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MASTER

November 1978

LAND AND FRESH WATER ENVIRONMENTAL SCIENCES GROUP
DEPARTMENT OF ENERGY AND ENVIRONMENT

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ABSTRACT

AQUATICS TASK FORCE ON ENVIRONMENTAL ASSESSMENT
OF THE ATIKOKAN POWER PLANT:
EFFECTS ON AQUATIC ORGANISMS

The United States Environmental Protection Agency and the State Department sponsored a workshop (University of Minnesota, April 1978) to evaluate possible impacts of an 800-MW coal-fired power plant to be built near Atikokan, Ontario. It is feared that the emissions of SO_2 will lead to the deposition of sulfuric acid and result in the acidification of freshwaters in nearby parks and wilderness areas.

The most obvious biological effects of acidification are damages to populations of fish. Less conspicuous but no less severe damages also occur to other organisms ranging from frogs to bacteria. It appears that all trophic levels are affected: species numbers are reduced, biomasses altered, and processes such as primary production and decomposition are impaired.

Reduced decomposition is evidenced by an unusual accumulation of coarse organic debris and plant remains in acidified waters. Field experiments (e.g., stream acidification and lake neutralization) and laboratory experiments (e.g., respirometry and tracer studies) indicate that microbial activity is reduced and that the recycling of materials is greatly impeded at low pH. This may interfere with nutrient supplies to plants, and decrease the microbial biomass available to higher trophic levels.

Phytoplankton densities appear to decrease in acidified lakes and there is a reduction in some species of macrophytes. On the other hand, Sphagnum and benthic filamentous algae have been observed to greatly increase in acidified conditions. The total primary productivity of lakes and streams may actually increase because of such dense growths on the bottom.

Zooplankton and benthic invertebrate communities become less complex as acidity increases. This may in part be due to reduced food supplies (bacteria, phytoplankton), but direct inhibition by H_2SO_4 has also been demonstrated. This removal of fish food organisms may exacerbate damage to fisheries, especially in the pH range of 5 to 6. When a lake loses all fish because of low pH, a few species of invertebrates may become very abundant.

The salamanders *Ambystoma jeffersonium* and *A. maculatum*, sensitive to acidity below pH 7.0 and 5.0 respectively, are being eliminated from small ponds or temporary pools in the region around Ithaca, N.Y. because of the impact of acid precipitation. Species of frogs in some lakes are also being eliminated because of acidification. Frogs and salamanders are important predators on invertebrate pests and are themselves prey for higher trophic levels. A listing of step functions for damages caused by decreasing pH is provided.

INTRODUCTION

An 800-MW coal-fired electricity generation plant is being constructed near Atikokan, Ontario. Adverse effects are anticipated on the Boundary Waters Canoe Area (BWCA), a Class I wilderness area in Minnesota, 80 to 120 km south of Atikokan, and on Quetico Provincial Park and the proposed Voyageurs National Park, just north of the U.S.-Canada border adjacent to the BWCA. The U.S.-EPA and the State Department sponsored the Aquatics Task Force on Environmental Assessment of the Atikokan Coal-Fired Power Plant which met as a workshop at the University of Minnesota, St. Paul, in April 1978.

One of the major consequences of coal combustion is the emission of SO_2 which may be converted to H_2SO_4 in the presence of water. This conversion may occur in the atmosphere or following absorption into water on vegetation or other surfaces, or directly into lakes and streams. In Scandinavia and North America, many lakes and streams have been acidified by H_2SO_4 from fossil fuel combustion, and effects on organisms have been documented.

The most obvious biological effects of acidification are damages to populations of fish. Less conspicuous but no less severe damages also occur to other organisms ranging from frogs to microbes. In fact, acidification affects organisms at all trophic levels in freshwaters. The numbers of species are reduced, biomasses are altered, and major processes are interrupted. The evidence used in this report is taken primarily from literature pertaining to acid precipitation.

Although the literature concerning effects of acid mine drainage (AMD) on freshwater ecosystems is extensive, it is not directly applicable to the acid precipitation problem. Often the uncontaminated waters of coal mining areas have higher alkalinity and hardness than the very soft waters acidified by acid precipitation. AMD water usually has a heavy load of iron and other heavy metals, and frequently depresses the oxygen concentration of receiving waters. High turbidity and the presence of chemical floc are also common and greatly alter aquatic habitats. These factors make it very difficult to extrapolate observations from AMD situations to those in the Laurentian Shield, for example.

