THE EFFECT OF ACID MINE DRAINAGE ON THE LIMNOLOGY OF A SMALL IMPOUNDMENT IN SOUTHWEST VIRGINIA[1]

Robert E. Wollitz
Virginia Commission of Game and Inland Fisheries

ABSTRACT

Apparently extensive fish mortalities were reported to have occurred in the North Fork Pound Reservoir during February, 1969 and February, 1970. A study was initiated in September, 1969 and continued through October, 1970, in order to ascertain the causes of these mortalities. Chemical water analyses disclosed that the lake pH varied from 4.0-6.4, with a mean near 5.0. The heavy metals, copper, mercury, zinc, iron and manganese were found in the lake waters at levels reported to have chronic effects on fish.

Biological investigations revealed fish populations were at low levels (smallmouth bass, channel catfish, largemouth bass, black crappie, green sunfish, bluegill, redear sunfish and brown and yellow bullheads). Reproduction of largemouth bass, green sunfish and black crappie appeared to be nonexistent. Standing crops of zooplankton and phytoplankton appeared extremely low.

The reduction of the fishery and the low standing crops of plankton appeared to be due to the toxicity of copper, mercury, zinc and to some extent the toxicities of iron, manganese, and/or low pH, and low carbonate alkalinity.

INTRODUCTION

The North Fork Pound Reservoir is a U.S. Army, Corps of Engineers flood control reservoir located in the coal fields of the Cumberland Mountains of Southwest, Virginia. The reservoir is long (about five miles), narrow and deep (maximum depth - 57 feet). It has a surface acreage of approximately 154 acres at the conservation pool elevation and the shoreline is mostly steep and wooded.

Immediately following impoundment the reservoir was stocked with the following species of fish by the Virginia Commission of Game and Inland Fisheries:

Date Stocked	Species	Number
10/21/66	Bluegill (*Lepomis machrochirus*)	60,600
10/21/66	Channel Catfish (*Ictalurus punctatus*)	4,620
6/19/72	Largemouth Bass (*Micropterus salmoides*)	7,500
7/3/67	Smallmouth Bass (*Micropterus dolomieu*)	7,500

At the time of impoundment (1966), the reservoir watershed was relatively undisturbed. Shortly thereafter (1968), however, coal strip contour and auger mining operations were initiated. During the late winter of 1969 (probably February), game wardens reported that local residents had observed large numbers of dead fish lying on the lake bottom in the upper extremities of the reservoir. Similar reports were received during February, 1970. Acid drainage from the mining operations and corresponding leaching of various heavy metals from overburden spoils was thought to have been responsible for the reported fish mortalities.

Following the reported fish mortalities, a study was initiated to investigate the validity of the reports and to determine the extent of damage to reservoir fauna. A survey conducted in September, 1969, indicated good reproduction by most

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species, however, adult fish appeared to be low in number as was indicated by cove rotenone samples and gill net sets. Chemical analyses indicated abnormal chemical conditions in the lake water, i.e. manganese in surface waters, high total hardness and low total alkalinity. Further chemical analyses indicated the North Fork Pound River, just above the lake, maintained a low pH and a high content of manganese.

METHODS

Most chemical analyses were determined at two week intervals from May through October 7, 1970, using a Hach Direct Reading Engineers Laboratory. One series of samples was also taken during September, 1969 and again in March, 1970. Routine analyses included dissolved oxygen, pH, total alkalinity, total hardness, phenolphthalein alkalinity, manganese and total iron. Copper and sulphate analyses were not made routinely. Apparent color determinations were made on most sampling dates after June 15, 1970. Water for these determinations was obtained by means of a brass Kemmerer 1,190 cc water sampler. Dissolved oxygen, temperature, manganese and total iron determinations were made at five foot depth intervals (ranging from the surface to near the bottom) at three stations in the lake (Figure 1). Alkalinity, hardness and pH were determined from surface water and from water collected near the bottom at all stations. At the same time, chemical analyses were determined from surface water from Meadow Branch and from the North Fork Pound River immediately above the lake. Samples were taken on one occasion from Phillips Creek, Hopkins Branch, Laurel Fork Creek and Bad Creek to determine the water quality of these tributaries entering the lake.

In addition to the above analyses, water samples were obtained and analyzed from the surface and near the bottom at stations "A" and "B" and from the surface only at station "D", North Fork Pound River, Meadow Branch, Laurel Fork Creek, Hopkins Branch, Bad Creek and Phillips Creek. These samples were obtained on February 26, 1971 and sent to Virginia Polytechnic Institute and State University for neutron activation analyses. Samples for these tests were obtained by means of an inert plastic water sampler.

From May to October 8, 1970, plankton samples were obtained at the same time, stations and depths from which chemical analyses were obtained. From each station a total of five 1,190 cc Kemmerer water samples from each five foot depth interval were filtered through a Wisconsin plankton net of number 25 silk bolting cloth and concentrated to a composite 20 ml sample. Samples were then preserved with modified Lugol's Solution.

Analyses of plankton samples was by the survey method. A one ml alloquot was transferred to a one ml Sedgwick-Rafter cell and all plankton within the cell were counted. Results were expressed as the number of plankters per liter of lake water. Phytoplankton was identified to order and zooplankton to genus (except for rotifers which were identified to order only).

During September, 1969, fish populations samples were obtained by means of cove rotenoning near the dam and from one series of gill net sets. Each gill net series consisted of one net each of the following mesh sizes; one, one and one-half and two inch bar mesh. Nets were 200 feet in length and eight feet deep.

