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Article 161

EFFECT OF TREE LEAVES ON WATER QUALITY IN THE CACAPON RIVER, WEST VIRGINIA

By KEITH V. SLACK, Washington, D.C.

Abstract.—Accumulation of leaf litter in pools at low flow increases water color and results in marked changes in water composition. Temperature decreases rapidly from surface to bottom in the shallow pools. Dissolved-oxygen concentration decreases, but concentrations of many other solutes increase directly with water color. A film, believed to be ferric hydroxide, occurs on the surface of pools in which decomposition of litter is especially intense. Flushing of the pools by a rise in stream stage reduces the color and improves water quality.

Changes in water composition resulting from natural additions of organic matter were investigated as part of a study of biological influences on water quality of streams. Previous work in Indiana indicated that the autumnal accumulation of tree leaves in streams coincident with the annual low-flow period occurs widely and is important in cycling of elements in nature. This accumulation is unusual in that it represents a natural environment in which decomposition greatly exceeds production of new organic matter. The environment is marked by low dissolved-oxygen concentration and considerable water color, which presumably is due to decomposition of plant material. Although of short duration, the condition seriously degrades water quality and can result in the death of aquatic organisms.

The literature contains many references to the effects of leaf litter on the chemical quality of streams; for example, Schneller (1955) and Slack (1955) reported that the decay of leaves in pools generally resulted in greater water color and in the formation of free CO_2 and lower dissolved-oxygen concentrations. Sylvester (1959) reported that replacement of native coniferous forests with deciduous trees in the Wenatchee River basin, Washington, resulted in increased water color. Hynes (1960) described Huet's (1951) work, which indicated that a substance toxic to fish was derived from needles of spruce and red cedar. Chase and Ferullo (1958) showed that leaves deplete dissolved oxygen under aerobic conditions in the laboratory; after 386 days, maple leaves had consumed a weight of oxygen equivalent to 75 percent of their initial dry weight. In the same length of time, oak leaves and pine needles exerted oxygen demands of about 50 percent of their dry weight. Myers (1961) suggested that manganese in San Clemente Reservoir, Calif., was leached from oak trees in the watershed. Robinson and others (1958) showed that leaves of hickory trees concentrated rare-earth elements to a remarkable degree. Thus, various species of trees may make widely differing chemical contributions to streams through leaf litter.

Discolored water is neither a perennial phenomenon nor does it occur in all streams. Frequent rains during the peak leaf-fall period may flush the organic load downstream and dilute substances leached from the fresh leaves. The most favorable conditions for development of discolored water are a pooled stream with little or no surface flow and with stands of deciduous trees near the channel.

Discoloring of water begins when tree leaves begin to drop, usually in September. The freshly shed leaves accumulate at the downstream end of pools, where they float on the surface at first but gradually sink to form a blanket over the streambed; later arrivals replenish the surface layer. Eventually the lower ends of pools become filled with a waterlogged mass of leaves that may inhibit flow over riffles. Unless there is a rise in stage and a flushing and exchange of water in the pool, a critical period is established.

As the waterlogged leaves decompose by bacterial action, the supply of dissolved oxygen in the pool is depleted. Although decomposition of the leaves causes an increase in the mineral content of the water, the amount of the increase attributable to factors such as leaching of soluble substances from leaves, concentration by evaporation, mineral-matter release from sedi-

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ments by organic complexing and chemical reduction, and bacterial breakdown of leaf tissue is not known. The literature indicates that all these processes must be considered. In early stages of decomposition the color of the pool water closely resembles that of bog water. Under extreme conditions, the water acquires an inky appearance, which gives rise to the name "black water" in parts of the Midwest where discoloration is common.

STUDY OF THE CACAPON RIVER, W. VA.

A reach of the Cacapon River, Morgan County, W. Va., about 14 stream miles above the mouth where a series of elongate wooded islands extend parallel to the river bank, was selected for detailed study. At times of low flow, the channel which normally separates these islands from the right bank of the river becomes dry or is reduced to a few pools. Discolored water was general in the pools and in partly isolated marginal waters along this reach in October 1961.

Three different environments, shown on figure 161.1, were sampled: (a) a riffle of the Cacapon River about 18 centimeters deep; (b) a slightly colored pool or backwater channel, which was connected with the river and in which the intensity of color increased with distance from the river, sampled at the upper end, about 5 meters from its junction with the main stream; and (c) an isolated highly colored pool about 6½×3 m in area, at the base of a steep bank. In addition, a moderately colored pool (d) was sampled as part of a temperature study on October 30, 1961 (table 161.3). The reach of river studied was shaded by a hardwood forest consisting of the following kinds of trees: maple, cottonwood, tulip tree, blue beech, sycamore, elm, dogwood, aspen, and oak. Many kinds of deciduous leaves were visible in the water on October 22, 1961, the date of the initial sampling, and most had sunk to the bottom.