The variety of species of both plants and invertebrate animals occurring in fresh waters is enormous and speciation differs markedly from one locale to another even though water chemistry may be similar. It is at best difficult and probably futile to try to interpret ecosystem damages at lower trophic levels by comparing lists of species. On the other hand, changes in major processes such as primary and secondary production, and decomposition can be broadly described and compared. Effects of stress on the major functional guilds may be compared from place to place. Finally a few groups of organisms seem to be remarkably insensitive to strong mineral acidity and are common to many acid environments, while some other groups are clearly intolerant of pH levels below 6.0 to 5.5.

EFFECTS ON MICROBIOTA

The production of fish and other animal life in a lake is ultimately dependent upon the availability of organic food resources, primarily plant materials. The sources of organic materials may be divided into two major categories: autochthonous, originating by primary production in the lake, and allochthonous, transported into the lake by inflowing water, airborne litter, or dissolved in rain. The relative importance of each of these sources varies greatly from lake to lake. One principal route for both authochthonous and allochthonous organic matter into the trophic system of a lake is via the detritus.

Bacterial consumption and mineralization of detrital organic matter, both particulate (POM) and dissolved (DOM), allows a cycling of carbon which dominates the structure and the functioning of the system and provides what Wetzel (1975) has called a fundamental stability to the system. In the deep, open water of the pelagic zone, where phytoplankton production normally provides a substantial portion of the nonrefractory organic matter, bacteria rapidly assimilate dissolved labile organic substances (PDOM) derived from photosynthesis (Hellebust 1974, Fogg 1977) and convert it into bacterial biomass. Particulate organic matter (POM) from phytoplankton is assimilated at a somewhat slower rate. Only a small portion of the PDOM is refractory material likely to survive longer than 24 hr (Saunders and Storch 1971). The bacterial mineralization rate appears to be rather slow, a few percent per day (Wiebe and Smith 1977, Cole and Likens 1978), so that this new biomass is actually available to other trophic levels. Not only do the bacteria conserve the energy stored in labile PDOM, which otherwise would be lost from the system, but they also convert (at a slower rate) some of the refractory DOM into a usable form. Fungal and bacterial communities render other POC into forms which are useful for detritovores (Boling et al. 1975). The significance of these activities to ecosystem energetics can be better appreciated when one considers that on the order of 90% of the organic carbon in the water column is DOM and that detrital POM is many times larger than the total living carbon biomass.

There are other sources of detritus in the pelagic zone. In some lakes, particularly smaller and/or shallow lakes, macrophytes and benthic algae are important sources of autochthonous organic carbon. Material from these plants may contribute significantly to detritus in the pelagic zone. In deciduous forest lakes, leaf litter falling or blown onto the surface has been found to be 200 to 500 g dry leaves per meter of wooded shore line (Jordan and Likens 1975, Gasith and Hassler 1976). This forest litter, plus that which is added by stream imputs, contributes to both DOM (after leaching) and POM.

Water column detritus generated from all of these sources has three possible fates. It can be transformed biologically, it can sink to the sediments where it accumulates and/or is transformed biologically, or it is lost from the system by outflow. In the first two cases, microbial activity plays a key role in removing detritus.

The inhibition of microbial decomposition can have profound effects throughout an aquatic ecosystem. Detritus removal, conservation of energy, nutrient recycling, primary production, detritivore production and thus production at higher trophic levels, can all be affected by changes in microbial activity. Several investigations have indicated that microbial decomposition is greatly inhibited in waters affected by acid precipitation.

An abnormal accumulation of coarse organic detritus has been observed on the bottoms of six Swedish lakes where the pH decreased by 1.4 to 1.7 units in the past three to four decades (Grahn et al. 1974). Bacterial activity apparently decreased, while in some of the lakes the sediment surfaces over large areas were made up of dense felts of fungal hyphae. In one of the lakes, Gårdsjön, 85% of the bottom in the 0 to 2 m depth zone was covered with a thick felt of fungus. Lime treatment caused a rapid decomposition of the organic litter as well as great reductions of the fungal felt (Andersson et al. 1974), indicating that an inhibition of bacterial activities had taken place at low pH. Similar neutralizations of acidified lakes in Canada resulted in a significant increase in aerobic heterotrophic bacteria in the water column (Scheider et al. 1975). Results from field and laboratory experiments with litterbags in Norway (Hendrey et al. 1976) also indicate reduced weight loss of leaves in acidic waters. Dissolved organic carbon (DOC) in the inflowing water was found to contribute ca. 50% of allochthonous inputs and 8% of all organic carbon in Mirror Lake, while fine particulate organic carbon (FPOC) was negligible (Jordan and Likens 1975). The extent to which this DOC input is converted to bacterial biomass or otherwise enters into the energetics of a lake is not known. Observations of abnormal accumulations of organic debris have also been made in AMD waters in South Africa (Harrison 1958) and West Virginia (J. DeCosta pers. comm.).