During 1970, gill nets were set monthly from March through October, except for April and May, in the same general area at which chemical analyses were obtained (stations A, B, and C). One series of sets, consisting of 200 feet each of one, one and one-half and two inch bar mesh nets were set at each location each month. Results from gill net catches are expressed in numbers of fish per net hour. On occasions when total time intervals of nets were not recorded; the average time per set for other series was used. The average time that nets were in the water was 21 hours and ranged from 19-22 hours. During September, 1970, three rotenone cove samples were obtained. At the lower end of the lake, the same cove was sampled in 1969. Rotenone samples were obtained in two additional areas, one midway in the lake and one at the upper extremity (Figure 1). Cove sizes were only estimated as was the amount of rotenenone used. Observations indicated that an adequate amount of rotenone was used to obtain a complete kill of fish in all coves except cove number one. This cove was treated a second time during the 1970 sampling inorder to assure a complete kill. Resulsts are expressed as the number and weight of fish recovered from each sampling area.

RESULTS

Chemical and Physical Properties:

Thermal stratification occurred about July 1, 1970 and extended through September 23 (Table 1). During most of the period the epilimnion extended from the surface to a depth of approximately 22 feet. From this depth to 50 feet the thermal properties were characteristic of a thermocline. No evidence of a hypolimnoin was observed. During summer stratification temperatures varied from 75°F. to 79°F. in the region of the epilimnion. Below the epilimnion, temperatures decreased uniformly to 60° at a depth of 50 feet.

The water was quite clear over the entire expanse of the lake but clarity was greatest at station "A". During most of the study period the apparent color of the surface water at station "A" was O-platinum units (Table 2). During September and October, the apparent color increased to 10 and 20 units, respectively, at this station. Except for September and October, no color determinations were made at station "B", in Laurel Fork Cove. During September and October the color at station "B" was 20 and 0-platinum units respectively. At station "C", near the upper limit of the lake, the apparent color was 10 units on all sampling dates except September and October when color rose to 30 and 15 units respectively. Apparent color in bottom waters varied throughout the period from 20 to 80 units at station "A", from 10 to 40 units at station "B" and from 15 to 160 units at station "C".

Dissolved oxygen was high at all times in the epilimnion, being 6-7 ppm throughout the study period. Below the epilimnion oxygen decreased with depth, being absent near the bottom (50 foot depth) during the period July 1 through September 23 (Table 1). After October 7 oxygen levels in the deeper waters began to increase with initiation of the fall overturn. Due to iron concentrations found in the deeper water of the lake, the permanganate modification of the Winkler method (Standard Methods, 1965) was used to determine dissolved oxygen.

The concentration of total iron and manganese (Table 1) increased during summer stagnation with depth. Stratification of these metals began about May 20 and was still in effect at the termination of the study period. During most of the period manganese varied from 1.2 to 2.0 ppm at the surface and increased progressively with depth to a concentration of 4.0 to 5.0 ppm near the bottom (50 ft.) at station "A" (Table 1). The depth distribution of total iron was similar to that of manganese. Iron was absent from all depths above 30 feet during the entire sampling period except for March 10 and May 7, when iron was present in the surface water at a concentration of 0.1 ppm. Below 30 feet the total iron concentration increased progressively from 0.1 ppm to 16 to 25 ppm near the bottom (Table 1).

At station "B", the conentration of manganese was similar to that at station "A", according to depth. The concentration of total iron at station "B", however, differed considerably according to depth from that at station "A". At station "B" total iron concentrations were consistently found at shallower depths and at higher levels than at station "A". Total iron at station "B" increased from 0.1

ppm at the 15 foot depth in July and August to 2.0 to 3.0 ppm near the bottom. At station "A" total iron was usually not found above a depth of about 30 feet and when present concentrations did not exceed 0.1 ppm. Concentrations as high as those found at the 25 foot depth of station "B" were not detected at station "A" until a depth of 40 to 45 feet was reached.

Concentrations of manganese at station "C" were similar to those of stations "A" and "B", except that higher levels were found at shallower depths. Concentrations of 4.0 to 5.0 ppm were detected at a depth of 15 feet as station "C", while concentrations of this magnitude were not encountered at station "A" until a depth of 45 to 50 feet was reached. The concentration of total iron appeared less at station "C" than at the other stations, but was present at shallower depths. Iron at station "C" was detected in small amounts (0.1 to 0.4 ppm) at all depths, except for the period August 27 through September 24, when iron was found only at depths in excess of 12 to 15 feet.

The surface water pH was low at all stations during the study period, ranging from 5.1 to 6.4. At station "A", the pH ranged from 5.1 on March 10 to 6.4 (from July 1 through August 9). After August 9, pH levels dropped to 5.9 and gradually decreased throughout the remainder of the study period to a low of 5.4 on October 7 (Table 2). The pH at station "B" was similar to that of station "A". At station "C" pH was generally less than that of the other stations and ranged from 4.9 to 5.4 at the surface. The pH of bottom waters usually approximated that of the surface water except at station "A". At station "A" pH of the bottom water was slightly higher than at the surface and remained higher for a longer period of time (Table 2). The surface pH at station "A" was 6.4 during the period July 1 through August 9, while the bottom pH ranged from 6.4 to 6.7 during the period July 1 through September 23.

Total alkalinity of the surface water was 10 ppm or less at all times. The total alkalinity of bottom waters was usually 10 ppm or less at stations "B" and "C". Total alkalinity of the bottom water ranged from 20 to 70 ppm at station "A" after June 15. On July 28, the total alkalinity of the bottom water at station "B" rose to 20 ppm.

The total hardness of surface water was similar at all stations, ranging from 30 to 85 ppm (Table 2). Comparison of total alkalinity and total hardness indicates that most of the hardness was non-carbonate hardness. The total hardness of bottom water at station "B" approximated that of surface water on most sampling dates. Bottom water hardness at station "A" approximated that of the surface only through May 20 and at station "C" through March 10. During the remainder of the sampling period water hardness near the lake bottom varied from 10 to 65 ppm higher than the surface at station "A" and from 15 to 70 ppm higher than the surface at station "C".

