1.53	3.16	2.41	49	67	48	64

*May be due to analytical error

Table 3. Water quality characteristics from the Little, Glover, and Cossatot rivers, August 1980.

Sites [1]	Temperature (°C)	Conductivity (µmhos/cm)	Dissolved oxygen (mg/ℓ)	pH	Alkalinity (mg/ℓ as $CaCO_3$)	Total iron (mg/ℓ)	Total manganese (mg/ℓ)	Ammonia nitrogen (mg/ℓ)	Total organic matter (mg/ℓ)	Total inorganic matter (mg/ℓ)	Total dissolved solids (mg/ℓ)
1	24.5	50.0	0.2	6.4	38.0	2.6	1.5	0.20	1.84	0.35	40.8
2[2]	27.0	49.0	5.7	6.5	30.0	1.9	1.4	0.30	1.47	2.14	50.3
3[2]	24.0	44.0	5.5	6.4	39.0	2.6	1.8	0.60	1.46	5.45	52.3
4[2]	29.0	51.0	4.8	6.5	29.0	1.4	0.9	0.30	2.11	5.29	53.6
5	28.5	64.0	4.0	6.3	52.0	0.6	0.2	0.20	1.51	2.41	67.4
6a[2]	31.0	-	4.8	6.5	43.8	0.5	0.5	0.20	1.05	5.38	88.5
6b[2]	30.5	97.0	4.7	6.8	48.0	1.0	0.9	0.20	2.04	6.08	54.2
7	28.0	42.0	6.6	6.6	17.0	0.7	0.0	0.01	1.44	3.93	48.8
8	31.0	33.0	5.9	7.4	19.0	0.5	0.1	0.00	3.75	1.78	78.0
9	29.0	33.0	3.6	6.7	20.0	0.8	0.1	0.00	0.34	3.62	34.9
10	30.0	36.0	8.6	7.0	21.0	0.6	0.1	0.01	0.66	1.98	30.6
11	30.0	32.0	7.7	6.9	23.0	0.6	0.1	0.00	2.48	2.47	31.8
12	30.0	36.0	8.4	6.7	21.0	0.6	0.1	0.00	0.24	5.42	36.4
13	30.0	36.0	7.4	6.8	21.5	0.9	0.1	0.01	2.03	4.16	38.1
14	31.0	48.0	5.5	7.0	19.0	0.6	0.2	0.01	1.82	2.84	46.0

[1] See Figure for site locations.

[2] Note: Little River sample Sites 1, 2, and 6a were measured before, Site 3 during, and Sites 4 and 6b after a 14.2 cms discharge from Pine Creek Lake.

DISCUSSION

The quality of the water released from the reservoirs in winter (February) appeared to have little effect downstream. In summer (August), Pine Creek and Gillham lakes were physically and chemically stratified, and discharge from both reservoirs had been at low flow since early July. The downstream effects of water released from the reservoirs in the summer depended on intake elevations within the reservoirs.

Gillham Lake appeared to have no adverse effects on downstream water quality, even when the reservoir was stratified. Chemicals that might have been detrimental to water quality in the Cossatot River were present in the reservoir but were below the 5 m release level. Influence from the Cossatot River flowing into the Little River was shown by increased temperature, TOM, and TDS below the confluence of the two rivers, especially in August. Particulate matter samples may have been influenced by the mixing of the two systems.

The Little River below Pine Creek Lake was more turbid than the other rivers, particularly in August, when the water released from the reservoir was from an anoxic hypolimnion. High amounts of the reduced forms of iron, manganese, and ammonia nitrogen and sulfur were released into the tailwater. At or near minimum flow, aeration through the outlet structure and over the substrates allowed for the dissipation of ammonia and sulfides and some precipitation of iron and manganese oxides. However, the increased discharge (14.2 m^3/sec) to flush out the tailwater after a prolonged period of low flow, permitted hypolimnetic water with high total iron, total manganese, and ammonia nitrogen to move farther downstream (Station 3; 2.1 km) before the metals precipitated or the ammonia dissipated. Total inorganic matter was also higher downstream (Station 4; 12.1 km), possibly as a result of the suspension of inorganic materials from the substrates by the increased flow. At the reservoir release levels (6 m at low flow and 19.8 m at flows above 4.2 m^3/sec), flushing of the Little River system below Pine Creek Lake with a flow of 14.2 m^3/sec, carried hypolimnetic reservoir water farther downstream (36.5 km), without a reduction in certain, possibly detrimental chemicals, by precipitation or aeration.

The practice of releasing high volumes of water from reservoirs to flush out a tailwater system should be carefully analyzed. Thermal and chemical stratification occurs in many reservoirs during the summer, while the multi-level discharge gates are possibly in an anoxic zone containing high levels of undesirable chemicals. Under low flow conditions, water released through the outlet structure may change its chemical properties after aeration and precipitation, becoming more suitable for aquatic life. However, increased discharges from the anoxic zone or from floodgates located on the bottom of gate tower structures does not allow for the aeration or precipitation to occur near the dam. Results from this study and a study below Buford Dam, Georgia (Grizzle, Trans. Am. Fish. Soc. 110 (1):29-43, 1981) showed that the anoxic water, with increased amounts of the reduced forms of various chemicals, may be carried farther downstream during high volume water releases, possibly increasing the distance donstream in which the invertebrate and fish communities may be stressed.

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