In laboratory experiments, Bick and Drews (1973) found that the decomposition rate of peptone by microbiota decreased with pH and that the oxidation of ammonia ceased below pH 5. Bacterial cell counts and the species number of ciliates also decreased. Numerous other studies indicate that the microbial decomposition of organic materials is markedly reduced at pH levels commonly encountered in lakes affected by acid precipitation (Hendrey et al. 1976).

Accumulations of organic debris and extensive mats of fungal hyphae, as observed in the Swedish Lakes (Grahn et al. 1974), both seal off the mineral sediments from interactions with the overlying water and hold organically bound nutrients which would otherwise have become available if normal decomposition had occurred. The reduction in nutrient availability can be expected to have a negative feedback effect on the organisms, further inhibiting their activities. The reduction of nutrient supplies to the water column from the sediments, because of the physical covering and from reduced mineralization of organic materials in the water itself, will lead to reduced phytoplankton productivity. These ideas have been formulated into the hypothesis of "self-accelerating oligotrophication" by Grahn et al. (1974). Qualitative observations support this hypothesis but a quantitative evaluation is lacking.

Reduction of microdecomposer activities may have a direct effect upon the invertebrates. Although certain benthic invertebrates appear to feed directly on the allochthonous detritus material, it seems that "conditioned" (colonized by microorganisms) material is preferred, and that the nutritional value of the detritus is highly increased by conditioning (Boling et al. 1975). Bacteria may also be a food source to be removed by the filtering apparatus of organisms such as Calanoida. An inhibition of the microbiota or a reduction in microbial decomposition processes would therefore have a direct impact on the lakes' animal communities.

EFFECTS ON BENTHIC PLANTS

In waters affected by acid precipitation major changes occur within plant communities. Most of the available data are qualitative and descriptive although some experimentation has been done. Intact lake sediment cores which included the rooted macrophyte *Lobelia dortmana* were incubated at three pH levels (4.0, 4.5 to 5.5, 6.0) at Tovdal in southern Norway. The growth and productivity of the plant (O_2 production) were reduced by 75% at pH 4 compared to the control (pH 4.3 to 5.5) and the period of flowering was delayed ten days at the low pH (Laake 1976).

In five lakes of the Swedish west coast, a region severely affected by acid precipitation, Grahn (1975) reports that in the past three to five decades the macrophyte communities dominated by Sphagnum have expanded. In the sheltered and shaded locality Lake Örvattnet, in the 0 to 2 m depth zone, the bottom area covered by Sphagnum increased from 8 to 63% between 1967 and 1974. In the 4 to 6 m depth zone, the increase was from 4 to 30%. At the same time, pH in Örvattnet decreased 0.8 units to ca. 4.8. Similar growths of Sphagnum occur in other Swedish lakes, in Norwegian lakes, and in AMD water as well (Harrison 1958; Harrison and Agnew 1962; Hagström 1977). At the pH of these acid waters, essentially all of the available inorganic carbon is in the form of CO_2 or H_2CO_3. Conditions are more favorable for Sphagnum, an acidophile which is not able to utilize HCO_3^- as do many other aquatic plants. The moss appears to simply outgrow the flowering plants under acid conditions.

In developing their hypothesis on oligotrophication, Grahn et al. (1974) have stressed two biologically important consequences of this Sphagnum expansion. First, Sphagnum has an ion-exchange capacity which results in the withdrawal of base ions such as Ca from solution, thus reducing their availability to other organisms. Secondly, dense growths of Sphagnum form a distinct biotope which is unsuitable for many members of the bottom fauna.

Under some acid conditions, unusual accumulations of both epiphytic and epilythic algae may occur. In the Swedish lakes, Grahn et al. (1974) report that Mougeotia and Batrachospermum become important components of the benthos. In Lake Oggevatn (pH 4.6), a clear-water lake in southern Norway, not only is Sphagnum beginning to choke out Lobelia dortmana and Isoetes lacustris, but these macrophytes have been observed to be festooned with filamentous algae.

Heavy growths of filamentous algae and mosses occur not only in acidified lakes but have also been reported in streams in Norway affected by acidification. In experiments in artificial stream channels using water and the naturally seeded algae from an acidified brook (pH 4.3 to 5.5), an increase in the acidity to pH 4 by addition of sulfuric acid led to an increased accumulation of algae compared to an unmodified control (Hendrey 1976). The flora was dominated by Binuclearia tatrana, Mougeotia spp., Eunotia lunaris, Tabellaria flocculosa, and Dinobryon spp., each accounting for at least 20% of the flora at one time or another. The rate of radioactive carbon uptake per unit of chlorophyll in the channels, measured on just two occasions, was found to be lower in the acid channel by ca. 30%, suggesting greater algal accumulation at low pH despite lower productivity.

