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EFFECTS OF ACID PRECIPITATION ON WETLANDS

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ACID PRECIPITATION RESEARCH

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EFFECTS OF ACID PRECIPITATION ON WETLANDS

by
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ACID PRECIPITATION RESEARCH

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PREFACE

This report is the result of a contract funded jointly, by Inland Waters Directorate and Lands Directorate of Conservation and Protection, Environment Canada, through the Long Range Transport of Airborne Pollutants (LRTAP) program. It reviews the current state of knowledge on the sensitivity of wetlands to acid precipitation, summarizes current research projects, and makes recommendations for future research. The report is intended to provide direction to LRTAP wetland initiatives.

The following individuals have contributed comments and suggestions during the preparation of this paper: P. Blancher, Canadian Wildlife Service; E. Gorham, University of Minnesota; L. Lowe, University of British Columbia; C. Wren, University of Toronto; V. Glooschenko, Ontario Ministry of Natural Resources; J. Riley, Ontario Ministry of Natural Resources; J. Kerekes, Canadian Wildlife Service; D. McNicol, Canadian Wildlife Service; I. Kessel-Taylor, Lands Directorate; C. Rubec, Lands Directorate; and E. Wiken, Conservation and Protection. The assistance of all of these individuals is gratefully acknowledged.

ABSTRACT

The effects of acid precipitation on wetlands have only recently become the focus of extensive research. This report summarizes existing information on the sensitivity of wetlands to acid precipitation and provides recommendations for future research.

The report consists of five major sections. 1) A review of the literature on the effects of acid precipitation on wetland hydrology, hydrochemistry, vegetation, and wildlife is presented. It is felt that current data remain sparse, such that it is only possible to approximate wetland sensitivity to acid precipitation. 2) Preliminary criteria with which to rate wetland sensitivity to acid precipitation are developed and used to rank the major wetland classes in Canada. Poor fens and poor swamps are determined to be the most sensitive to acidification by acid precipitation. 3) A summary of current research in eastern North America addressing the effects of acid deposition on wetlands is provided. 4) A peatland survey in Ontario is used as an example for a proposed regional evaluation of wetland acidification impacts. 5) A summary and recommendations for further research are presented.

RÉSUMÉ

L'apport des précipitations acides sur les terres humides n'est que récemment devenu le sujet de recherches importantes. Ce rapport présente un sommaire de l'information existante concernant la sensibilité des terres humides à la déposition acide et fournit des recommandations quant aux recherches futures.

Le rapport est divisé en cinq sections majeures. 1) Une revue de la littérature sur les effets des précipitations acides sur l'hydrologie, l'hydrochimie, la végétation et la faune des terres humides est présentée. L'impression est que les données courantes sont éparses, ne rendant possible qu'une approximation de la sensibilité des terres humides aux dépositions acides. 2) Des critères préliminaires visant à évaluer la sensibilité des terres humides aux précipitations acides sont développés et utilisés afin de classer les catégories majeures de terres humides au Canada. On a déterminé que les tourbières peu minérotrophes et les marécages pauvres sont les plus vulnérables à l'acidification dûe à la déposition acide. 3) Un sommaire des études en cours dans l'est de l'Amérique du Nord concernant les effets de la déposition acide sur les terres humides est fourni. 4) Un inventaire des tourbières de l'Ontario est utilisé en guise d'exemple pour une proposition d'évaluation régionale des impacts de l'acidification des terres humides. 5) Un sommaire et des recommendations pour études futures sont présentés.

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1.0 INTRODUCTION

Eastern Canada, where wetlands are a major landscape component, receives the heaviest annual inputs of airborne pollutants and acid precipitation. In the six eastern provinces there are approximately 49 000 000 ha of wetlands, 17% of the eastern Canada land area (National Wetlands Working Group, 1986). The term wetland identifies a variety of ecosystems distinguished on the basis of vegetation, morphology, hydrology or chemistry which are divided into five major classes: bog, fen, marsh, swamp, and shallow water as identified by Tarnocai (1980) (Appendix I).

To date, wetlands in eastern Canada have not been rated in the existing long range transport of airborne pollutants (LRTAP) multidisciplinary sensitivity evaluations (Canada-United States, 1983; Li, 1985; Cowell, 1986). These regional evaluations have been developed to aid in assessing the resources at risk due to acid precipitation and to assist in the development of ecosystem monitoring and LRTAP control programs.