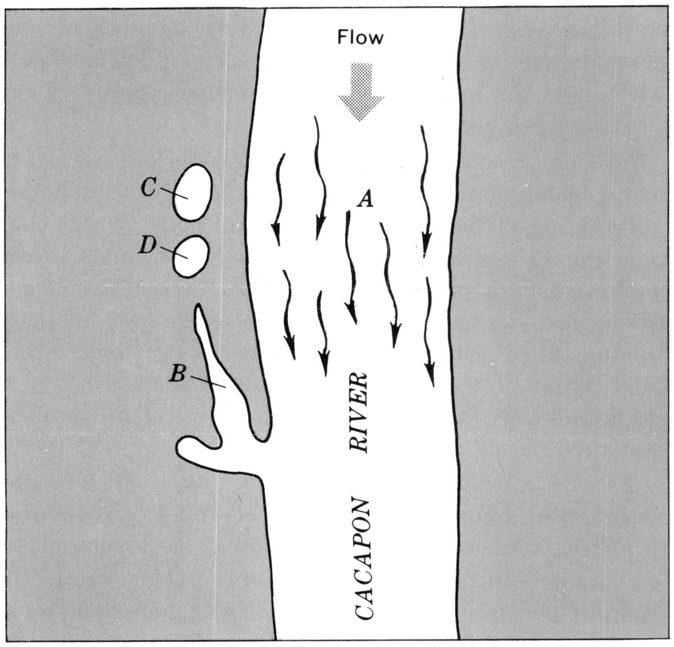

Figure 161.1—Sketch showing sampling sites on the Cacapon River, Morgan County, W. Va. *A*, riffle on the river; *B*, slightly colored pool; *C*, highly colored pool; and *D*, moderately colored pool.

Chemical composition

The chemical composition of the water of the river and the pools is shown in tables 161.1 and 161.2, which permit comparison between sampling sites on a single date and on different dates. The tables show that concentrations of many substances tend to increase as water color increases, although calcium, bicarbonate alkalinity, dissolved solids, and specific conductance, all were higher in the slightly colored pool (*B*) than in the highly colored pool (*C*). The appearance of the ground on October 22 and 29 suggested that water from the main channel had recently flowed into the highly colored pool (*C*), although the composition of water of the channel and the pool differed greatly. Pool C was separated from the river by a low mound of wet leaves and rocks about 1 m in width. Wet masses of a green alga (*Oedogonium*) covered much of this barrier; however, the fresh appearance of the algae must have resulted from a light rain recorded on October 21, because streamflow records show no significant rise of the river during October.

The low calcium and carbonate concentrations of the highly colored pool (*C*) could be explained in various ways; for example, much of its water could have been derived from local runoff or dilute ground water containing alkalies leached from the leaves. Another possibility is that ion-exchange reactions between the leaf material and the pool water produced water enriched in alkalies but depleted in calcium and bicarbonate (Hutchinson, 1957, p. 573). Still another explanation is that snails (*Gyraulus*) inhabiting this isolated pool extracted calcium carbonate from solution for shell formation, thus causing a lower calcium concentration. The volume of the highly colored pool was roughly 2,000 liters, indicating a deficit of 18.5 milligrams of calcium per liter compared with the calcium content of the other waters sampled, or a total loss of 37 grams. If this quantity were spread among an estimated population of 100 snails, the necessary uptake of 0.37 g calcium or 0.92 g calcium carbonate per animal would seem excessive for this thin-shelled form. However, without better population data the possibility of biological utilization cannot be excluded as a factor causing depletion of calcium carbonate in the highly colored

TABLE 161.1.—*Water properties at three sampling sites, Cacapon River, W. Va., during autumn 1961* [1]

[Analyses by H. R. Feltz, Washington, D.C.]

