Journal of the Arkansas Academy of Science

Volume 38 | Article 19

1984

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WATER QUALITY IN THE GILLHAM LAKE-COSSATOT RIVER SYSTEM DURING DRY AND WET PERIODS*

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ABSTRACT

Water samples were collected in the Cossatot River-Gillham Lake system during an extended dry period and after heavy rains to determine the spatial variations in certain water quality characteristics. Of particular interest was the influence of the reservoir discharge on the water quality of the tailwater compared with the effects of four tributaries entering the tailwater below the reservoir. The water quality of the Cossatot River below Gillham Lake at low-flow (dry periods) and during the first 3 days after heavy rainfall (wet period) was influenced more by the tributaries entering the tailwater than by the reservoir water release. We estimated, however, that the amount of particulate inorganic matter released to the tailwater from the reservoir after the initial 3-day wet period would be greater than the amounts entering the tailwater from the tributaries.

INTRODUCTION

Reservoirs can be regulated to benefit downstream environmental quality, however, many requirements for downstream habitats and biota are not totally understood or substantiated. Changes in various physicochemical characteristics associated with reservoir water release greatly influence the composition and abudnance of species in the tailwater communities. Methods for determining the quality, quantity, and timing of reservoir water release to maintain the tailwater ecosystem are inadequate. In 1979 the National Reservoir Research Program (U.S. Fish and Wildlife Service) and the Waterways Experiment Station (U.S. Army Corps of Engineers) began a cooperative study to evaluate environmental criteria and operational methods applicable for the maintenance of desirable tailwater aquatic habitat and associated biota (Walberg et al., 1981; Walberg et al., 1983).

Water quality measurements during the 3 year study period were taken in Gillham Lake, Arkansas, and in the Cossatot River downstream from the dam structure. Periodic collections of water samples were adequate to understand some water quality relationships during the related time periods; however, spatial variation of water quality characteristics could not be determined, particularly with regard to tributary influence on the tailwater system during extended dry periods and after heavy rainfall. We therefore began a short term study in 1981 to investigate the spatial variation of water quality in the Cossatot River-Gillham Lake system during an extended dry period and after heavy rains.

STUDY AREA

Gillham Lake (153 m above mean sea level) is a 554-ha multipurpose U.S. Army Corps of Engineers impoundment on the Cossatot River in the Little River drainage of southwest Arkansas. The reservoir was designed with multiple level water release outlets at 4.5 and 9.0 m below conservation pool to maintain lowflow (1.5 to 4.2 m^3/sec) into the tailwater, and at 19.7 m below conservation pool to discharge higher flows (4.2 to 85 m^3/sec). The lake has a drainage area of 702 km^2 and a storage ratio of 0.1. The average annual rainfall near Gillham Lake is 137.2 cm.

We selected 10 sample collection sites that would best describe the Cossatot River above and below the reservoir, the reservoir itself, and the major tributaries that might influence the water quality within the tailwater (Fig. 1).

METHODS

In situ measurements of water temperature, dissolved oxygen, pH, and specific conductance were taken with a Hydrolab model 8000**** at mid-depth at all riverine sample sites and at 1 m intervals at the two reservoir stations. We collected water samples (500 mL) at about 3-m depth intervals in the reservoir, and at mid-depth at the other sampling sites. The samples were acidified (pH less than 2) with H_2SO_4 and returned to the laboratory for analysis of total iron and manganese. An additional 10-L sample of water from each location was filtered through an 0.08-mm mesh net to retain coarse particulate matter. A 1-L subsample of the filtrate was vacuum pumped through a preweighed glass-fiber filter paper to retain fine particulate matter. The filtrate (100 mL) from the fine particulate matter was used for analysis of total dissolved solids.

Total iron and manganese were analyzed by atomic absorption spectrophotometry at the chemistry department of Ouachita Baptist University. The coarse particulate matter samples were retained on a glass-fiber filter paper for drying. The coarse and fine particulate matter filter papers were then oven dried at 60 °C for 24 hours. Inorganic portions of coarse and fine particulate matter were determined by ashing the samples at 550 °C for 20 minutes (American Public Health Association et al., 1976).