The need for studies to address the effects of acid precipitation and the interactions within wetland ecosystems was identified in 1980 in the federal LRTAP program (Cowell, 1980). It was proposed that a series of long-term wetland monitoring studies be established to evaluate the ecological function of wetlands. These studies would provide baseline data for the detection of change in wetland environments due to acid precipitation. Some elements of these monitoring studies are now in place.

This report presents an overview of current literature and research on the impact of acid precipitation on wetlands. These data are then used as a basis for a first approximation of wetland sensitivity to acid precipitation. Current programs, studies or workshops on research into wetlands and acid precipitation in Canada and the United States are also summarized. Agencies contacted include a wide range of academic, government, and multidisciplinary institutions. General recommendations are made for future research.

2.0 ACID DEPOSITION AND WETLANDS: A REVIEW OF THE LITERATURE

Wetlands are ecosystems with complex hydrologic and biogeochemical cycles. These cycles directly influence or modify biotic parameters such as pH and dissolved oxygen, which in turn cause a specific biotic response in both vegetation and wildlife (Gooselink and Turner, 1978) (Figure 1). Acid precipitation could disrupt the balance of the entire ecosystem.

This section reviews existing literature on the effects of acid precipitation on wetland hydrology and hydrochemistry, vegetation, and wildlife.

Quantifying the anthropogenic acidification of wetlands is difficult. The growth and decay of vegetation such as Sphagnum cause many wetlands, particularly ombrotrophic bogs, to become acidified naturally.

In the context of this study, wetland sensitivity to acidification by acid precipitation is the decrease in pH that a wetland will experience from a given addition of acidity. The pH change is inversely related to buffering capacity, which is a measure of the amount of acid or base required to change the