	October 22			October 29			November 19		
	Main stream (*A*)	Slightly colored pool (*B*)	Highly colored pool (*C*)	Main stream (*A*)	Slightly colored pool (*B*)	Highly colored pool (*C*)	Main stream (*A*)	Slightly colored pool (*B*)	Highly colored pool (*C*)
Color (platinum-cobalt scale units)	7	20	120	4	60	90	2	3	3
Chemical constituents (ppm):									
Silica	2. 0	7. 3	6. 2	2. 6	8. 3	7. 9	4. 1	6. 1	7. 8
Iron	. 08	1. 1	1. 9	. 1	1. 1	2. 2	. 02	. 02	. 02
Manganese	. 00	. 93	2. 8	. 00	. 40	3. 0	. 02	. 08	. 01
Calcium	28	28	9. 5	31	30	9. 5	30	27	18
Magnesium	5. 8	7. 1	3. 0	5. 2	7. 8	4. 5	4. 0	4. 3	3. 9
Sodium	1. 7	5. 6	3. 1	1. 7	4. 8	3. 1	1. 9	2. 5	2. 2
Potassium	1. 5	7. 5	6. 8	1. 6	8. 2	6. 8	1. 8	2. 5	2. 2
Bicarbonate	106	134	44	110	142	55	99	97	69
Sulfate	10	4. 4	8. 2	11	4. 4	6. 0	11	9. 8	8. 0
Chloride	1. 5	3. 0	3. 0	1. 5	3. 5	3. 0	2. 5	3. 0	3. 0
Fluoride	. 1	. 2	. 2	. 1	. 2	. 1	. 0	. 1	. 1
Nitrate	. 1	. 4	1. 2	. 1	. 6	. 8	. 1	. 1	. 2
Phosphate	. 16	. 08	. 12	. 06	. 05	. 12	. 01	. 01	. 01
Dissolved solids (ppm) (residue at 180°C)	107	143	78	115	155	80	103	105	77
Hardness (ppm)	95	100	36	99	108	42	90	85	62
Free carbon dioxide (ppm)	4. 2	34	56	4. 4	28	55	4. 0	12	14
Specific conductance (micromhos at 25°C)	197	233	106	205	244	117	190	184	138
pH	7. 6	6. 8	6. 1	7. 6	6. 9	6. 2	7. 6	7. 1	6. 9
Ignition loss (ppm)	--------	15	18	--------	22	12	--------	--------	--------

[1] Sample locations shown on figure 161.1.

TABLE 161.2.—*Spectrographic analyses of minor-element content, in micrograms per liter, of three types of water, Cacapon River, W. Va., during autumn 1961* [1]

[Analyses by W. D. Silvey, Sacramento, Calif.]

	October 22			October 29			November 19	
	Main stream (*A*)	Slightly colored pool (*B*)	Highly colored pool (*C*)	Main stream (*A*)	Slightly colored pool (*B*)	Highly colored pool (*C*)	Main stream (*A*)	Highly colored pool (*C*)
Aluminum	12	32	93	15	14	82	22	18
Cobalt	≦3. 3	≦3. 3	≦3. 3	<3. 3	≦3. 3	≦3. 3	≦3. 3	≦3. 3
Copper	7. 3	<3. 3	<3. 3	<3. 3	<3. 3	<3. 3	<3. 3	<3. 3
Iron	35	>100	>100	28	>100	>100	47	>100
Manganese	11	>200	>200	31	>200	>200	9. 3	33
Molybdenum	<. 67	<. 67	<. 67	<. 67	≦. 67	≦6. 7	<. 67	<. 67
Nickel	≦. 67	3. 6	7. 0	<. 67	4. 5	6. 7	. 87	1. 5
Lead	88	27	80	20	<3. 3	32	13	8. 0
Titanium	<1. 3	3. 4	≦1. 3	<1. 3	≦1. 3	≦1. 3	<1. 3	<1. 3
Vanadium	<. 67	<. 67	≦. 67	<. 67	<. 67	≦. 67	<. 67	<. 67

[1] Sample locations shown on figure 161.1.

pool. Both Slack (1955) and Schneller (1955) found that alkalinity increased with color in all their samples of leaf-colored waters in Indiana.

Some differences between the highly colored pool (*C*) and the slightly colored pool (*B*), as noted in the October 22 and 29 samples, may have resulted from differences in redox potentials, which could explain the greater concentrations of iron, manganese, and free CO_2 in the more nearly anaerobic, highly colored pool (*C*). Just the opposite was observed for magnesium, sodium, and potassium, which were more concentrated in the slightly colored pool (*B*). In both colored waters (*B*, *C*), sulfate values were lower than in the river water (*A*). This may have resulted from reduction of sulfate to sulfide. Although one might expect the sulfate concentration to be lowest in the highly colored pool (*C*), minimum values were found in the slightly colored pool (*B*).

Concentrations of aluminum and nickel increased as water color increased (table 161.2). Similarly, iron and manganese concentrations were higher in the colored waters than in the main stream. The distribution of lead in the different environments resembled that of sulfate in that the slightly colored water (*B*) contained lower concentrations than either the main stream or the highly colored water (*C*). Data for other minor elements are inconclusive.

It is tentatively concluded that the compositional differences observed between the river and the colored waters resulted from leaching and decomposition of leaf litter in isolated environments. Differences between the highly colored and slightly colored pools probably reflect differences in source of the water.

Between October 22 and 29 the solute concentration in the highly colored water (*C*) increased somewhat, possibly due to evaporation. Although the pool was still isolated on November 19, its color had disappeared; the pool probably had been flooded and flushed by a rise in river stage on November 7 and 8. Discharge at the gaging station about 7 miles downstream from the sampling sites increased from 59 cubic feet per second on October 29 to 240 cfs on November 8, but decreased to 82 cfs on November 19.