Conductivity was similar at stations "A" and "B" but was somewhat higher for the surface waters at station "C" (Table 2). Conductivity readings from 82 to 220 microhmos at station "A" and "B", averaging 125. At station "C" the conductivity ranged from 85 to 220 microhmos and averaged 176, indicating increase in conductivity from the lower portion of the lake near the dam to the upper limit of the lake.

Conductivity of the bottom water at station "B" approximated that of the surface. At the other stations, however, conductivity was considerably higher. At station "A" it ranged from 82 to 220 microhmos at the surface and 100 to 310 near the lake bottom. At station "C" the surface conductivity ranged from 85 to 220, compared to a range of 165 to 330 near the lake bottom.

Copper determinations were made at infrequent intervals, but on only one occasion was it detected by methods used in field analyses. On March 10, 1970, the concentration of copper at station "A" varied from 0.1 ppm at the surface to 0.7 ppm near the bottom. Determinations made midway between stations "A" and "C" indicated concentrations ranging from 0.12 at the surface to 0.3 near the bottom. At station "C" the copper concentration varied from 0.11 at the surface to 0.25 ppm at the bottom.

Measurements of sulphate concentrations were carried out on surface and bottom waters on September 9 at station "B" and on September 10 at station "C". Concentrations of sulphates ranged from 45 to 50 ppm at station "B" and from 49 to 90 ppm at station "C", at the surface and bottom respectively.

Neutron activation analyses were carried out on water samples obtained from all three lake stations and from water from six tributary streams (Table 3). An evaluation of these analyses indicated that, of the elements encountered, only copper, mercury and zinc were of a sufficiently high concentration to affect biological activity. Copper varied from 0.39 at the surface of station "A" to 0.23 ppm near the bottom; from 0.17 ppm at the surface of station "B" to 0.07 near the bottom; and at station "C" the copper content was 0.06 ppm at the surface. Since the lake was at winter pool level, samples were not obtained from bottom waters at station "C" because of shallow water depths (maximum depth - 8 feet). Concentrations of mercury at station "A" varied from 0.16 at the surface to 0.04 ppm near the bottom; at station "B" from 0 ppm at the surface to 0.07 ppm near the bottom; and at station "C", 0.29 ppm at the surface. Zinc levels at station "A" ranged from 4.54 ppm at the surface to 0.20 near the bottom; at station "B" from 0 ppm at the surface to 0.89 ppm near the bottom and at station "C" the zinc level was 1.73 ppm at the surface. From the foregoing it should be noted that the highest concentrations of copper and zinc occurred near the dam in surface waters and was lowest near the upper limits of the lake. Mercury appeared lowest at the upper extremity of the lake. The low concentrations of these metals found in Laurel Fork Cove (station "B") may have been due to dilution water entering the cove from two tributary streams (Hopkins Branch and Laurel Fork Creek).

The concentration of manganese obtained by these analyses closely approximated those obtained during field analysis. No comparison was possible between the two methods for iron determinations. Concentrations of iron determined through field analyses indicated the level of iron was less than 22 ppm and levels of less than 50 ppm could not be detected by neutron activation. It does tend to indicate, however, that the iron present for the most part is probably in the ionic form. It has been noted that for other waters the 1,10 orthophenthroline method used in field analyses, apparently only detects the free iron and not that portion involved in biological activity or organically bound.

Fish Populations:

During September 22 and 23, 1969, fish populations samples were obtained from the North Fork Pound Reservoir in order to evaluate reports of large fish mortalities having occurred during the previous winter. An estimated one quarter acre cove near the dam designated cove number one (Figure 1) was treated with rotenone. A total of 150 fish (Table 4) weighing slightly over 5.2 pounds (Table 5) were recovered. Most fish recovered from this sample were young of the year fish, indicating that reproduction by most species appeared adequate. Absent from this sample were channel catfish and smallmouth bass which had been introduced three years previous.

At the same time that the rotenone sample was obtained, one series of gill nets was set at intervals from the dam to the upper end of the lake. Numbers of fish taken from these nets indicated an apparent lack of adult fish (Table 6). An estimated 63 hours of fishing yielded only 0.1107 fish per net hour.

Species taken in order of abundance were bluegill (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*), white bass (*Roccus chrysops*), white sucker (*Catastomus commersonii*), green sunfish (*Lepomis cyanellus*), and yellow bullhead (*Ictalurus natalis*). Again, smallmouth bass and channel catfish were not represented in the sample. While too few gill net sets were made to give any definite results, the comparative ease with which members of the catfish family are usually taken in gill nets and the lack of catfish in the samples indicates a lack of adults for this species.

Gill nets were again set during March, 1970. At this time three series of three nets each were made, spanning the length of the lake. Nets were fished approximately 186 hours and yielded 0.0752 fish per net hour. All fish captured were white suckers. Cold water temperatures (48° F), causing relative inactivity of other species, was thought responsible for the lack of other species in net catches. All white suckers taken appeared to be in spawning condition; thus accounting for greater activity among this species and in more being caught.

Series of gill net sets were made in a like manner during June, July, August and September, except that the series set midway in the lake was shifted into Laurel Fork Cove. The movement was made because anglers reported Laurel Fork Cove provided a higher rate of angling success than the remainder of the lake. From this, it was assumed that this area was less toxic than the remainder of the lake. Gill net catches tended to confirm the assumption (Table 3); although too few fish were taken to definitely establish such a finding.

During the above mentioned months total hours fished by gill nets varied from 128 in July to 189 in August. The lower figure for July was due to the one and one half inch net being lost. Results of the July and August series of sets again indicated a scarcity of fish in the size range susceptible to nets. Rate of catch ranged from 0.0312 in July to 0.1005 per net hour in August.