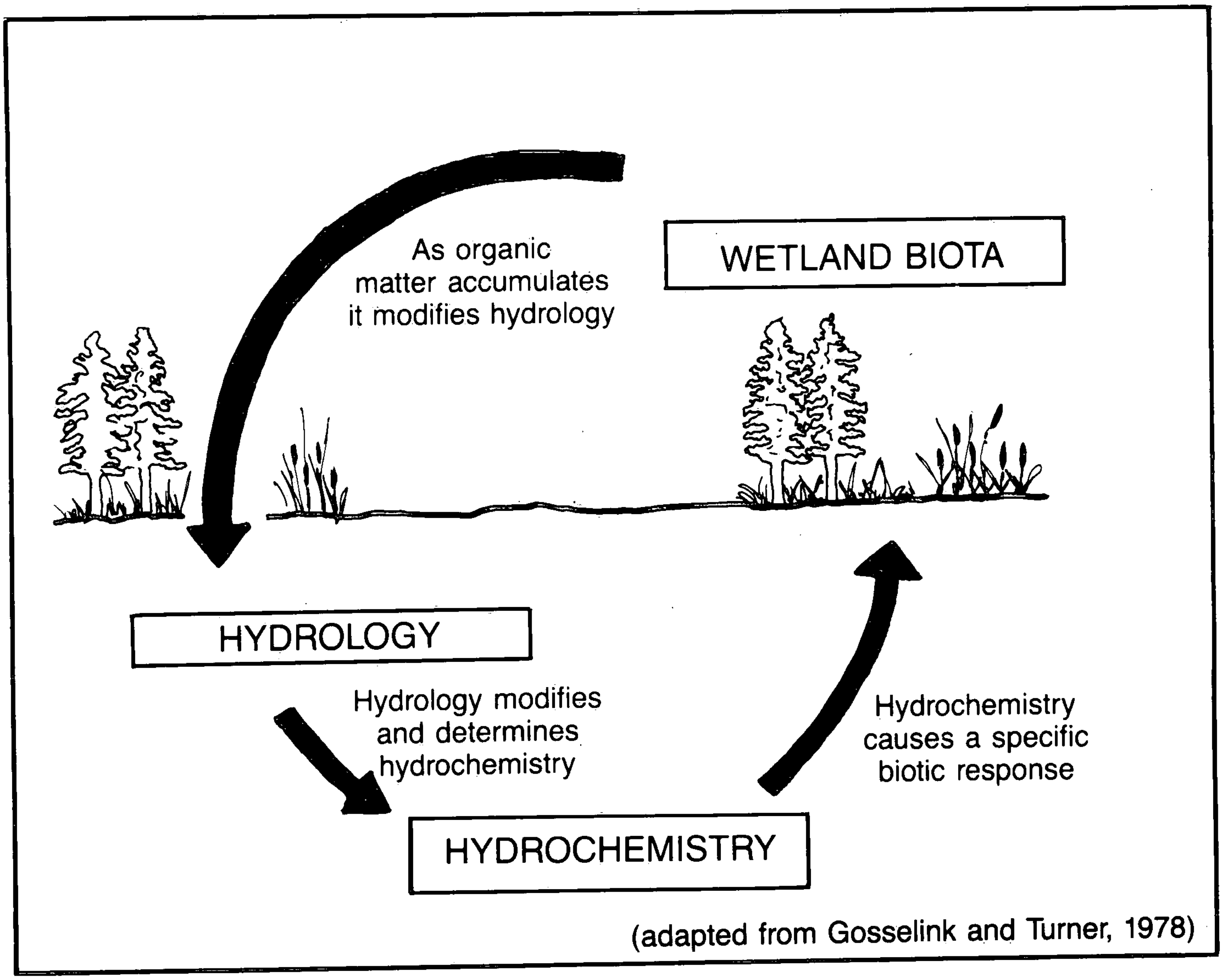

Figure 1. A Simplified Wetland Model.
Acid precipitation can imbalance this cycle.

pH of a soil by one pH unit. Wetlands with a low buffering capacity therefore have a high sensitivity to acidification and conversely, wetlands with a high buffering capacity have a low sensitivity to acidification. The potential for a wetland to neutralize incoming acidity from acid precipitation is a function of soil substrate, hydrology and hydrochemistry, and vegetation.

2.1 Wetland Hydrology and Hydrochemistry

Several studies of wetland hydrology and hydrochemistry in both Europe and North America have linked a decrease in the pH of wetlands, specifically peatlands, with acid precipitation. A lysimeter study by Braekke (1978) found that following the addition of acidified water (pH 2.0), there was an increase in the acidity of the waters draining an oligotrophic peat as compared to that of a eutrophic peat. The buffering capacity of the eutrophic peat was found to be significantly higher. This was attributed to a higher cation-exchange capacity and redox reactions in the peat. Subsequent field studies by Braekke (1980a; 1980b) found that the groundwater zone in peat is a strong sink for sulphate and other minerals, reducing sulphate to sulphide in the anaerobic conditions of the groundwater zone.

A strong relationship was determined between pH and the proportion of sulphate anions in the drainage waters of wetlands in New Jersey (Johnson, 1979), in bog pools in England (Gorham, 1958), and in Belgium (Vangenechten, 1981). This suggests that the controlling acids in these waters are mineral acids rather than organic acids (humic and fulvic acids).

Researchers in England investigated the fate of acid precipitation as it moved through a small watershed which includes a bog (Rippon et al., 1980). Major components of polluted precipitation (sulphate, nitrate, hydrogen ion, and organic acids) were measured in the bulk precipitation and throughfall, and also in the soil water and stream water that drained the bog. Results indicate that sulphur compounds are transformed in the bog. Streams draining the bog contain less sulphate than the surface water run-off. It is suggested that sulphate-reducing bacteria transform the sulphate into hydrogen sulphide.

One published cation-anion balance study of a wetland is part of an extensive investigation of the biogeochemistry of Thoreau's Bog in Massachusetts by Hemond (1980). Significant transformations of nitrate and sulphate were found to occur within the bog. The annual input of nitrate and sulphate to the bog exceeded output by a factor of three to four. Hemond suggests that much of the nitrate is transformed either by biological uptake or denitrification. Similarly, sulphate is also transformed by biological uptake or reduction to hydrogen sulphide which is returned to the atmosphere in gaseous form.

While the bog system is able to counteract the effects of increasingly acidic precipitation, Hemond recognized that there is a theoretical limit on the extent to which the system can be protected. A rise in acidity in the precipitation would cause an increase in sulphate reduction possibly causing toxic levels of hydrogen sulphide in the free water of the bog.