On October 22, small patches of a thin inflexible surface film were present on the highly colored pool.

A week later the entire surface was covered with a film in which there were only a few breaks or tears. The film probably was composed of ferric hydroxide, which formed where air oxidized ferrous iron in the water. Pearsall and Mortimer (1939) described such a condition on stagnant pools in bogs. The contribution of other metallic ions, for example manganese, to a surface film is unknown. In the colored pools under discussion, the films tended to remain in the center of an open space. Reducing conditions may have been so intense near the margins of pools that formation of the oxidized film was impossible. The effect of a surface film on reactions at the air-water interface may be important. For example, evaporation and reaeration probably are inhibited.

Colored water resulting from leaf decay generally is accompanied by low concentrations of dissolved oxygen. Analysis, by the Alsterberg (azide) modification of the Winkler method, of two samples of highly colored pool water gave an average of 0.09 parts per million dissolved oxygen or about 0.8 percent of saturation on October 30. This method is not recommended for samples containing 1 mg or more of ferrous iron per liter or appreciable quantities of sulfite (Rainwater and Thatcher, 1960, p. 233). Because of the effects of interfering substances, the dissolved-oxygen values reported here may be too low, but they indicate very low concentrations. A few measurements made with a polarographic oxygen electrode (Kanwisher, 1959), on October 23, supported this conclusion. Readings in the highly colored pool (*C*) were 2 percent of saturation at the bottom (24.5 cm), and a maximum of 6 percent at other places.

On October 30, the slightly colored pool (*B*) had a dissolved-oxygen concentration of 1.9 ppm (18 percent of saturation) and the main stream of the river (*A*) had 10.3 ppm (99 percent of saturation). As with most other quality factors, water color correlated well with dissolved-oxygen content. The lowest oxygen concentration, 0.06 ppm, was measured near the upstream end of the highly colored pool (*C*), where decomposition of litter seemed to be especially far advanced.

A further indication of low-dissolved oxygen content was the presence of many snails (*Gyraulus*) on leaves at the water surface along the margins of the highly colored pool (*C*). These snails are able to withstand unfavorable enrivonments better than most mollusks, owing to their ability to breathe air at the surface. Similar groups of snails were not observed in the slightly colored pool (*B*), which retained a connection with the oxygenated river water.

Water temperature

Temperature measurements made on two dates (table 161.3) indicated marked thermal stratification during the study period. On October 23, the temperature of the highly colored pool (*C*) increased from 6.6°C at a depth of 2.5 cm to 10°C at a depth of 11.5 cm. Below 11.5 cm the water was isothermal, although the thermometer used did not permit determination of the exact inflection points on the temperature-depth curve. On October 30, the water temperature of all colored pools decreased with increasing depth (table 161.3). The steepness of the thermal gradients in the three pools tested varied directly with intensity of water color. This relationship suggests that the mechanism involved was the rapid absorption of solar radiation near the surface by the colored water. No differences in temperature were noted in the main stream at comparable depths. The river-water temperature was highest and the temperature of the highly colored pool (*C*) was lowest on 4 of 5 days for which bottom-water temperatures were measured. Bottom-water temperature of the slightly colored pool (*B*) was always higher than that of the highly colored pool (*C*). This could have resulted from slow mixing with warmer river water from the downstream end of the slightly colored pool. It could also have resulted from a flow of cool ground water from the highly colored pool (*C*) through the moderately colored pool (*D*) into the slightly colored pool (*B*). The October 30 series of bottom temperatures seems to support this possibility.

In summary, the effect of leaves on stream-water quality and temperature is a localized interaction be-

TABLE 161.3.—*Water temperature, in degrees centigrade, at three sampling sites, Cacapon River, W. Va., during autumn 1961*

Depth (cm)	October 23	October 30			
	Highly colored pool (*C*)	Main stream (*A*)	Slightly colored pool (*B*)	Moderately colored pool (*D*)	Highly colored pool (*C*)
2.5	6.6	13.2	14.9	14.1	14.1
11.5	10.0				
16.5				10.2 (bottom)	
18.5			10.8 (bottom)		
19.0		13.2 (bottom)			
20.0					8.5 (bottom)
24.5	9.8 (bottom)				
Average thermal gradient, (degrees centigrade per cm)	0.14	0.00	0.26	0.28	0.32

tween the marginal vegetation and the water in low-flow pools, in backwater, or flood-plain pools. Leaf litter from other parts of the drainage area contributes also to the particulate and dissolved load of the stream. Probably this effect is delayed until heavy rains produce sufficient runoff to transport these materials downstream and out of the basin or into larger water bodies where their effects are less noticeable.

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