During September, 1970, three cove rotenone samples were taken to determine relative species composition and reproductive success. Cove number one was treated on two separate occasions, approximately 16 days apart. Observations indicated that not all fish were killed during the first treatment thus this cove was treated a second time. Results were then compared to results obtained in 1969 in the same cove (Table 1 and 2). The total number of fish recovered varied from 150 in 1969 to seven in 1970 and weight of fish dropped from slightly over 5.2 pounds in 1969 to 0.2 pounds in 1970. A total of nine species were recovered in 1969 compared with two species in 1970. All of the fish recovered in 1970 were bullheads. Small yellow bullhead (*Ictalurus natalis*) were captured along with brown bullhead (*Ictalurus nebulosus*) (which were represented by both young of the year and adults).

Cove two and three were sampled for the first time in 1970. These coves were approximately the same size as cove number one. Sampling results were similar to the 1970 cove number one. A total of 14 fish comprised of five species and weighing just over 1.2 pounds were taken in cove number two. Captures of young of the year were limited to yellow bullhead only.

Cove number three, located at the upper end of the lake yielded 18 fish weighing approximately 0.1 pound (Table 1 and 2). The sample consisted of bluegill and yellow bullhead. Young of the year bluegill (or redear sunfish) were only found at this station.

Plankton

During the period May through October 8, 1970, plankton samples were obtained at the same three stations as were water chemistry samples except for station "B", in order to establish the relative standing crop of net plankton in the lake. No samples were taken prior to June, 1970, at station "B".

Total numbers of zooplankton at station "A" varied from a low of 0.0 on May 20 to a high of 25.5 per liter on September 23 (Table 7). Copepoda predominated in samples. *Cyclops* and *Orthocyclops* were predominant during most of the period with *Diaptmus* being present in samples after the latter part of August. Following the Copepoda in predominance were rotifers belonging to several genera. Also present, but much less abundant, were *Daphnia* (Cladocera) and Ostracoda.

Net phytoplankton numbers exceeded 19 per liter on only two occasions - May 20 and June 15. Except for the sample of July 28 all samples consisted primarily of filamentous forms (Table 7). On July 28 the ciliate, *Dinobryon* predominated. Diatoms were also present although rarely encountered at station "A". Phytoplankton appeared most abundant during May, June and early July.

At station "B" the summer zooplankton minima occurred with the June 16 sample and the maxima with the August 27 sample (Table 8). As at station "A", Copepoda dominated all samples followed in order of abundance by Cladocera and Ostracoda. Station "B" was the only station at which *Bosmina* (clodocera) was found. Ostracoda appeared more abundant at station "B" than at any other station.

Phytoplankton were scarce at station "B" just as at station "A" (Table 8). The Summer maxima occurred September 9. Diatoms were the predominant phytoplanktors present in most samples. Following diatoms in order of abundance were filamentous algae and desmids.

Station "C" differed somewhat from station "A" and "B". Zooplankton were only slightly more abundant than at the other stations, reaching a peak in late September and early October (Table 9). Predominance was shared by Copepods and Rotifera whereas at other stations Copepoda alone was predominant. Clodocerans were rarely encountered at station "C" while Ostroceds were entirely absent from samples.

Phytoplankton were scarce in most samples at station "C" except for a maxima which occured September 10, (Table 9). Diatoms were the predominant form of algae present, followed by filmentous algae and desmids.

While the numerical count of phytoplankton indicated production of phytoplankton was low; it is recognized that these figures do not represent the true standing crop of phytoplankton, but only the relative abundance of plankters of a sufficient size to be contained by the number 25 silk bolting cloth plankton net. However, other indicators of phytoplankton abundance were observed. Clarity of the water (water sampler disappeared from view at about 25 feet) and apparent color of the water, in the epilimnion (0.0-30 platinum units) also indicated an apparent lack of phytoplankton.

DISCUSSION

From numerous gill net and cove rotenone samples, it seems apparent that the fish population has been drastically reduced, and that reproduction by largemouth bass, green sunfish and black crappie was virtually nonexistant during the sampling period. Such a marked change in fish population within a short period of about two years cannot be strictly documented, for no data prior to the reports of fish mortalities in 1969 is available. However, personal observations prior to this time indicated the lake was producing good to excellent sport fishing. The only problem at the time being a moderate infestation of parasitic copepods (species unidentified).

The loss of the North Fork Pound Reservoir fishery appeared to have been the result of the low pH of reservoir water either alone or in combination with the heavy metals iron, manganese, copper, zinc and mercury, which were shown to be present both by chemical analyses and by neutron activation analyses. According to Jones (1964), the pH tolerance limit for most fish where the hydrogen ion is the only factor involved is about 5.0. Chemical analyses indicated that during much of the year the pH of most portions of the reservoir was close to 5.0, particularly during the fall, winter, and spring months. Only during the summer months did the pH rise appreciably above 5.0 in the lake. In the upper portion of the lake (station "D") the pH approximated 5.0 during the entire study period.

The heavy metals copper, mercury and zinc have been shown to be extremely toxic to fish, although the toxicity varies according to species. Moore and Kellerman (1905) indicated copper sulfate is toxic to sunfish at a concentration of 1.33 ppm, to largemouth bass at 2.00 ppm and to catfish at 0.4 ppm. Eckhart and Mahoney (1971) found the 96-hour TLM for copper to bluegill to be 0.5 ppm. Cairns and Scheier (1957) report the toxicity of zinc (96-hour TLM) to bluegill sunfish in soft water to be 2.86 to 3.78 ppm at 20°C and 1.93 to 3.63 ppm at 30°C. Eckhart and Mahoney (1971) indicate the 96-hour TLM for zinc to bluegill to be 3.2 ppm. According to Jones (1964) mercury is one of the most toxic metals to fish. He found the toxicity threshold for sticklebacks to about 0.008 ppm mercury. From this it may be seen that the listed metals are near or above lethal toxic levels in the North Fork Pound providing they are in a toxic form, as is thought to be the case at least during some periods. Since the neutron activation method measures the total amount of an element present in the sample, regardless of its form, it cannot be definitely stated as to whether or not the copper, mercury and zinc concentrations detected by this method were present in toxic forms. However, the reported fish mortalities indicate that at least some of them may have been. In addition to the individually toxic effect of copper and zinc, the synergistic effect of these metals probably increased their toxicities drastically (Douderoff and Katz, 1953). Eckhart and Mahoney (1971) found that the 96-hour TLM of a mixture of copper and zinc to bluegill was 0.27 ppm copper and 2.0 ppm zinc compared to 0.5 ppm copper by itself.