Recent work by Gorham et al. (1985) supports the conclusions reached by Hemond. Strongly acidic surface peats in bogs from Minnesota to Newfoundland have been observed to have substantially lower concentrations of ammonium sulphate and nitrate ions than the precipitation. It is suggested that plant uptake and chemical reduction are responsible for the removal of these ions. Mineral acids are replaced by organic acids that are the product of Sphagnum moss decomposition, so that the bog waters maintain a pH range of 3.7 to 4.7.

Subsequent examination of the data collected by Gorham et al. (1985) by Urban et al. (1985) revealed a gradient of impact that appears to be correlated with acid input. This suggests that, while bogs can appreciably counter the effects of acid deposition, there is a limit to this ability.

Evidence suggesting that bog acidity can be dominated by mineral acids has also been found. Gorham (1967) reported that sulphuric acid from polluted rain was the dominant source of hydrogen ion in surface waters of seven British bogs as indicated by charge balance analysis and by the correlation observed between sulphate and hydrogen ion concentrations.

A study by the Wildlife Branch, Ontario Ministry of Natural Resources, on wetlands near Sudbury differentiates between acidity due to sulphates from anthropogenic sources and that from natural sources (e.g. humic acids from peat). Charge balances were constructed for each of 47 water samples. These showed that sulphates contributed more than organic acids to the acidity of these waters. On average, the concentration of sulphate anions was 31.6 times the concentration of organic acid anions. The available evidence suggests that the sulphate was from anthropogenic rather than geological sources (Glooschenko and Stevens, 1985).

Organic acids are not the sole source of low pH. Weak organic acids, ion exchange and mineral acids from either acid precipitation or in situ oxidation of reduced sulphur compounds together can be determining factors of the pH of bog systems.

Water chemistry of four oligotrophic basin mires in northwestern Ontario was studied by Vitt and Bayley (1984) to provide baseline data for future acid precipitation experimentation. Surface water samples at both the inflow and outflow of one bog were collected and analysed for hydrogen ion and sulphate concentrations. It was found that sulphate concentrations in the water were significantly reduced after flowing through the surface peat and vegetation and that hydrogen ion concentrations had increased. From these findings, it seems reasonable to suggest that the mechanisms of biological uptake and chemical reduction previously cited are responsible for removal of these cations and anions. Results from future perturbation experiments will be most important in elucidating the response of non-acid stressed wetlands to acid precipitation.

Effects of acid precipitation on wetland hydrology and hydrochemistry have received an increasing amount of attention from acid precipitation researchers. To date, it is difficult to reject or accept the hypothesis that acid precipitation is stressing these wetland components. Some studies reviewed here suggest that wetland hydrochemistry accommodates acidity in the precipitation

(Rippon et al., 1980; Hemond, 1980; Gorham et al., 1985). However, other studies indicate that the hydrochemical regime of wetlands is unbalanced by acid precipitation (Braekke, 1980a, 1980b; Vangenechten, 1981; Gorham, 1967; Glooschenko and Stevens, 1985).

2.2 Wetland Vegetation

Few studies have examined the effects of acid precipitation on wetland vegetation. The disappearance of several species of *Sphagnum* moss from the large blanket bogs of the Southern Pennines in Britain was first noted by Tallis (1964). Further studies by Ferguson et al. (1978) have shown that certain species of *Sphagnum* exhibit marked decline in growth and other indications of general decline in vigour when exposed to ambient levels of acid precipitation under laboratory conditions.

Historical changes in diatom assemblages between 1920 and 1978 in Dutch moorland pools were reported by Van Dam et al. (1980). Plankton data collected approximately fifty years ago were compared with recent collections in sixteen pools in the Netherlands. A significant increase in acidobiotic diatoms was observed in contemporary collections. There was also a coincident decrease in water pH values from 4.0-6.0 to 3.7-4.6. These findings suggest that acid precipitation has caused a change in diatom populations. Only the very resistant species have been able to survive, reducing diversity within and differences between the pools.

Most research investigating the effects of acid precipitation on vegetation has focussed on agricultural crops and forests. To date, research has documented the variability of plant responses to simulated acid rain experiments, according to species, environment and method of exposure. From this work an overall picture of the effects of acid precipitation on plants is beginning to emerge (Cowling, 1979). A review of general plant responses to acid precipitation is of value because similar effects could occur in the sedges, grasses, reeds, and ericaceous shrubs that are characteristics of wetlands.

