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POSSIBLE EFFECT OF ACID MINE DRAINAGE ON THE WATER QUALITY AND FISH POPULATION OF DALE HOLLOW RESERVOIR, TENNESSEE AND KENTUCKY

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ABSTRACT

Various water quality parameters of Dale Hollow Reservoir, a 30,000 acre Corps of Engineers impoundment of the Obey River, were studied. Emphasis focused upon the effects of acid mine drainage which enters the impoundment from one of the tributaries.

Since the reservoir is a "two story" impoundment, the study involved a vertical as well as a horizontal profile. Some of the differences observed in affected portions of the reservoir are associated with acid mine drainage. These included higher levels of sulfate and iron along with lower pH and alkalinity. Comparison with a creel census indicated higher productivity in the unaffected areas.

INTRODUCTION

Dale Hollow Reservoir is a 30,000 acre U.S. Army Corps of Engineers storage impoundment formed by inundation of parts of the Wolf and Obey Rivers (Figure 1). Physical features, thermal stratification and dissolved oxygen characteristics of the reservoir are described by Ragsdale and Bulow (1975). The East Fork of the Obey River has been severely polluted by acid mine drainage (Nichols and Bulow, 1973). The West fork of the Obey River is affected by intermittent acid mine drainage but tends to buffer the effect of the East Fork on Dale Hollow Reservoir (Carrithers and Bulow, 1973). The purpose of the present study was to determine effects of acid mine drainage on water quality and fish population. Potentially affected areas of the reservoir were compared with unaffected areas. For such comparison the reservoir can be divided into the Obey River embayment (B in figure 1), the Wolf River embayment (A) and the reservoir proper (C).

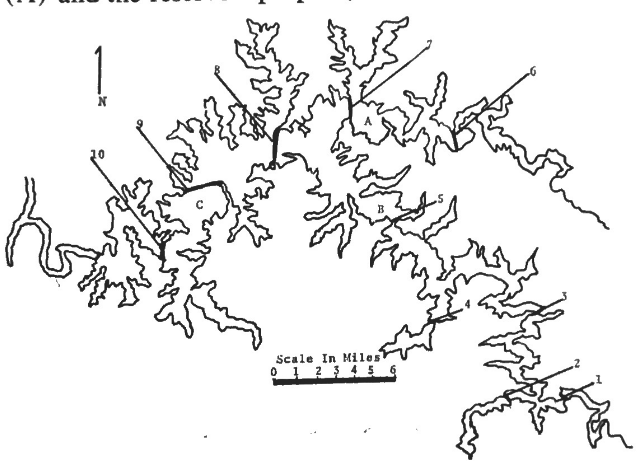

FIG. 1:
Map of Dale Hollow Reservoir, Tennessee, indicating the Wolf River Embayment (A), Obey Embayment (B), Reservoir Proper (C), and Individual Transects (1 through 10)

MATERIALS AND METHODS

Ten transects, spaced at five to seven mile intervals, were established throughout the reservoir (Figure 1). Two transects were located on the Wolf River branch of the reservoir, four were located on the Obey River branch, and three were located below the confluence of these two major branches. To obtain maximum vertical distribution, water samples were taken at the deepest point along the transect as indicated by a Lowrance Model LFP 300 Fish Lo-K-Tor. As a result, the sampling site was often equidistant from both banks and located in the old river channel. Notable exceptions occur at transects near the headwaters of the reservoir, these due primarily to the channel there being narrow and deeper on one side.

Monthly sampling was conducted from February, 1971, through January, 1972. Two boats were stationed at different points on the reservoir and used to travel to the individual transects. Four stations were sampled in a single day. To produce valid comparisons between the various transects, time lapse between sampling trips was not greater than three days.