The field chemical analyses and neutron activation analysis strongly suggest that most of the copper, mercury and zinc present in the North Fork Pound Reservoir was entering the lake by way of the North Fork Pound River and Meadow Branch (Tables 10 and 3). During the period July 1 through October 8, 1970, the pH of Meadow Branch ranged from 4.0 to 4.5. Total alkalinity was usually 0.0 ppm and total hardness varied from 225-750 ppm, indicating that the hardness was almost entirely non-carbonate. The concentration of manganese ranged from 12-45 ppm and total iron from 0.0-3.5 ppm (Table 10). Most of the copper entering the lake appeared to be coming from this stream. The concentration of copper found on February 26, 1970 by neutron activation was 0.32 ppm.

The major effect of the North Fork Pound River (Tables 3 and 10) was in contributing water of low pH (4.7-5.8), some manganese (5-15ppm), a small quantity of iron (0.2-0.6 ppm), a small amount of copper (0.10 ppm), and some zinc (0.68 ppm).

The effect on the water quality of the lake exerted by waters entering the reservoir from the four remaining tributaries is questionable. Total alkalinity, hardness, pH and conductivity measurements (Table 10) provided no indication of any pollutants. However, neutron activation analysis (Table 3) indicated the presence of small amounts of copper and mercury and moderately high concentrations of zinc. The presence of fish in these streams suggests that the toxic materials were in a nontoxic form. After water from the streams in question enters the lake it cannot be definitely ascertained whether or not these metals remain in a nontoxic form. Nevertheless, the lack of apparent color in the epilimnion of the lake indicateds the absence or near absence of suspended and dissolved organic material, and of plankton with which these metals could be intergrated. Thus, the possibility exists that the metals are present in the ionic form at least during some periods, particularly in the light of the reported fish kills.

The effect of heavy metal toxicity on *Daphnia magna* has been studied by Anderson (1948). He reported that the threshold concentrations of zinc chloride in Lake Erie water (pH, 8.2-8.4) was less than 0.15 ppm, for copper chloride, 0.027 ppm and for mercuric chloride, less than 0.006 ppm. Anderson (1948) cites work done by Hutchinson (1933) in which 0.00001 molar zinc solutions killed

Daphnia magna and pulex in less than five days and *Ceriodaphnia reticulata* in less than four days, along with a study by Fowler (1931) in which a 0.0001 molar zinc solution killed *Daphnia longispina* in 15 hours.

In addition to heavy metal toxicity, pH may have been a toxic factor in the acid North Fork Pound Reservoir (pH, usually near 5.0 during most of the year). The Federal Water Pollution Control Administration (1968) states that nonlethal limits of pH are narrower for some fish food organisms than they are for fish. *Daphnia magna* does not survive experimentally in water having a pH below 6.0. Ellis (1937) reported 100 percent mortality of *Daphnia magna* in a sulphuric acid solution below a pH of 6.5 and stated that many proteins are precipitated in living tissue at an isoelectric point of 5.5.

The apparent effect of the heavy metals and/or low pH on zooplankton populations in the North Fork Pound Reservoir is quite noticeable. The numerical abundance of cladocerans was extremely low (particularly at station "C") while numbers of copepods and rotifers were only slightly higher. Although no before and after comparisons can be made concerning the zooplankton of the North Fork Pound Reservoir it seems logical to assume that conditions prevalent during the study period limited the standing crop of zooplankters, particularly cladocerans.

In addition to the low abundance of zooplankton, net phytoplankton abundance was also low. The presence of toxic metals and low carbonate alkalinity is thought to be responsible. Literature reviewed by the Federal Water Pollution Control Administration (1968) indicates that many species of algae are adversely affected by concentrations of 0.5 ppm or less of copper, zinc and mercury. In the case of mercury they cite work done by Corner and Sparrow (1956), who reported that "the toxic effects of mercury salts are accentuated by the presence of toxic amounts of copper". Benoit *et al.*, (1967) reported damage to diatom populations in and below Keswick Reservoir, California, and downstream from Spring Creek, which was carrying high concentrations of toxic heavy metals (iron, copper and zinc) and acid into the lake. The concentration of manganese in the North Fork Pound Reservoir may have been sufficiently high to be toxic to some algae, although little information concerning its toxicity is available. Gerloff and Skoog (1957) report that there is some indication high concentrations of manganese in the absence of calcium can limit blue-green algae (*Microcystis aerugenosa*).

The low carbonate alkalinity (usually less than 10 ppm) encountered in the lake may also have been a factor responsible for apparently low standing crop of phytoplankton. According to the Federal Water Pollution Control Administration (1968), "the major buffering system in natural waters is the carbonate system which forms an indispensible reservoir of carbon for phytosynthsis. Thus the productivities of waters are closely correlated with the carbonate buffering system. The addition of mineral acids preempts the carbonate buffering capacity and the original biological productivity is reduced in proportion to the degree that such capacity is exhausted."

Thus it appears that the reduced fish population, lack of reproduction by certain species of fish, and extremely low standing crops of plankton may be correlated with heavy metal toxicity, low pH and low carbonate alkalinity.