Visible lesions, which have been observed when simulated precipitation pH falls below 3.4, are preferentially located at the bases of trichomes, in guard cells, and in epidermal cells above vascular tissues. Alterations in the normal function of these cells may affect gas exchange in plants, causing exposed foliage to be more subject to wilting. Accelerated leaching of plant nutrients from foliage has been documented, as has a reduction in plant productivity through disturbance of normal metabolism. Pollen inhibition of several forest species has been observed in *in vitro* assays with ambient levels of acidity (Cox, 1983). These data were collected from experiments conducted in laboratory or greenhouse environments. Most field experiments have failed to give definitive results for changes in plant productivity or survival due to acid precipitation (Evans, 1982). It has been suggested that changes may be subtle enough to be masked by natural, annual fluctuations in climate (Hutchinson and Havas, 1980).

Across Canada, a series of vegetation monitoring stations for *Sphagnum* mosses have been established. They have been found to display regional patterns of heavy metal deposition. Extrapolation of these results to

LRTAP evaluations is underway (W.A. Glooschenko, pers. comm.).

Documentation of the effects of acid precipitation on the normal functioning of vegetation in wetlands is neither complete nor conclusive. Studies reviewed here indicate that some alteration or stress occurs, but more research, particularly field studies, must be done on this subject before stronger conclusions can be reached.

2.3 Wetland Wildlife

The literature which specifically addresses the impact of acid deposition on wetland wildlife is still limited. However, knowledge of aspects of wetland wildlife ecology such as physical habitat or the food chain may suggest ways in which acid precipitation influences the ecosystem. This is valuable in directing research efforts toward these topics (as outlined below and in more detail in Section 4.3 of this report).

A review of the effects of acid precipitation on wetland wildlife is currently in preparation by the Canadian Wildlife Service (Blancher, 1985a, 1985b). Physiological functions such as sodium and calcium regulation, respiration, and acid-base balance, which are affected by low pH are measurable responses of aquatic animals to acidification. Animals under pH stress, particularily amphibians, show a variety of responses including impaired reproduction, reduced growth, skeletal deformation, and death (Blancher, 1985b).

It is anticipated that the most predominant impact of acid precipitation on wetland wildlife will be indirect, through their habitat. Several avenues of injury are possible. The first of these is a potential increase in the concentration of heavy metals in wildlife habitats. In a low pH environment, some heavy metals (Al, Fe, Mn, Zn, Hg,) tend to be solubilized in soils and mobilized from sediments; others are co-contaminants in precipitation (Cu, Ni, Pb, Zn, Cd) (Havas, 1980). These processes could lead to a toxic environment for wildlife in either terrestrial or wetland ecosystems. A field survey of amphibian habitat in forty ephemeral ponds and wetlands in the Killarney area, adjacent to Sudbury, Ontario, indicated that total aluminum, aluminum fluoride and inorganic monomeric aluminum were inhibiting amphibian reproduction in twenty percent of the ponds surveyed (Glooschenko _et al._, 1985a). In Sweden, moose living in close proximity to polluting sources were observed to have high levels of cadmium in their tissues (Frank _et al._, 1981; Mattson _et al._, 1981). In 1984, a preliminary study showed that tissue levels of cadmium in Ontario moose were up to three times higher than the Swedish studies (Glooschenko _et al._, 1985b). However, it has yet to be established whether the increased presence of metals in these animals detrimentally affects their health.

Another factor which may indirectly affect wildlife in wetlands is the possibility of a change in the availability of food caused by effects of acidic precipitation on the food web. Initial observations in lakes have been made which support this hypothesis. Investigations on the effects of acid precipitation on waterfowl in Quebec by DesGranges (1982, 1985) and DesGranges and Darveau (1985), have observed a positive correlation between the abundance of aquatic birds and the pH of lakes. It was suggested that the decrease in amount of available food in acid lakes was responsible for their lack of attractiveness to birds. Acid lakes were found to be used infrequently by waterfowl.