Chemical parameters sampled were total hardness, calcium hardness, magnesium hardness, total alkalinity, phenolphthalein alkalinity, methyl orange alkalinity, pH, sulfate and iron. The pH was measured at the sampling site, while remaining water samples were analyzed in the laboratory. Samples were taken at ten meter intervals before stratification appeared. After summer stratification had begun, however, sampling was adjusted to correspond with the epilimnion, metalimnion, and hypolimnion. As a result, values were grouped as either top, middle or bottom. Subsurface samples were taken with a 3.1 liter Kemmerer water sampler attached to a graduated line. Cubitaners (Hedwin Corp., Baltimore, Maryland 21211) were used for the collection and transport of samples. All bottom samples were taken as close to the water-mud interface as possible. Field analysis of pH was accomplished with a Hach Kit Model AL-26-WR. Laboratory analysis of samples was accomplished within 12 hours of collection; these determinations were made with a Hach Kit Model DR-EI. Total hardness was determined by titration. Calcium hardness was then measured and subtracted from total hardness to obtain magnesium hardness. Alkalinity was measured by Methyl Orange Titration. Other values were determined by direct readings from the DR-EL-AC Colorimeter.

RESULTS AND DISCUSSION

The chemical composition of ground water that drains from a mine is frequently altered. This chemical alteration in coal mines is generally understood to begin when pyrite (FeS_2), which is usually associated with coal deposits, is exposed to the atmosphere. The resulting oxidation produces soluble sulfuric acid and associated iron compounds. Any ground water coming into contact with these substances dissolves the metallic salts and also acts as a carrier for the sulfuric acid which in turn dissolves mineral deposits such as manganese and calcium (Appalachian Regional Commission, 1969). The specific chemistry of the entire process is extremely complex and not precisely defined. However, it can generally be represented by equations described by Hill (1968). Waters affected by acid mine drainage can be characterized in terms of 11 parameters; these, along with the values which make them indicators, are listed below.

pH	$<$ 6
Acidity	$>$ Alkalinity
Manganese	$>$ 0.5 ppm
Total Iron	$>$ 0.5 ppm
Sulfate	$>$ 75 ppm

[illegible]	>	[illegible] ppm
Total Hardness	>	[illegible] ppm
Magnesium Hardness	>	[illegible] ppm
Calcium Hardness	>	[illegible] ppm
Color	>	100 ppm
Turbidity	>	100 ppm

Although each of the above is treated as an independent factor they all normally act in synergism with each other (U.S. Department of Interior, 1968). When sulfuric acid contacts an alkali, a neutralization reaction takes place. This can occur naturally if acid drainage flows over geologic formations of limestone. The alkali in limestone is calcium carbonate which can be highly soluble in acid water. Neutralization causes an increase in the pH but it also reduces the alkalinity of the water. The increase in pH will decrease the solubility of the metallic salts which will precipitate and often form a smothering blanket over benthic organisms.

Sulfate is a naturally occurring substance which can enter a body of water either dissolved in rain or by the solution of sulfate bearing compounds in geologic formations (Reid, 1961). Fifty per cent of the United States waters which support good game fish populations have sulfate levels below [illegible] ppm, and ninety-five per cent contained less than 90 ppm (McKee and Wolf, 1963). Sulfate is not highly soluble, however, and an average of 25 ppm is representative of waters not affected by acid mine drainage. High sulfate levels are characteristic of waters where acid mine drainage occurs because one gram molecular weight of sulfate is produced for every gram molecular weight of sulfuric acid. This involves a separate radical and should not be confused with the one contained in the sulfuric acid. Sulfate serves as an especially useful indicator of acid mine pollution for two reasons. First, the barium sulfate turbidimetric method used is a reliable and accurate test (Hach, 1969). Second, sulfate has a tendency to stay in solution even after acidity has been neutralized (Federal Water Pollution Control Administration, 1969). Sulfate can indicate traces of acid pollution even when other parameters such as pH show no differences. Since the Wolf River does not receive acid pollution and acid pollution is very light in the West Fork, sulfate levels should be relatively low in these transects. Theoretically, introduction of acid mine drainage through the East Fork of the Obey should result in high sulfate values at transect 1, low values at 2, intermediate levels below their confluence at 3, low values at 4, which should be unaffected, intermediate values at 5, low values at 6 and 7, and intermediate values in the reservoir proper at 8, 9, and 10. The mean values illustrated in Figure 2 represent this kind of distribution. The sulfate levels at transects 6 and 7 are slightly below the representative average of 25 ppm. The standard deviations indicate much greater dispersions at the transects which receive even small amounts of acid pollution.