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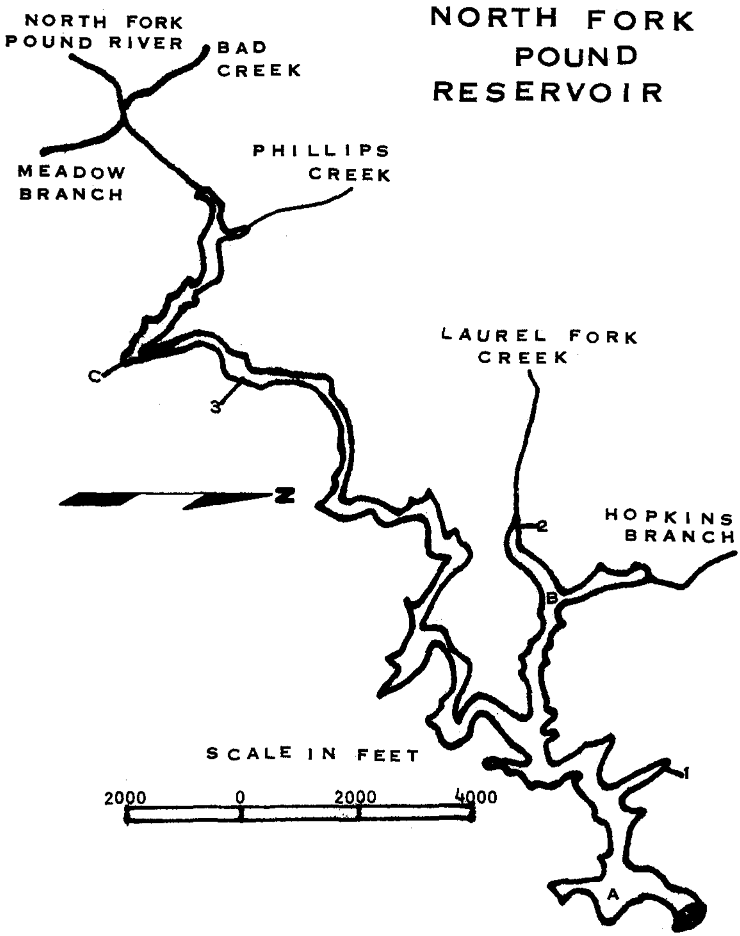

Figure 1. Outline of the North Fork Pound Reservoir showing location of chemical, plankton (A, B, & C) and rotenone sampling stations (1, 2, & 3) and locations of tributary streams.

Table 1. Water temperature (°F), dissolved oxygen, total iron and manganese (ppm), according to depth, from the North Fork Pound Reservoir during the period May 7 - October 7, 1970, at station A.

					Depth						
Date	Sur.	5	10	15	20	25	30	35	40	45	50
5/7	61	60	60	60	58	56	54	53	52	52	
5/20	65	63	63	62	60	58	57	56	54	54	
6/15	72	72	72	70	67	64	63	51	60	58	
7/1	75	74	74	73	73	70	67	64	62	59	56
7/13	76	74	74	74	74	70	67	67	62	59	56
7/28	79	78	78	77	76	73	68	66	62	59	56
8/9	76	76	76	76	76	73	69	66	63	60	56
8/26	79	78	76	76	76	73	70	68	66	64	60
9/8	77	77	77	77	77	74	72	69	66	64	60
9/23	76	76	76	75	75	74	72	69	68	66	63
10/7	69	69	69	69	69	69	69	69	68	68	68

					Dissolved Oxygen						
5/7	9.0				9.0					9.0	
5/20	9.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	
6/15	7.0	8.0	7.0	7.0	7.0	7.0	7.0	7.0	6.0	3.0	
7/1	7.0	7.0	7.0	7.0	6.0	6.0	6.0	5.0	3.0	1.0	0.0
7/13	7.0	7.0	7.0	6.0	6.0	6.0	6.0	4.0	2.0	0.0	0.0
7/28	7.0	7.0	7.0	7.0	7.0	6.0	6.0	3.0	2.0	1.0	0.0
8/9		7.0	7.0	6.0	6.0	6.0	5.0	2.0	1.0	1.0	0.0
8/26	7.0	7.0	7.0	7.0	6.0	4.0	3.0	3.0	1.0	0.0	0.0
9/8	6.0		7.0	6.0	6.0	2.0	3.0	1.0	1.0	1.0	0.0
9/23	7.0	7.0	6.0	6.0	7.0	5.0	3.0	2.0	1.0	1.0	0.0
10/7	7.0								7.0	5.0	3.0

					Depth						
Date	Sur.	5	10	15	20	25	30	35	40	45	50
					Total Iron						
5/7	0.05				0.1					0.5	
5/20	0.05	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.2	
6/15*	0.1	0.1	0.1	0.1						0.2	
7/1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	2.0	7.5
7/13	0.0						0.0	0.2		7.0	16.0
7/28							0.0	0.3	0.5	10.0	16.0
8/9						0.0	0.1	1.0	7.0	13.5	25.0
8/26								0.0	0.0	8.0	20.0
9/8								0.0	1.5	11.0	21.0
9/23								0.0	2.0	7.0	13.0
10/7									0.0	0.5	3.0

Manganese

5/7	4.0				2.0					2.5	
5/20	2.0	2.7	1.6	1.4	2.3	2.5	2.6	1.5	2.5	2.0	
6/15	1.5	1.2	1.5	1.5	2.0	2.0	1.2	2.0		2.5	
7/1	1.2	1.2	1.0	1.0	1.0	2.0	1.7	1.7	2.5	2.5	2.5
7/13	1.0	1.5	1.5	1.7	1.7	1.7	1.7	1.5	1.7	3.0	4.0
7/28	1.2	1.2	1.2	1.2	1.2	1.2	1.5	1.5	2.0	3.0	4.0
8/9	1.5	1.5	1.5	1.5	1.5	1.5	1.7	1.7	2.5	3.2	3.5
8/26	1.7	1.7	1.7	1.7	2.0	2.5	2.5	2.5	3.5	3.5	6.0
9/8	2.2	2.0	2.2	2.2	2.2	2.7	3.2	3.7	3.7	4.7	5.0
9/23	2.5	2.5	2.5	2.5	2.5	3.5	3.2	3.5	3.5	4.2	4.5
10/7	3.5	3.2	3.2	3.2	2.7	3.2	3.5	3.5	3.5	3.2	3.7

*Chemicals did not react properly between the 20 and 40 foot depths.