Recent lake studies by McNicol et al. (1985) in the heavily acid stressed area of Wanapitei, Ontario, in the vicinity of Sudbury, indicates a decline in the abundance and occurrence of fish in these lakes. This, in turn, has reduced the capacity of these habitats to support broods of fish-eating birds, such as Common Merganser (Mergus merganser). Insectivorous waterfowl, such as Common Goldeneye (Bucephala clangula) preferred fishless lakes, regardless of acidity levels, appearing to derive short-term benefits from reduced competition with fish for insect prey. In summary, lake acidification has had varied and opposing impact on different waterfowl species, depending on feeding habitat.

The Eastern Kingbird (Tyrannus tyrannus), which nests in or near wetlands or in the littoral zone of lakes has been studied by Glooschenko et al. (1985c). Results show a strong association between water chemistry, egg quality and bone growth rate of kingbirds. Egg weight loss and bone growth rates were correlated with sulphate, nitrate, alkalinity and pH. However, there was no proof of causality or evidence of serious reproductive impairment linked to possible aluminum interference with calcium and phosphorous metabolism in the female bird. No prey limitation could be attributed to lake acidity.

In summary, acid precipitation has the potential to influence wetland wildlife directly through physiological changes and indirectly through wetland habitat changes. Continued research is necessary to identify positively the areas of impact.

2.4 Conclusions

From the literature it is possible to make the following generalized statements concerning the environmental impact of acid precipitation on wetlands.

(1) Field studies have focused on the hydrochemistry of peatlands, which have been shown to be strong sinks for sulphate, nitrate, and ammonium ions in acid precipitation. It is suggested that sulphate and nitrate inputs are removed by vegetation uptake and microbial reduction, although limits to these processes are anticipated.

(2) Laboratory studies indicate that the bog mosses (Sphagnum spp.) are affected by simulated acid precipitation at ambient pH levels. Lack of research to date into the specific impact of acid precipitation on wetland vegetation requires that results obtained for terrestrial vegetation studies be extrapolated to wetland vegetation.

(3) Evidence is still inadequate to make firm statements about effects of acid precipitation on wetland wildlife habitat and species. It is anticipated that the impact on wetland wildlife will be indirect, through changes in both habitat and food sources.

In summary, some research indicates that the normal functioning of wetlands is affected by acid precipitation, while other findings reveal the homeostatic nature of these ecosystems (Table 1). This research is now being expanded, addressing the inherent importance of these ecosystems and their role in vital land-water linkages.

3.0 FIRST APPROXIMATION OF WETLAND SENSITIVITY TO ACID PRECIPITATION

Based on the literature it is only possible to establish preliminary criteria which determine wetland sensitivity, buffering capacity, and to identify those wetland classes potentially at risk to acidification due to acid precipitation. This section discusses wetland sensitivity from the hydrological, hydrochemical, biotic and temporal aspects.

3.1 Wetland Sensitivity

Anthropogenic input, climate, natural episodic events, topography, soils, geology and biota are factors important in determining wetland sensitivity to acid precipitation (National Academy of Sciences, 1981). The first three factors are extrinsic to the ecosystem, the last four are considered intrinsic characteristics.

Extrinsic factors have received considerable attention (e.g. Canada-United States, 1983; Schnoor, 1984), and their influence on ecosystem sensitivity has been identified. Anthropogenic input causes the acidity in precipitation. It is determined by energy utilization in urban and industrial settings, and by the degree of control on atmospheric emissions. Climate influences how much polluted precipitation falls upon an ecosystem by affecting the amount of precipitation, direction and speed of air mass movements. To a much lesser degree, natural episodic events like volcanoes and fire, contribute to acidic precipitation. These extrinsic criteria must be taken into consideration when determining the sensitivity of wetlands, or indeed of any ecosystem, to acid precipitation. However, because they do not uniquely affect wetlands, these criteria will not be discussed further.

Unlike extrinsic characteristics, there is a paucity of information on how those factors which are intrinsic to wetlands influence wetland sensitivity to acid precipitation. Topographical characteristics such as water depth and water flow patterns control the hydrological pathways of acid precipitation and their interaction with plant-sediment interfaces in a wetland. Attributes such as bedrock lithology, chemistry and texture of surficial geological deposits, and the nature of soil and peat directly influence the hydrochemical regime of wetlands. Biota are often sensitive indices of change, as well as mediators of processes which alter incoming acid precipitation (e.g. microbes and biogeochemical cycles).