Iron, one of the most abundant minerals in the earth's crust, is rarely present in natural waters. The ferric form that is encountered in unpolluted waters is almost insoluble and the ferrous form can only exist in the absence of oxygen (Ruttner, 1963). Since metallic salts of iron are a product of pyrite oxidation, iron is a good indicator. In contrast to sulfate, iron is a relatively short range indicator because metallic salts tend to precipitate out as acid becomes neutralized. Figure 3 demonstrates the insolubility of iron compounds. The bottom values are relatively high in contrast to the surface values which become progressively lower. Although the distribution pattern illustrated by sulfate is not repeated with iron, the mean values for iron are relatively higher in the Obey environment.

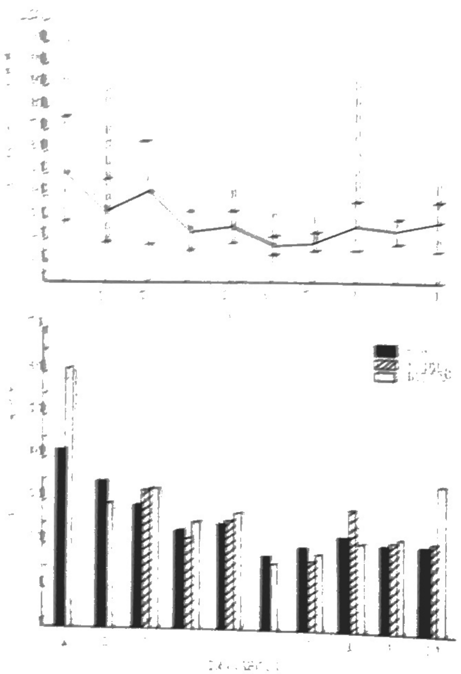

FIG. 2:
Maximum, Minimum, Mean and Standard Deviation of Sulfate Values at East Transect (Top Graph); Mean Values Grouped as Top, Middle, and Bottom at each Transect (Lower Graph), Dale Hollow Reservoir.

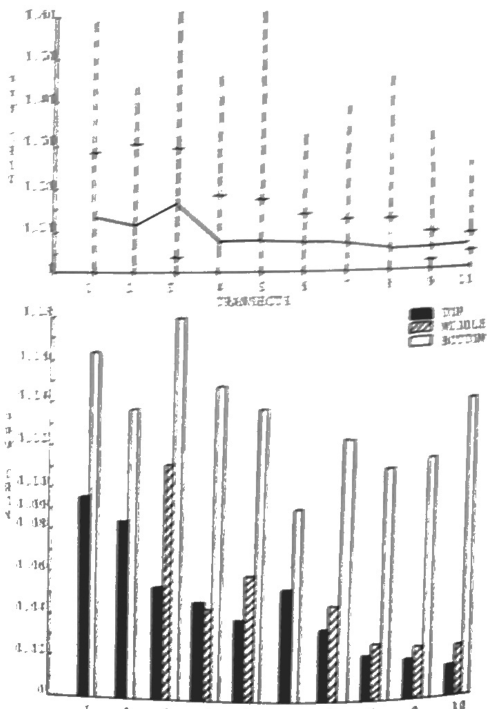

FIG. 3:
Maximum, Minimum, Mean and Standard Deviation of Iron Values at East Transect (Top Graph); Mean Values Grouped as Top, Middle and Bottom at East Transect (Lower Graph), Dale Hollow Reservoir, Tennessee.