The dry period was characterized by continuous low-flow discharge (1.5 m^3/sec) from the reservoir for 41 days prior to sampling on October 1, 1981. A single rainfall (2.3 cm) occurred 17 days before sampling however, it did not raise the lake level.

A wet period (defined as occurring immediately after $>$ 5.0 cm of rain fell within a 48-hour period) did not develop in the Gillham Lake watershed until January 20, 21, and 22, 1982, when 1.65, 1.73, and 2.4 cm of rainfall occurred, respectively. The lake level during that time rose 7.2 m. During sampling on January 23, reservoir discharge was increased from 1.5 m^3/sec to 18.7 m^3/sec one-half hour before we began collecting water samples in the tailwater.

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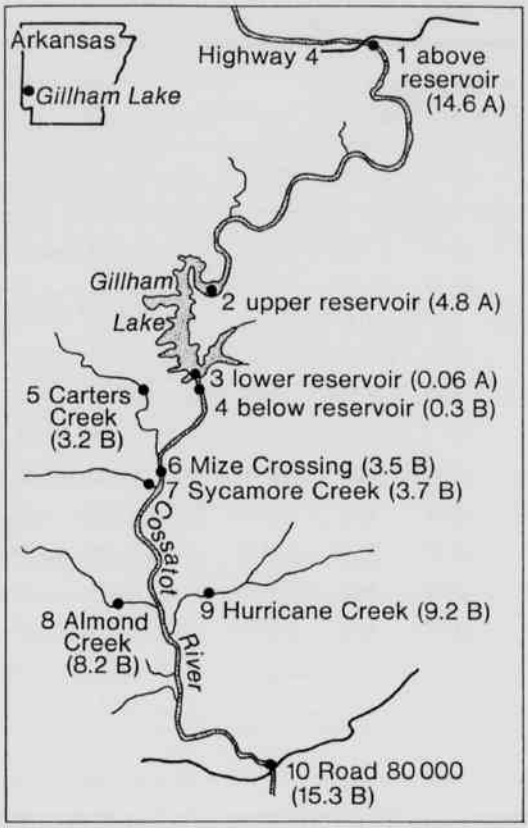

Figure 1. Water quality sampling stations in Gillham Lake watershed; numbers following station names show distance in kilometers above (A) and below (B) the dam.

Low-flow discharge into the tailwater during the dry period (1.5 m^3/sec) was only from the upper low flow gate, 4.5 m below conservation pool level. Discharge during the wet period (18.7 m^3/sec) was from all three reservoir release levels (4.5, 9.0, and 19.7 m below conservation pool).

RESULTS

Reservoir

During dry conditions, temperature variation within the water column was small at sampling sites in the upper and lower reservoir (Stations 2 and 3, respectively). However, an oxycline occurred at 5 m in the upper reservoir and at 7 m in the lower reservoir. A stable anoxic hypolimnion (dissolved oxygen, $<$ 0.5 mg/L), in the lower reservoir led to chemically reduced conditions and higher amounts of total iron and manganese and total dissolved solids than in the upper reservoir (Table 1).

****Mention of trade names of manufacturers' does not imply U.S. Government endorsement of commercial products.

Temperature and dissolved oxygen profiles at both reservoir stations showed little variation during the wet period. However, a spate at Station 2 in the upper reservoir contained allochthonous materials from the Cossatot River above the reservoir and from the tributaries entering the reservoir above the sampling site. Total particulate organic matter (POM) was 3.5 times greater and total particulate inorganic matter (PIM) 40 times greater in the upper reservoir where samples were collected within the spate, commpared to the lower reservoir. Total iron and total dissolved solids were also greater in the freshet indicating leaching of the soils during runoff (Table 1).