3.1.1 Hydrology

Wetland processes are generally the result of, or closely related to, wetland hydrology (Carter *et al*., 1978). The presence, movement, quality and quantity of water dictate how waterborne substances interact with wetland soils and biota. These hydrologic criteria determine the ability of a wetland to mitigate the effects of incoming acid precipitation by mediating access to potential buffering sources within the wetland (Bache, 1984). Wetland hydrological parameters important to the neutralizing of incoming acid precipitation include water flow, flushing or turn-over rate, and seasonal and annual

Table 1: Summary of Existing Literature on Acid Precipitation and Wetlands

Author (Year of Publication)	Location of Study	Wetland Effects Topic(s)
Hydrochemistry		
Braekke (1978, 1980a, 1980b)	Norway	. ion transport in peat . sulphur turnover in peat . peatland water response
Vangenechten (1981)	Belgium	. physiochemical composition of peatland waters . historical changes in alkalinity
Rippon *et al.* (1980)	England	. alteration of chemistry of acid waters flowing through bog . microbial reduction of sulphate
Hemond (1980)	Massachusetts (USA)	. cation-anion balance in bogs
Gorham *et al.* (1985); Urban *et al.* (1985)	Minnesota to Newfoundland (Canada/USA)	. regional variations in bog chemistry . cation-anion balance in bogs
Glooschenko and Stevens (1985)	Northern Ontario (Canada)	. charge balances in wetlands
Vitt and Bayley (1984)	Northwest Ontario (Canada)	. wetland chemistry and acidification processes
Vegetation		
Tallis (1964); Ferguson *et al.* (1978)	England	. effects on *Sphagnum*
Van Dam *et al.* (1980)	Netherlands	. historical change of diatom assemblages in moorland pools
Cowling (1983)	USA	. effects on floristic growth/ functions
Cox (1978)	USA	. pollen inhibition in flora
Evans (1982); Hutchinson and Havas (1980)	USA/Canada	. vegetation changes and damage

Table 1: Summary of Existing Literature on Acid Precipitation and Wetlands (cont'd)

Author (Year of Publication)	Location of Study	Wetland Effects Topic(s)
Wildlife		
Blancher (1985a, 1985b)	Northern Ontario (Canada)	. effects on biota
Glooschenko et al. (1985a)	Northern Ontario (Canada)	. effects on amphibians
Glooschenko et al. (1985b)	Northern Ontario (Canada)	. effects on moose
Frank et al. (1981); Mattson et al. (1981)	Sweden	. effects on moose, deer, hare
DesGranges (1982, 1985); DesGranges and Darveau (1985)	Quebec (Canada)	. effects on waterfowl
McNicol et al. (1985)	Northern Ontario (Canada)	. effects on fish, birds
Glooschenko et al. (1985c)	Northern Ontario (Canada)	. effects on birds

variations in water depth (Kaldec and Kaldec, 1979).

Water flow, as determined by the flushing or turn-over rate of incoming waters, controls the extent to which incoming waters are in contact with wetland substrates (Glaser et al., 1981). Fast flowing water interacts differently than water which stands stagnant; the same can be said of surface and subsurface flow. It is suggested that a flow rate which maximizes the interaction of acid precipitation with potential buffering sources, decreases the sensitivity of wetlands. In contrast conditions such as "pipe-flow" and permafrost minimize the contact of wetland waters with soil substrates, increasing wetland sensitivity. Pipe-flow is the concentrated, rapid subsurface throughflow in natural channels caused by erosion, animals, or roots. Such channels are prevalent in wetlands, particularily swamps. Braekke (1981) found that about one-third of the water draining a small catchment in southern Norway had been 'short-circuited' and had avoided any interaction with soil.

Permafrost also increases the flow of water through a wetland by restricting the volume of substrate accessible to the incoming waters. Water flow in many northern peatlands which are subject to permafrost, is restricted to the surface so that deeper pore-waters are unlikely to be very significant as a reservoir of neutralizing alkalinity (Gorham et al., 1984).

The influence of the hydrologic regime of wetlands on general water quality is widely recognized (Goode et al., 1975). However, the hypothesis that it also influences the sensitivity of a wetland requires more field observations like those of Braekke (1981).