Sulfuric acid associated with acid mine drainage lowers the pH and affected waters exhibit characteristically low pH values. Streams in Tennessee with pH values lower than [illegible] generally indicate the presence of acid mine pollution (Parsons, [illegible]). The pH range of lakes having some degree of [illegible] 6 to 9 (Reid, 1961). The National Technical Advisory Committee (U.S. Department of Interior, 1968) recommends that no [illegible] material be added that would extend pH outside the range [illegible] range limits recommended for primary contact recreation were 6.5 to 8.3. Although the safe range of pH for most species of fish seems to be 5 to 9 (Mackenthun, 1969), a pH of [illegible] the distribution of some important game fishes such as [illegible] trout (Appalachian Regional Commission, 1969). The distribution pattern of mean pH values for sample sites is illustrated in Figure 4. The pattern varies inversely with that of Figure 2. Since low pH values are indicative of acid pollution, this is only logical. The ranges which are given for each mean all fall within the recommended limits [illegible]. However, the trend is definitely toward lower pH values in the transects influenced by the East Fork.

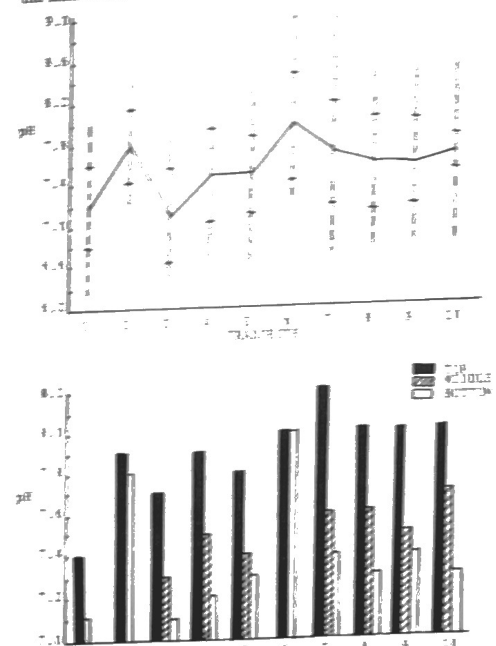

FIG. 4:
Maximum, Minimum, Mean and Standard Deviation of pH Values at East Transect (Top Graph); Mean Values Grouped as Top, Middle and Bottom at Each Transect (Lower Graph), Dale Hollow Reservoir, Tennessee

Introduction of large quantities of acid can seriously weaken
the carbonate buffering system and, in so doing, indirectly
endanger the reservoir of available carbon. The introduction of
acid results in a reaction with bound carbonates which produces
neutral bicarbonates. This causes the pH to be lowered, but
not as radically as it would if there were no buffering system
(Reid, 1961). However, the alkalinity itself is also lowered. The
National Technical Advisory Committee (U.S. Department of
Interior, 1968) recommends that in order to protect produc-
tivity, acid should not be added to natural waters in quantities
sufficient to lower the total alkalinity to less than 20 ppm.
Moyer (1949) classified the productivity of natural waters ac-
cording to their alkalinity. Lakes with a total methyl orange
alkalinity of 20 ppm or less were low in fish and [illegible] [illegible] Figure 5 illustrates the mean values for alkalinity. The pattern of distribution generally follows the one shown for the pH values. Lower values are encountered in all the transects influenced by drainage from the East Fork. The larger standard deviations at these transects also seem to suggest a greater fluctuation in the values recorded.