Several factors may contribute to these unusual accumulations of certain algae. The intolerance of various species to low pH or to consequent chemical changes (Moss 1973) will allow just a few algal species to utilize the nutrients available in these predominantly oligotrophic waters. Many species of invertebrates are absent at low pH, and removal of algae by grazing is probably diminished. Microbial decomposition is inhibited, as was previously noted, also reducing the removal of algal mass.

EFFECTS ON PHYTOPLANKTON

There is no consistency among various investigations as to which taxa are likely to be dominant under conditions of acidification. The Pyrrophyta may be more common (e.g., species of Peridinium and Gymnodinium) than others in lakes near 4.0. With decreasing pH in the range 6.0 to 4.0, many species of the Chlorophyta are eliminated, although a few tolerant forms are found in the acid range. In their survey of 155 Swedish West Coast lakes, Almer et al. (1974) found that blue green algae became less important with decreasing pH, but Kwiatkowski and Roff (1976) found the opposite to be true in lakes of the Sudbury, Ontario, region.

There are, however, conspicuous decreases in phytoplankton species number, species diversity, biomass and production per unit volume (mg/m^3) with decreasing pH. Lake clarity and the compensation depth increase with lake acidification, so that areal primary production (mg/m^2), although lower in acid than nonacid lakes, is not as severely depressed as is production per unit volume (Johnson et al. 1970; Almer et al. 1974; Hendrey and Wright 1975; Kwiatkowski and Roff 1976). The low phytoplankton biomass (< 1 mg/ℓ) has been correlated to the concentration of available phosphorus, which generally decreases with lower lake pH (Almer et al. 1974). Low availability of inorganic carbon has also been suggested as a factor limiting primary production in acidic lakes (King 1970; Johnson et al. 1970).

Kwiatkowski and Roff (1976) have carried out a highly quantitative study of phytoplankton in six lakes of the Sudbury region, which are impacted by atmospheric effluents from a huge nickel-copper smelter complex. Curvilinear equations are presented for the following variables as functions of pH:

1. Phytoplankton Diversity = Y;
   $Y = -10.01 + 4.18X - 0.33X^2$ ($r = 0.76$).
2. Secchi Transparency Depth, m, = Y;
   $Y = 77.29 - 23.28X + 1.82X^2$ ($r = 0.93$).
3. Chl. a, $\mu g\ \ell^{-1}$ = Y;
   $Y = -9.39 + 2.14X$ ($P < 0.01$).
4. Productivity, $mg\ C\ m^{-3}\ h^{-1}$ = Y;
   $Y = -249.6 + 92.9X - 8.1X^2$ ($r = 0.51$).
5. Productivity, $mg\ C\ m^{-2}\ h^{-1}$ = Y;
   $Y = -882.7 + 347.5X - 31.4X^2$ ($r = 0.45$).

EFFECTS ON INVERTEBRATES

Zooplankton analyzed from net samples collected from 84 lakes in Sweden showed that acidification caused the elimination of many species and led to simplification of zooplankton communities (Almer et al. 1974). Crustacean zooplankton were sampled in 57 lakes during a Norwegian lake survey in 1974 (Hendrey and Wright 1975), and the number of species observed was found to decrease with pH. The distributions and associations of crustacean zooplankton in 47 lakes of a region of Ontario affected by acid precipitation were strongly related to pH and to the number of fish species present in the lakes. However, fish and zooplankton were each correlated with the same limnological variables, especially pH (Sprules 1975). Zooplankton communities become less complex with fewer species present as acidity increases. Food supply, feeding habits, and grazing of zooplankton will probably be altered following acidification, as a consequence of decreased biomass and species composition of planktonic algae and bacteria. Parsons (1968) reports that, in streams continuously polluted by AMD, the number of zooplankton species was small compared to the numbers of individuals, and to less polluted conditions downstream.

Surveys at many sites receiving acid precipitation in Norway, Sweden, and North America (Andersson et al. 1974, Conroy et al. 1975, Hendrey and Wright 1975; Borgstrøm et al. 1976) have shown that waters affected by acid precipitation have fewer species of benthic invertebrates than localities which are less acid. In 832 lakes, J. Økland (1969) found no snails at pH values below 5.2; snails were rare in the pH range 5.2 to 5.8 and occurred less frequently in the pH range 5.8 to 6.6 than in more neutral or alkaline waters. The amphipod Gammarus lacustris, an important element in the diet of trout in Norwegian lakes where it occurs, is not found in lakes with pH less than 6.0 (K. A. Økland 1969). Experimental investigations have shown that the adults of this species cannot tolerate 24 to 48 hours of exposure to pH 5.0 (Borgstrøm and Hendrey 1976).