Table 2. Chemical analyses and physical properties of the surface and bottom water at three stations on the North Fork Pound Reservoir - 1970.

		Total Alkal. (ppm)		Total Hrdns. (ppm)		pH		Color		Conductivity (microhmos)	
Station	Date	Sur.	Bot.	Sur.	Bot.	Sur.	Bot.	Sur.	Bot.	Sur.	Bot.
A	3/10	10	0	30	40	5.1	4.9				
	5/7	10	40	30	5.4	5.1			82	100	
	5/20	10	10	30	30	5.5	5.7			105	100
	6/15	10	-	40	70	5.8	5.8			100	150
	7/1	10	70	35	100	6.4	6.7	0	20	110	240
	7/13	10	65	40	60	6.4	6.6	-	-	11-	290
	7/28	10	80	40	75	6.4	6.6	0	60	120	230
	8/9	10	60	50	70	6.4	6.7	-	40	130	290
	8/26	10	65	60	105	5.9	6.5	0	60	150	310
	9/8	10	50	60	90	5.8	6.5	0	80	-	-
	9/23	10	50	70	85	5.7	6.4	10	50	190	270
	10/7	10	20	85	95	5.4	5.8	20	35	220	220
B	3/11	10	10	50	60	5.1	5.0				
	5/7	10	10	40	30	5.9	5.3			105	95
	5/20	10	10	40	30	5.5	6.2			105	85
	6/15	10	10	35	40	6.0	6.0			100	85
	7/1	10	10	50	30	6.2	5.9			115	100
	7/14	10	10	40	40	5.9	6.0			120	110
	7/28	10	20	50	80	5.9	6.2		40	120	120
	8/11	10	0	50	45	7.6	6.4		30	140	100
	8/27	10	10	50	60	6.1	7.0		20	130	150

Station	Date	Total Alkal. (ppm) Sur.	Total Alkal. (ppm) Bot.	Total Hrdns (ppm) Sur.	Total Hrdns (ppm) Bot.	pH Sur.	pH Bot.	Color Sur.	Color Bot.	Conductivity (microhmos) Sur.	Conductivity (microhmos) Bot.
B	9/9	10	10	60	70	6.0	5.4		-	-	110
	9/23	10	10	75	65	5.5	5.9	20	20	190	160
	10/7	10	10	85	85	5.4	5.4	0	10	200	200
C	3/10	10	10	60	60	5.0	5.1				
	5/7	10	10	45	60	5.1	4.9			145	165
	5/21	10	10	50	70	5.0	4.9			85	190
	7/2	10	10	60	90	4.9	5.2			190	230
	7/15	10	10	80	80	5.0	5.0			190	200
	7/29	10	10	60	130	5.1	4.4	10	45	180	330
	8/12	10	10	65	120	5.5	4.8	10	70	185	220
	8/27	10	10	70	125	5.4	4.9	10	160	190	260
	9/10	10	10	80	130	5.4	4.9	10	30	-	-
	9/24	10	10	80	125	5.5	4.8	30	40	200	280
	10/8	10	10	85	105	5.4	5.2	15	15	220	220

= less than

Table 3. Neutron activation analysis of water samples taken from the surface and near the bottom in North Fork Pound Reservoir at stations "A" and "B", from the surface at station "C" and from the surface water of tributary streams - February 26, 1971.

	Element in ppm											
Station	Au	Br	Ca	Cl	Cu	Fe	Hg	K	Mg	Mn	Na	Zn
A- surface	0.003	1.92	16.30	2.21	0.39	50	0.16	15.05	13.00	1.66	74.88	4.54
A- bottom	0.000	0.17	18.90	1.86	0.23	50	0.04	10.31	33.50	3.21	43.20	0.20
B- surface	0.002	0.05	10.36	1.25	0.17	50	0.00	7.05	14.75	0.49	44.60	0.00
B- bottom	0.000	0.04	14.00	2.71	0.07	50	0.07	11.83	22.00	2.52	39.70	0.89
C- surface	0.002	0.15	33.33	1.70	0.06	50	0.29	11.99	28.92	3.93	44.88	1.73
N. Fk. Pound R.	0.002	0.07	28.83	2.95	0.10	50	0.05	11.03	32.12	3.95	44.42	0.68
Meadow Br.	0.001	0.09	122.70	0.00	0.32	50	0.00	11.71	143.00	18.66	58.90	0.00
Laurel Fork Cr.	0.004	0.05	12.85	0.85	0.07	50	0.02	4.20	9.93	0.01	74.02	2.32
Hopkins Br.	0.004	0.09	32.00	1.14	0.15	50	0.11	6.10	4.00	0.02	83.06	1.76
Phillips Cr.	0.003	0.13	8.40	1.12	0.02	50	0.05	18.02	5.20	0.03	64.55	1.67
Bad Cr.	0.002	0.06	8.18	0.00	0.02	50	0.00	16.31	4.09	0.00	49.37	1.50

Table 4. Number of fish recovered from coves treated with rotenone during September, 1969 and 1970.

Species	Cove #1 1969	Cove #1 1970	Cove #2 1970	Cove #3 1970
Largemouth bass	31			
Redear sunfish	19		2*	
Bluegill	8		1	16
Green sunfish	16			
Rock Bass	4		1	
Black Crappie	4			
Yellow bullhead	18	1	9	2
Brown bullhead	42	6	1	
Misc. minnows	8			
Total	150	7	14	18

*includes one longear sunfish

Table 5. Weight (pounds) of fish recovered from coves treated with rotenone during September, 1969 and 1970.