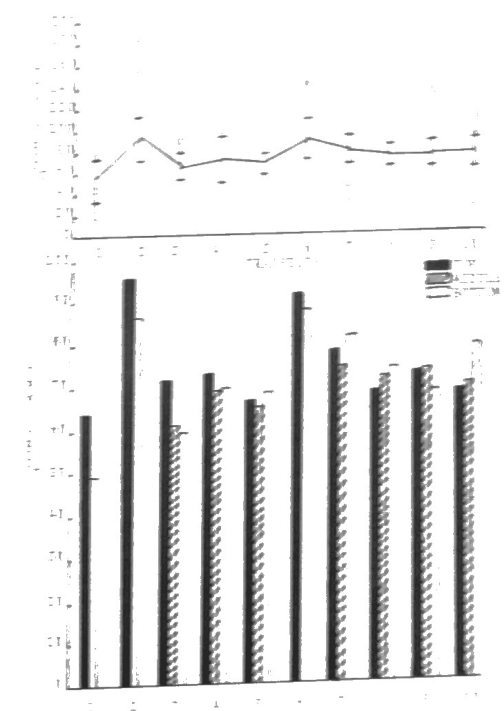

FIG. 5:
Maximum, Minimum, Mean and Standard Deviation of Total Alkalinity Values at East Transect (Top Graph); Mean Values Grouped as Top, Middle and Bottom at Each Transect (Lower Graph), Dale Hollow Reservoir, Tennessee

Hardness was the final parameter considered. Ruttner (1963)
defines hardness as the total alkaline earths present without
reference to the particular anions to which they are bound. In
most natural waters, hardness is generally attributed to calcium
and magnesium. Other ions such as barium, strontium, and
manganese may be present but their quantities are usually
negligible in unpolluted waters. Hardness is expressed in the
same terms as alkalinity but it is not equal to alkalinity. Total
hardness can also be related to the productivity of water but
the biological significance is reduced since it does not express
the specific elements involved. The presence of calcium and
magnesium does seem to increase the productivity of natural
waters (U.S. Department of Interior, 1968). Total hardness
values which fall within the suggested range for acid mine
drainage were only observed at transects 1, 2, and 8 (Figure 6).

None of the mean values approached the characteristic 150 ppm referred to by Hill (1968). The lower graph in Figure 6 indicates that the fluctuations in total hardness are strongly influenced by the levels of calcium hardness. The standard deviations plotted in Figure 6 offer the clearest example of the trend toward greater fluctuations at the transects which are most closely associated with the sources of acid mine drainage.

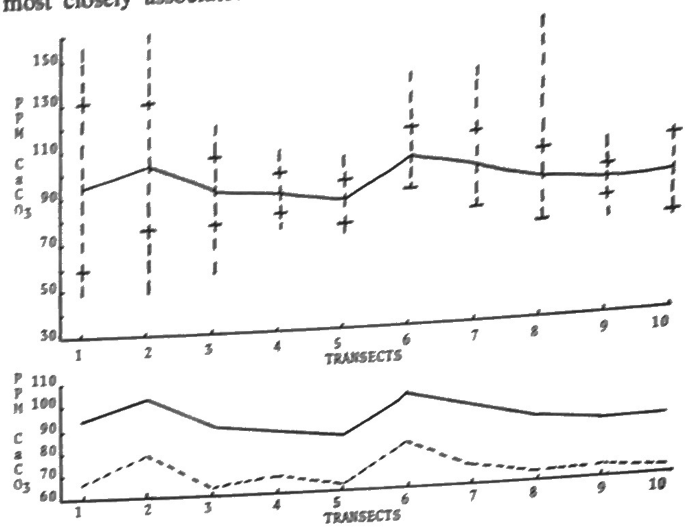

FIG. 6:
Maximum, Minimum, Mean and Standard Deviation of Total Hardness Values (Top Graph); Mean Values of Calcium and Magnesium Hardness (Lower Graph)

A creel census is most often used in the evaluation of a particular sport fishery. However, since a fishery is dependent upon the productivity of the waters where it is located, it could be used to gauge relative productivity. A creel census, directed by district fisheries biologist J. D. Little, is being conducted on Dale Hollow by the Tennessee Game and Fish Commission. The census began in 1967 and a summary of the data is given in Table 1. The data were grouped into the same three regions of the reservoir which were used in this study. Mean values for the four-year period indicate that more pounds of fish and greater numbers of fish were caught per hour in the Wolf River embayment than in either of the other regions. The data also indicates that a greater precentage of the fishermen were successful in the Wolf River. An interesting point that is also revealed is that these same creel census values are higher in the Obey River embayment than in the reservoir proper. The heavy fishing that results from the spawning runs in the Obey could partially explain this difference.