River

Dry Period: Flows within the tributaries that empty into the tailwater normally ranged from 0.08 to 0.42 m^3/sec. During the dry period the surface flow within the tributaries appeared to be negligible. However, hyporheic and subterranean flow from the tributaries apparently influenced some physicochemical characteristics in the tailwater. Dissolved oxygen decreased and total iron increased at Station 6, (Mize Crossing, Fig. 1) in the tailwater below the outfall of Station 5, (Carters Creek). Water temperature downstream decreased slightly as a result of the lower water temperatures in the three tributaries entering the tailwater below Station 6. Conductivity and total dissolved solids in the tailwater showed little spatial variation, even though values in the tributaries were nearly two times greater (Table 2).

Concentrations of coarse particulate organic and inorganic matter below the dam (Station 4) were similar to those in the lower reservoir. Allochthonous material in Carters Creek resulted in increased coarse POM and coarse PIM at Station 6 in the tailwater. At Station 10 (Road 80000) the amounts of particulate matter decreased, with no apparent influence from the other tributaries (Fig. 2).

Fine POM was higher in the tailwater below the dam than in the lower reservoir. Higher values of fine POM and fine PIM were recorded at Station 6 below the outfall from Carters Creek. Both fine POM and PIM continued to increase with increasing distance downstream. The tributaries entering the tailwater (Carters, Sycamore, Almond, and Hurricane Creeks) and erosional effects of flow within the tailwater increased the amount of fine POM and PIM within the tailwater, even though surface flow from the tributaries was not evident (Fig. 2).

Wet Period: Flow in the Cossatot River above Gillham Lake (Station 1) during the wet period was about 56 m^3/sec, as a result of 5.8 cm of rainfall. The initial runoff which contained large amounts of allochthonous material had passed Station 1 when samples were collected. However, total dissolved solids and total iron concentrations in the upper reservoir (Station 2) were high as a result of the freshet which did not move from the upper reservoir during the sampling period. The reservoir water discharged into the tailwater, therefore, was not influenced by the spate. Carters Creek, which drains mainly agricultural land, contributed to the higher concentrations of total iorn, total dissolved solids, and conductivity at Station 6 in the tailwater. Additional iron from the other three tributaries (Stations 7, 8 and 9) below Station 6 resulted in additional total iron and total dissolved solids at Station 10 in the tailwater (Table 2).

Coarse POM was low at both reservoir sample sites, even though fine POM was more than twice as great in the upper reservoir. In the tailwater and tributaries course and fine POM were without a pattern (Fig. 3).

Carters Creek contained high amounts of coarse PIM, which resulted in high amounts at Station 6. However, measurements of course PIM at Station 10 were lower than at Station 6, as a result of dilution by Sycamore, Almond, and Hurricane Creeks. Fine PIM was very high in the upper reservoir as a result of the surge of flood water but was low in the lower reservoir, which had not yet received the water from the upstream freshet. Fine PIM in the tailwater increased progressively with distance downstream. Increased reservoir discharge resulted in higher flow (18.7 m^3/sec) at the tailwater dam site and at Station 6; however, the increased flow had not reached Station 10 when samples were collected. Therefore, the higher fine PIM downstream (Station 10) was contributed by Almond and Hurricane creeks (Fig. 3).

Table 1. Profiles of certain water quality characteristics during dry (October 1981) and wet (January 1982) periods in Gillham Lake, Arkansas.