In the River Duddon in England, pH is the overriding factor which prevents permanent colonization by a number of species of benthic invertebrates, primarily herbivores, of the upper acidified reaches of the river (Sutcliffe and Carrick 1973). In the more acid tributaries (pH < 5.7), the fauna consisted of an impoverished Plecopteran community. Ephemeroptera, Trichoptera, Ancylus (Gastropoda), and Gammarus (Amphipoda) were absent. The epiphytic algal flora was reduced (in contrast to increases noted in Norway), and leaf litter decomposition was retarded. The food supply of the herbivores was apparently decreased, and this may have played a role in the simplification of the benthic fauna. Quantitative data concerning the effects of low pH on the benthic fauna are also available for some acid Norwegian lakes (Hendrey et al. 1976), where notably low standing crops have been observed.

Many studies of invertebrate communities in streams receiving AMD have been conducted. Comparisons are usually made between affected and unaffected zones or tributaries, and experimental acidification has been performed (Herricks and Cairns 1974). The numbers of species, species diversity, and biomass are usually greatly reduced. Generally, in AMD waters Chironomidae (midges) and Sialis (alderfly) are the most tolerant macroinvertebrates. The order Trichoptera has more tolerant species than does Plecoptera (stone flies), and Plecoptera has more tolerant species than does Ephemeroptera (mayflies) (Harrison 1958; Harrison and Agnew 1962; Dinsmore 1968; Parsons 1968, 1977; Dills and Rogers 1974; Wojcik and Butler 1977).

This order of tolerance is essentially the same as seen in waters acidified by acid precipitation. However, the Hemiptera, Notonectidae (backswimmer), Corixidae (water boatman), and Gerridae (waterstrider) are often abundant in acidified soft waters at pH as low as 4.0. This may, in part, be due to lack of fish predation.

Benthic plant communities in lakes may be greatly altered as a consequence of lake or stream acidification (as discussed above). Under these conditions, benthic invertebrate populations may be affected by starvation, evacuation, or extinction due to the loss of preferred habitat. Chironomids (Oliver 1971) and other benthic invertebrates (Cummins 1973), present in many of the poorly buffered northeastern lakes, have diverse feeding habits and habitats. These invertebrates, in many situations, will be affected by altered decomposition cycles and variations in available foods caused by increased acidification.

The tolerance of aquatic invertebrates to low pH varies over their life cycles, and the emergence of adult insects seems to be a period particularly sensitive to low pH levels. Bell (1971) and Moss (1973), in similar studies with Trichoptera and Ephemeroptera, found emergence patterns to be affected at pH levels which were higher than the 30-day survival limits. Many species of aquatic insects emerge early in the spring, even through cracks in the ice and snow cover. Because of the contamination of spring meltwaters by atmospheric pollutants, including heavy metals (Hagen and Langeland 1973, Hultberg 1975, Johannessen et al. 1975, Henriksen and Wright 1976), the early emergers must, in many cases, be exposed to the least desirable water conditions.

Damage to invertebrate communities will influence other components of the food chains. Benthic invertebrates assist with the essential function of removing dead organic material. In litterbag experiments, the effects of invertebrates on leaf decomposition were much more evident at higher pH than at low pH (Hendrey et al. 1976). A reduction of grazing by benthic invertebrates may also contribute to the accumulation of attached algae in acidified lakes and streams.

A short reach of Norris Brook, a tributary to Hubbard Brook in New Hampshire, was acidified to pH 4 in the spring-summer of 1977, to evaluate the effects of acidification on a stream ecosystem. Excessive accumulations of algae occurred, bacterial biomass and heterotrophic activity per unit of organic matter were reduced, and both invertebrate diversity and biomass decreased (Hall, Likens, Fiance and Hendrey, manuscript in preparation).

In unstressed lake ecosystems there tends to be a continuous emergence of different insect species available to predators from spring to autumn. In acid-stressed ecosystems the variety of prey is reduced and periods may be expected to occur in which the amount of prey available to fish (and waterfowl) is diminished.

EFFECTS ON VERTEBRATES

There is a large body of literature on the effects of pH, of acid precipitation, and of AMD on fish. This topic will be covered in the section, Effects of Impacts on Fish, by Harvey in the full report of the Aquatics Task Force (referred to in the introduction).