TABLE 1: *Summary of Creel Census Data Taken by Tennessee Game and Fish Commission, Dale Hollow Reservoir. Tennessee. 1967 through 1971*[a]

		1966[b]	1967	1968	1969	1970	1971[c]	Mean
Pounds/Hr.	(A)	0.433	0.444	0.483	0.609	0.558	0.484	0.502
	(B)	0.359	0.292	0.449	0.424	0.475	0.486	0.414
	(C)	0.280	0.352	0.545	0.365	0.364	0.606	0.412
Fish/Hr.	(A)	0.776	0.606	0.657	0.891	0.747	0.810	0.748
	(B)	0.530	0.377	0.462	0.551	0.524	0.486	0.488
	(C)	0.280	0.279	0.436	0.292	0.288	0.398	0.329
Average Wt./Fish[e]	(A)	0.562	0.729	0.733	0.684	0.745	0.596	0.675
	(B)	0.676	0.776	0.969	0.768	0.903	0.603	0.783
	(C)	1.117	1.265	1.248	1.120	1.250	1.529	1.255
No. Fishermen Sampled	(A)	1,671	1,864	2,088	1,984	2,223	299	1,688
	(B)	1,150	1,341	1,151	1,075	980	269	994
	(C)	809	1,353	1,730	1,433	1,602	329	1,209
% Successful Fishermen	(A)	65.2	68.7	57.6	56.4	55.8	34.8	56.42
	(B)	53.4	41.7	50.2	51.3	47.8	27.5	45.32
	(C)	26.9	23.9	30.4	27.7	22.7	27.7	26.55
Average Trip[f]	(A)	5.495	5.391	5.094	5.030	5.342	5.000	5.225
	(B)	4.301	3.598	3.464	4.279	4.826	5.000	4.245
	(C)	6.320	3.544	4.773	3.737	5.000	5.000	4.729

[a]Dates are based on fiscal year and therefore include data from July of the previous year to July of the current year.

[b]Census began in October and involves only three months of 1966.

[c]Involves data from July to December.

[d]Capital letters indicate major areas of the reservoir; A corresponds to Wolf River embayment, B corresponds to Obey River embayment, and C corresponds to the reservoir proper.

[e]Weight is expressed in pounds. [f]Time is expressed in hours.

SUMMARY

Two of the products of pyrite oxidation, iron and sulfate, were used as indicators of acid pollution. Both were high at the transects influenced by drainage from the East Fork, and the highest values occurred at transect 1. Sulfate demonstrated a more indicative trend than iron. This was probably due to the tendency of iron to precipitate as pH values rise.

The pH remained within the 6 to 9 range at all transects. This is indicative of the effectiveness of neutralization and buffering. However, the lowest pH observations occurred in the East Fork.

The greatest threat to water quality seems to be in the reduction of alkalinity and the subsequent reduction in the buffering capacity of the system. This can only be attributed to the introduction of dissociated materials into the lake. The lowest alkalinity appeared in the East Fork while the highest values occurred in the Wolk River. Lower mean values existed below the confluence of transects 1 and 2 as well as below the confluence of transects 5 and 6.

All parameters associated with acid mine drainage demonstrated a trend toward more extreme values in the East Fork. This trend cannot be attributed to differences in geologic formations since the same formations are predominant throughout the drainage system.

Acid mine drainage is alternately concentrated and diluted by periods of low and high runoff. This causes a great fluctuation in its severity. The higher standard deviations encountered at the Obey River transects reflect a greater fluctuation in recorded values. Therefore, the extreme value trend can be applied to the degree of variation in values as well as to their actual levels.

The buffering capacity of the West Fork and the Wolf River cannot be expected to maintain the water quality at its present level if there is a marked increase in amount of acid pollution entering the reservoir.

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