Section of reservoir and depth (m)	Iron (mg/L)		Manganese (mg/L)		Particulate matter mg/L				TDS (mg/L)		Conductance (µ mhos/cm)	
					Organic		Inorganic					
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Upper												
1	0.1	0.1	0.1	0.0	2.50	2.79	1.46	50.29	44.8	57.2	53	48
4	0.1	0.5	0.1	0.0	2.84	3.87	0.15	46.68	37.8	54.7	56	48
7	0.2	0.5	0.1	0.0	1.39	4.85	2.20	79.36	38.6	53.3	58	52
10	0.2	0.9	0.1	0.1	2.59	5.81	1.93	125.53	-	66.5	65	52
13	0.7	1.9	0.5	0.1	2.61	3.27	1.48	98.01	39.6	68.5	93	53
Lower												
1	0.2	0.1	0.2	0.0	2.61	0.62	1.06	2.83	36.4	36.2	53	53
4	0.0*	0.1*	0.1	0.0	2.44	0.83	0.11	1.63	32.8	36.4	53	53
7	0.0	0.0	0.0	0.0	2.56	1.73	0.38	1.70	31.8	37.7	52	53
10	0.1	0.0*	0.3	0.0	2.16	1.16	1.42	1.70	36.5	37.1	64	53
14	2.5	0.1	0.7	0.0	1.89	1.33	1.47	1.70	47.3	37.2	79	53
17	3.9	0.0*	0.9	0.0	1.48	1.20	0.58	1.91	53.0	-	99	53

[1]TDS - Total dissolved solids
*Gate levels for reservoir water release

DISCUSSION

The changes in inorganic matter between the dry and wet periods was due to differences in the amounts of allochthomus matter entering the system during October and January. However, the changes in organic matter between the dry and wet periods were not due to differences in allochthonous matter (leaf litter) during October and January but to autochthonus differences in standing stocks of algae and zooplankton and to dilution from increased water volumes during the wet period. Other variables may have been influenced by the seasonal variation; however, discussion of these variables is limited to comparisons within the dry or wet periods.

As discharged reservoir water moves downstream, it is typically influenced by local conditions that tend to characterize each tailwater (Pfitzer, 1954). During dry conditions and within about 3 days after heavy rainfall, certain physicochemical conditions in the Gillham Lake tailwater were influenced by its tributaries, and not by reservoir water release.

During dry conditions, the tailwater tributaries (Carters, Sycamore, Almond, and Hurricane creeks) became a series of disconnected pools. Seepage between these pools by way of hyporheic and subterranean flow caused the changes in tailwater temperature, dissolved oxygen, and total iron. However, increased conductivity that typically occurs downstream at low-flow (Hynes, 1970; Smith, 1982) was not apparent in the tailwater. During the wet period in January water temperature, conductivity, total dissolved solids, and total iorn increased downstream. The tributaries, especially Carters Creek, were responsible for these changes, even though water was being released at a higher rate from the reservoir.

During dry conditions POM was 21% greater below Gillham Lake than in the water entering the lake. Sedimentation within a reservoir results in reduced passage of detritus into the tailwater; therefore, the organic matter that is important in natural streams for energy transformation is usually not as available in a tailwater stream (Walburg et al., 1981). However, autochthonous POM from within the reservoir (usually plankton) will sometimes yield substantially higher amounts of organic matter below an upper level release reservoir in comparison to a hypolimnetic release reservoir (Maciolek and Tunzil, 1968; Lind, 1971; Spence and Hynes, 1971). Plankton collections were not made during the present short-term study; however, zooplankton was sampled during the summer in 1979, 1980, and 1981 (Smith, 1983; U.S. Fish and Wildlife Service unpublished data). These collections indicated that during the periods corresonding to the dry period, zooplankton populations were usually concentrated in the epilimnion, at the same level as the release gate. During wet conditions, POM was 9% higher below Gillham Lake than above the lake. Vertical distributions of zooplankton during periods that correspond to the wet conditions were uniform throughout the unstratified water column and their densities were therefore much lower.

Farther downstream in the tailwater (Station 10), POM increased during the dry period as a result of a cumulative effect from tributary influence and allocthonous input of some leaf litter. During the wet period, tailwater POM was slightly higher at Station 6 due to the initial surge of reservoir water that had reached the collection site. Collections there (3.5 km below the dam) were made 1 hour after reservoir

Table 2. Physiocochemical characteristics at sampling locations in Gillham Lake and in the Cossatot River and its tributaries, during dry (October 1982) and wet (January 1982) periods.