Pough (1976) has described effects of acid precipitation on spotted salamanders (*Ambystoma jeffersonianum* and *A. maculatum*), which breed in temporary rain pools. Below pH 5 and 7, respectively, these species suffered high mortality during hatching in laboratory tests. This mortality was associated with distinctive embryonic malformations. The development of salamander eggs in five ponds near Ithaca, N.Y., ranging from pH 4.5 to 7.0, were observed. An abrupt transition from low to high mortality occurred below pH 6. Although a synergistic effect of several stresses may have been possible, the studies suggested that pH was the critical variable. Pough cites studies which indicate a decline in British frog populations.

Hagström (1977) has investigated frog populations in Tranevatten, a lake acidified by acid precipitation, near Gothenburg, Sweden. The lake pH has declined to 4.0 to 4.5, and all fish have been eliminated. The frog species *Rana temporaria* is being eliminated as well. Currently, only adults 8 to 10 years old are found. While many egg masses were observed in 1974, few were found in 1977. The few larvae observed in 1977 subsequently died. Another frog species, *Bufo bufo*, is also being eliminated from this lake.

Frogs and salamanders are important predators on invertebrates, including mosquitoes and other pests, in lakes and puddles or pools. In turn, they are themselves important prey for higher trophic levels in an ecosystem (Pough 1976).

SUMMARY AND CONCLUSION

Acid precipitation, by causing increased acidity in lakes, streams, pools, and puddles, can cause slight-to-severe alteration in communities of aquatic organisms. The effects are similar to those observed in waters receiving acid mine drainage (AMD), but the toxicology and chemistry are not as complicated by the presence of high concentrations of heavy metals, chemical flocs, turbidity, etc., such as are found in AMD.

The kinds of effects that are likely to result from increasing acidification are shown in Table 1. In order to provide step-functions for damages, which may be of use in modeling ecosystem acidification, a summary of damages to aquatic organisms as functions of pH is presented in Table 2.

Table 1

Damages to Aquatic Biota Likely to Occur with Increasing Acidity

1. Bacterial decomposition is reduced and fungi dominate saprotrophic communities. Organic debris accumulates rapidly.
2. The ciliate fauna is greatly inhibited.
3. Nutrient salts are taken up by plants tolerant of low pH (mosses, filamentous algae) and by fungi. Thick mats of these materials may develop which inhibit sediment-to-water nutrient exchange and choke out other aquatic plants.
4. Phytoplankton species diversity, biomass, and production are reduced.
5. Zooplankton and benthic invertebrate species diversity and biomass are reduced. Remaining benthic fauna consists of tubificids and Chironomus (midge) larvae in the sediments. Some tolerant species of stone flies and mayflies persist as does the alderfly. Air-breathing bugs (water-boatman, backswimmer, water strider) may become abundant.
6. Fish populations are reduced or eliminated (see companion section by Harvey in the full report of the Atikokan Task Force referred to in the introduction).

Table 2

Summary of Damages to Aquatic Organisms with Decreasing pH

- Long-term changes of less than 0.5 pH units in the range 8.0 to 6.0 are likely to alter the biotic composition of freshwaters to some degree. The significance of these slight changes is, however, not great.
- A decrease of 0.5 to 1.0 pH units in the range 8.0 to 6.0 may cause detectable alterations in community composition. Productivity of competing organisms will vary. Some species will be eliminated.
- Decreasing pH from 6.0 to 5.5 will cause a reduction in species numbers and, among remaining species, significant alterations in ability to withstand stress.
- Below pH 5.5, many species will be eliminated, and species numbers and diversity indices will be reduced. Crustacian zooplankton, phytoplankton, molluscs, amphipods, most mayfly species, and many stone fly species will begin to drop out. In contrast, several pH-tolerant invertebrates will become abundant, especially the air-breathing forms (e.g., Gyrinidae, Notonectidae, Corixidae), those with tough cuticles which prevent ion losses (i.e., Sialis lutaria), and some forms which live within the sediments (Oligochaeta, Chiromomidae, and Tubificidae). Overall, invertebrate biomass will be greatly reduced.
- Below pH 5.0, decomposition of organic detritus will be severely impaired. Autochthonous and allochthonous debris will accumulate rapidly. Most fish species are eliminated.
- Below pH 4.5, all of the above changes will be greatly exacerbated, and all fish will be eliminated.