Species	Cove #1 1969	Cove #1 1970	Cove #2 1970	Cove #3 1970
Largemouth bass	0.03*			
Redear sunfish	0.7		0.1	
Bluegill	0.3		T	0.1
Green sunfish	0.7			
Rock bass	0.3		0.2	
Black crappie	0.2			
Longear sunfish			0.2	
Yellow bullhead	1.1	T	0.7	
Brown bullhead	1.6	0.2	T	
Misc. minnowsT				
Total	5.2+	0.2+	1.2+	0.1+

Table 6. Number of fish caught per hour from 200-feet each of one, one and one-half, and two inch gill nets fished at North Fork Pound Reservoir during 1969 and 1970.

Species	Sept. 1969	March 1970	June 1970	July* 1970	Aug. 1970	Sept. 1970
Largemouth bass	0.0158		0.0055			
Bluegill	0.0317		0.0166	0.0078	0.0317	
Green sunfish	0.0158					
Redear sunfish			0.0055	0.0078	0.0159	
Black crappie			0.0055		0.0159	0.0055
White bass	0.0158					
Yellow bullhead	0.0158					
Brown bullhead				0.9978		0.0164
White sucker	0.0158	0.0752	0.0333		0.0370	0.0492
Hog sucker			0.0055			
Rock bass				0.0078		
Total	0.1107	0.0752	0.0719	0.0312	0.1005	0.0711
Total hrs. fished	63	186	180	128	189	183

*One and one-half inch net not fished during July.

Table 7. Number per liter of zooplankton and phytoplankton found at station A, North Fork Pound Reservoir - May 7 through October 7, 1970.

	Number per liter										
	May		June	July			Aug.		Sept.		Oct.
Group	7	20	15	1	13	28	10	26	8	23	7
Copepoda	0	0	0.5	1.6	0.6	0.6	1.7	9.8	0.8	20.0	1.3
Cladocera	0.2	0	0	T*	0	0.6	0.6	0	0	0	0
Rotifera	0.2	0	0	0	0.6	1.1	2.2	T	0.8	4.5	0
Ostracoda	0	0	0	0	0	0	0	0	T	T	0
Total Zooplankton	0.4	0	0.5	1.6	1.2	2.3	4.5	9.8	1.6	25.5	1.3
Total Phytoplankton	.6	43.7	68.0	18.8	3.0	2.8	12.8	T	T	1.2	0.5

*less than 0.1 animal per liter

Table 8. Number per liter of zooplankton and phytoplankton found at station B, North Fork Pound Reservoir - June 16 through October 7, 1970.

	Number per liter								
	June		July		Aug.		Sept.	Oct.	
Group	16	1	14	28	11	27	9	23	7
Copepoda	2.7	7.6	6.0	10.4	8.0	20.4	8.0	6.8	6.8
Cladocera	0	0	0	0.4	0	0.4	1.6	0.8	0
Rotifera	0.4	0	0	5.2	0.8	1.2	7.2	4.4	2.0
Ostracoda	2.7	1.2	0.8	1.2	0	0.4	0.8	0	0
Total Zooplankton	5.8	8.8	6.8	17.2	8.8	22.4	17.6	12.0	8.8
Total Phytoplankton	1.6	12.4	0.8	2.8	0.8	0.0	66.1	1.2	7.9

Table 9. Number per liter of zooplankton and phytoplankton found at station C, North Fork Pound Reservoir - May 21 through October 8, 1970.

	Number per liter									
	May		June		July	Aug.		Sept.		Oct.
Group	21	17	2	15	29	12	27	10	24	8
Copepoda	0.7	1.4	1.4	9.1	9.1	5.5	13.9	9.7	12.5	23.0
Cladocera	0	0	0	0	0	0	0	0	0.7	1.4
Rotifera	0	0	4.2	17.4	4.2	5.5	12.6	12.6	24.4	13.3
Total Zooplankton	0.7	1.4	5.6	26.5	13.3	11.0	26.5	21.3	37.6	37.7
Total Phytoplankton	0.7	3.4	11.2	0	0.7	0.7	0.7	130.9	1.4	7.0

Table 10. Chemical water analyses and physical properties of six inlet streams to North Fork Pound Reservoir.

Stream	Date	Total alkal.	Total hrdn.	Phth. alkal.	pH	Mang.	Total iron	Temp.	Color	Conductivity
Bad Creek	5/21/70	10	10	0	6.0	0	0	19°C.	-	50
Laurel Fork Creek	9/24/70	25	20	0	6.9	0	0	24°C.	30	50
Hopkins Branch	9/24/70	10	10	0	6.8	0	0	21°C.	10	50
Phillips Creek	10/ 8/70	10	20	0	7.1	0	T	14°C.	5	50
North Fork Pound River	7/ 1/70	0	278	0	4.7	10	0.6	20°C.	-	470
North Fork Pound River	7/15/70	3	270	0	5.0	10	0.3	23°C.	-	500
North Fork Pound River	7/29/70	2	195	0	4.9	5	0.3	22°C.	-	440
North Fork Pound River	9/10/70	5	200	0	5.0	5	0.5	22°C.	-	-
North Fork Pound River	9/24/70	5	130	0	5.8	5	0.5	19°C.	20	300
North Fork Pound River	10/ 8/70	5	190	0	5.2	15	0.2	14°C.	5	400
Meadow Branch	7/ 1/70	0	500	0	4.5	25	0.4	19°C.	-	1,050
Meadow Branch	7/15/70	0	620	0	4.2	32	0.7	21°C.	-	1,300
Meadow Branch	7/29/70	0	720	0	4.3	40	3.5	21°C.	-	1,900
Meadow Branch	8/13/70	2	225	0	4.4	12	2.4	16°C.	-	700
Meadow Branch	9/10/70	0	750	0	4.1	45	1.2	22°C.	-	-
Meadow Branch	9/24/70	0	720	0	4.0	35	0.5	18°C.	10	1,300
Meadow Branch	10/ 8/70	0	580	0	4.2	25	0	12°C.	0	1,250