Station	pH		Conductance (µmhos/cm)		Total dissolved solids (mg/L)		Total manganese (mg/L)		Total iron (mg/L)	
No. Description	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1 Above reservoir	6.6	5.8	36	41	54	33	0.0	0.1	0.0	0.01
2 Upper reservoir (profile mean)	5.8	5.8	65	51	33	60	0.2	0.04	0.26	0.96
3 Lower reservoir (mean at release gate levels)[1]	5.9	6.0	53	53	32	37	0.1	0.0	0.0	0.03
4 Below dam*	6.2	5.9	54	54	31	34	0.1	0.0	0.1	0.0
5 Carters Creek	6.4	6.0	159	70	136	76	0.1	0.0	0.4	0.7
6 Mize Crossing*	6.4	5.8	54	59	39	52	0.1	0.1	0.2	0.6
7 Sycamore Creek	6.2	6.0	80	55	40	51	0.1	0.1	0.1	0.5
8 Almond Creek	6.0	5.2	66	56	56	57	0.1	0.0	0.3	0.5
9 Hurricane Creek	5.1	5.8	98	58	75	66	0.2	0.0	0.6	0.5
10 Road 80000*	6.4	5.8	58	61	32	60	0.1	0.1	0.1	0.8

*Tailwater

[1]Water release was at 4.5 m below conservation pool during dry period and 4.5, 9.0, and 19.7 m below conservation pool during wet period.

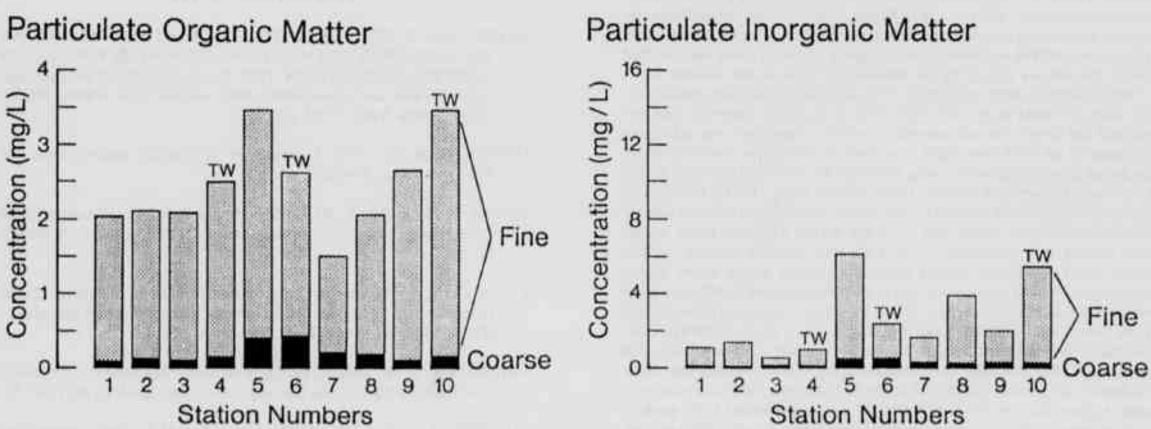

Figure 2. Fine and coarse particulate organic matter (left panel) and inorganic matter (right panel) during the dry period, October 1, 1981, in the Gillham Lake watershed. Fine particulate matter shown by the open portions of bars, and coarse particulate matter by shaded portions (TW - indicates tailwater sampling station).