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APPENDIX I

SUMMARY OF LIMNOLOGICAL ASPECTS OF ACID PRECIPITATION

A. Background

Over the past few decades, the acidity of lakes and rivers has been increasing in several areas of the world. In southern Norway, western Sweden, the Canadian Shield, and the northeastern United States, acidification of freshwaters has become a major environmental problem. It has been clearly established that acid precipitation is the cause of decreasing pH levels in waters of the affected areas (Conroy et al. 1975, Dickson 1975, Schofield 1975, Wright et al. 1975, Gjessing et al. 1976, Likens 1976). It has also been shown that this acidification results in the modification of communities of aquatic flora and fauna at all ecosystem levels (Almer et al. 1974, Grahn et al. 1974, Beamish 1975, Grahn 1975, Hendrey and Wright 1975, Hendrey et al. 1976, Schofield 1976). The numbers of species are reduced and changes in the biomass of some groups of plants and animals have been observed. Decomposition of leaf litter and other organic substrates is hampered, nutrient recycling appears to be retarded, and nitrification inhibited at pH levels frequently observed in acid-stressed waters.

Studies of the hydrobiological problems caused by acid precipitation have been primarily qualitative. Biological aspects of the synoptic lake surveys in Sweden (Almer et al. 1974), Norway (Hendrey and Wright 1975), Canada (Conroy et al. 1975), and the United States (Schofield 1975) have concentrated on changes in the kinds and numbers of species. Very little quantitative information is available concerning the effects of acidification on biomass. This is especially true for the bacteria, and other microorganisms. There is strong evidence indicating that processes such as phytoplankton production and microbial decomposition and inhibited, but quantitative data are scarce (Kwiatkowski and Ross 1976). Changes in the availability of inorganic nutrients and in nutrient recycling are hypothesized (Grahn et al. 1974) but have not been demonstrated; effects on food chains or webs are not well known, and no quantitative data are available concerning the effects on energy processing in natural aquatic ecosystems.

B. Acid Precipitation Problem in the Northeastern United States

The acidity of precipitation in the eastern United States has increased markedly in the past 20 years. A large portion of the Northeast now receives precipitation with an annual average pH of 4.2 or less. This expansion of the geographic areas affected by increasingly acid precipitation is well illustrated in Figure 1 (from Likens 1976).

The geographical extent of regions in which surface water quality is affected by acid precipitation is not yet known, but potentially sensitive areas have been estimated (Figure 2, Galloway and Cowling 1977). It is quite likely that any region with shallow soils on granitic basement rock will have surface waters which have low buffer capacities and which are sensitive to acid inputs. Other factors which tend to make a watercourse sensitive to acid are small drainage area, deficiency of divalent cations, and short hydrologic detention time. Obviously, some regions are more sensitive than others to pH depression.

The effects of acid precipitation on water quality are apparently most severe in the northeastern United States. But the problems there will become worse, and the geographical areas affected will become larger as present trends continue.

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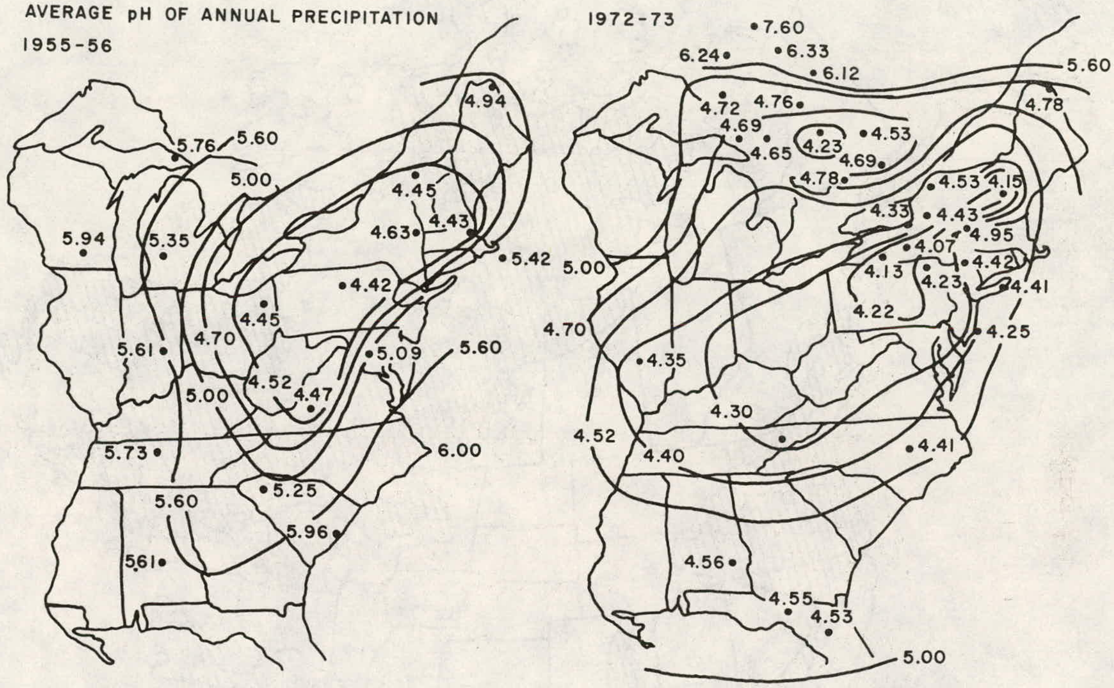

Figure 1. Changes in the pH of precipitation in the eastern United States between 1955-56 and 1972-73. From Likens, 1976.