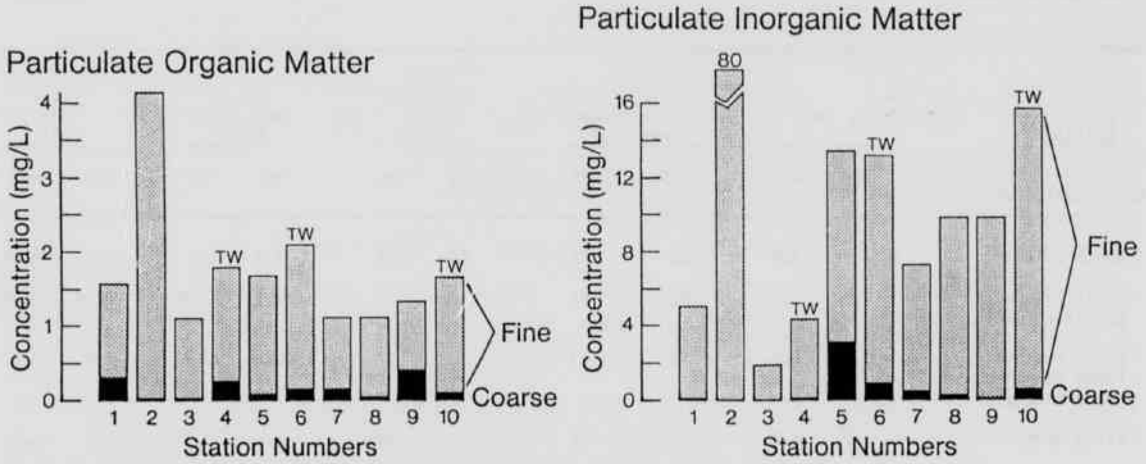

Figure 3. Fine and coarse particulate organic matter (left panel) and inorganic matter (right panel) during the wet period, January 23, 1982, in the Gillham Lake watershed. Fine particulate matter shown by the open portions of bars, and coarse particulate matter by shaded portions (TW - indicates tailwater sampling station).

discharge had been increased to 18.7 m^3/sec. Matter et al. (1983) found more POM during the initial surge of water from generation than during to pregeneration or during high flow. At Station 10, the surge of water from reservoir release had not reached the sampling station when samples were collected, resulting in lower POM there than at the upstream stations.

During dry conditions, PIM from the upper reservoir precipitated as the water moved through the reservoir. This precipitation resulted in values of PIM near the release gate in the lower reservoir of about half of the amount found in either the water entering the lake or in the upper reservoir. The PIM below the dam was higher than wighin the reservoir at the release gate level, due to resuspension of inorganic riverbed materials from the turbulence created by the reservoir water release. However, tributaries (especially Carters Creek) were the major contributors of PIM to the tailwater. The PIM in the tailwater increased as distance downstream increased. Additional input for the other tributaries and the suspension of inorganic material from the riverbed had a cumulative effect on the amount of PIM at the Station 10.

When samples were collected in Gillham Lake during wet conditions, the surge of flood water with high PIM in the upper reservoir had not reached the lower reservoir sampling stations. Therefore, we calculated the amount of PIM that might have been available for reservoir water discharge into the tailwater, using formulas for turbidity decrease within a reservoir (Jones and Rogers, 1952; Soltero et al., 1973). Particulate inorganic matter and turbidity were closely related and showed similar trends (correlation coefficient $r = 0.95$) within Gillham Lake watershed during wet conditions (U.S. Fish and Wildlife Service unpublished data). Turbidity usually decreases sharply as the water moves downstream within a reservoir, due to sedimentation of inorganic matter within a basin (Symons et al., 1964). However, increased lake volume from runoff into Gillham Lake would result in a smaller storage ratio (normally 0.1) and therefore, less sedimentation. Consequently, the amount of PIM that may have been discharged into the tailwater from Gillham Lake as a result of the spate in the upper reservoir was probably higher than the amount measured during the initial 3 day period.

In summary, the tributaries (particularly Carters Creek) had a greater effect on water quality in the tailwater during dry conditions and during the initial 3 days after heavy rains, then did the water released from the reservoir. However, estimates of PIM that may have been included in the reservoir water discharge following the initial wet period indicated that higher amounts of PIM may have entered the tailwater from water released from the reservoir than from the tributaries entering the tailwater.

ACKNOWLEDGMENTS

We thank Michael R. Dewey for his assistance in making the field collections. This study was supported in part by the U.S. Army Corps of Engineers Waterways Experiment Stations under interagency agreement.

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