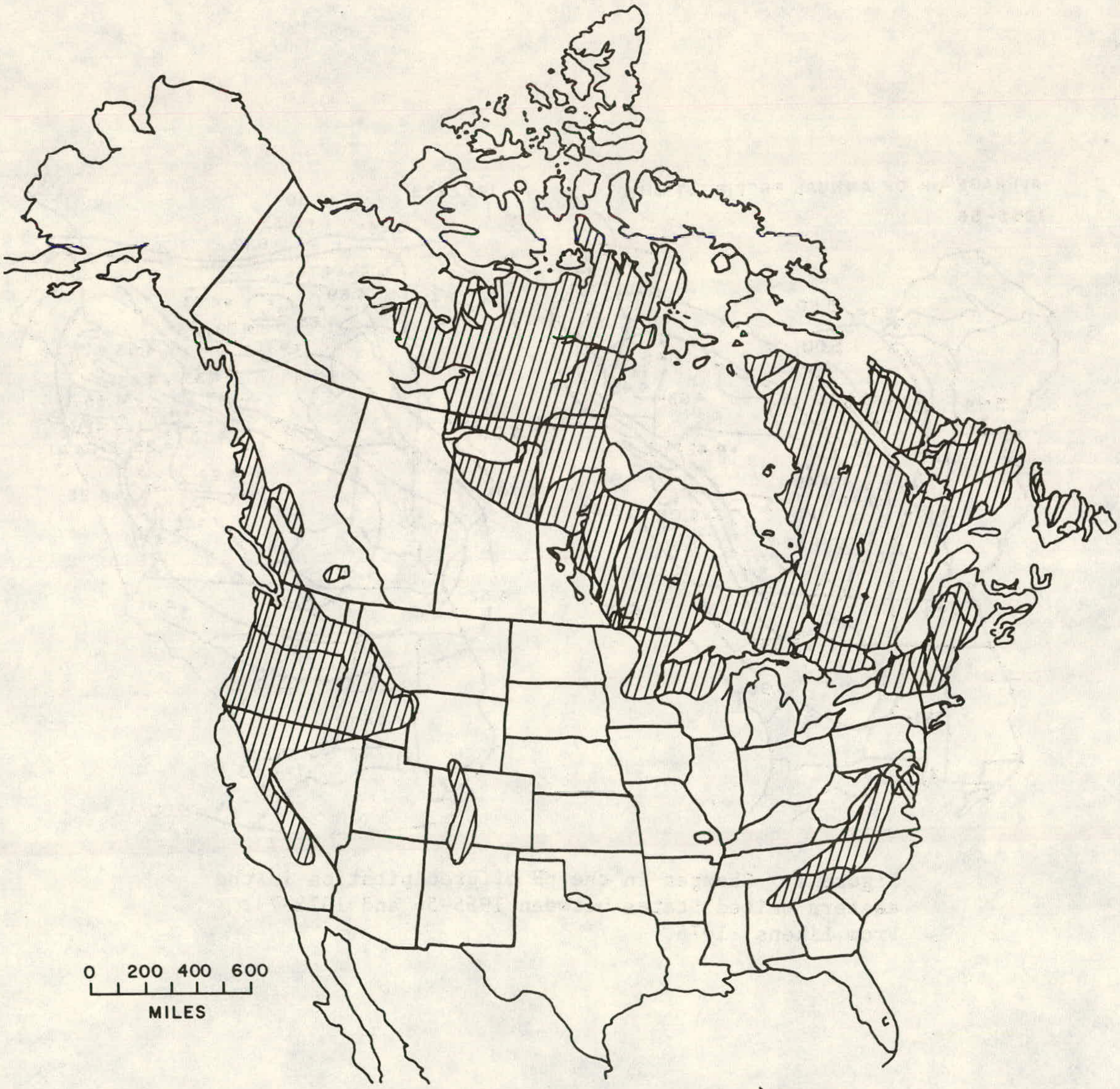

Figure 2. Regions in North America containing lakes that are sensitive to acidification by acid precipitation.