3.1.2 Hydrochemistry

The soil-water composition, or hydrochemistry, of a wetland is determined by the organic and mineral components within the wetland. Hydrochemistry is a key factor controlling sensitivity and is a function of the following chemical processes: 1) bicarbonate buffering; 2) cation-exchange reactions; and 3) redox processes at and below the water table. Each of these processes are discussed with respect to neutralizing the effect of acid precipitation.

A bicarbonate buffering system is present in wetland waters which have a pH above 5.0 (Wetzel, 1975). In these waters, incoming hydrogen ions are consumed as long as there is an adequate supply of alkalinity in the form of carbonates, bicarbonates, and hydroxides. The speciation of bicarbonates and carbonates is pH dependent; therefore, they cease to predominate in waters with low pH. As a result, acidic wetlands, such as ombrotrophic bogs, have little or no bicarbonate buffering. Similarly, those wetlands wich undergo anthropogenic acidification below pH 5.0 would cease to have this buffering system.

Cation-exchange reactions involve the exchange of cations in solution, (i.e. hydrogen ions in acid precipitation), with metal cations held on the negatively charged surfaces of soils and peat. When these cations are displaced into solution by hydrogen ions, they neutralize or even increase the pH of the acid solution (Shilts et al., 1981). The neutralizing effect of cation-exchange capacity is a function of the nature of the saturating cation and the nature and pH of the displacing solutions. As pH is lowered, cation-exchange capacity decreases (Clymo, 1983). Organic content and degree of decomposition of the peat and soil will also strongly influence cation-exchange capacity (Gorham, 1967). When the exchange sites are saturated by hydrogen ions, the ability to neutralize incoming acidity becomes negligible.

Redox processes occur at or below the water table and are controlled by microbes. Sulphate reduction and denitrification are two redox processes that can reduce acidity in wetlands. Sulphate is taken up by biological processes or reduced to hydrogen sulphide (Hemond, 1980; Gorham et al., 1984). Similarly, excess nitrate is transformed either by biological uptake or denitrification. However, there is a theoretical limit on the extent to which these processes can keep pace with a rise in sulphate and nitrate concentrations in precipitation (Hemond, 1980; Gorham et al., 1984; Urban et al., 1985).

Variation in water depth may affect the acidification process by altering the conditions in which redox processes take place. 'Drawdowns' during periods of drought cause the aeration of normally anoxic soils and peat, and this may oxidize organic sulphur or metallic sulphides to form sulphuric acid (Gorham et al., 1984). Other chemical buffering could come from aluminum and humic substances, but their capacity to resist acidification has not been measured (Gorham et al., 1984).

3.1.3 Biota Response

A review of the literature indicates that the role and dynamics of vegetation and organisms can be a major indicator and modifier of sensitivity in wetland ecosystems. Study of both of these characteristics has proven to be extremely useful to acid precipitation research because ecosystems affected by acid precipitation are exposed to multiple stresses (e.g. excess acid, nitrogen and sulphur) over an extended time frame.

Biological response can be studied at three levels: 1) floristic/faunal composition; 2) morphology; and 3) elemental composition (Grigal, 1972). Analysis of wetland flora and fauna reveals distinctive changes in the nature of both plant and animal communities along natural gradients of acidity (Gorham et al., 1984). This suggests that the study of organisms in a wetland would indicate whether or not that wetland was undergoing acidification. It has been suggested that bryophytes and microalgae are often the most sensitive plant species, as are small invertebrates, such as snails (Gorham et al., 1984). Amphibia, however, have also been identified as being sensitive to acidification, and may also be an indicator species (Glooschenko et al., 1985a).

3.1.4 Time Factors

When studying wetlands, consideration must be given to the fact that hydrological and hydrochemical processes are functions of time. Change and stress do not necessarily become evident immediately after the introduction of an external force like acid precipitation (Livingston and Loucks, 1979). It is important to differentiate between those processes that can be detected over the short term or over the long term. In the following section, hydrochemical and biological criteria are discussed in terms of this compounding factor.

The capacity of buffering systems in some wetlands such as poor fens is limited. Over the short-term (e.g. several years), the system is likely to counteract the effects of acid precipitation. However, chronic exposure to this stress will likely result in a saturation of neutralizing sources and acidification will become evident within a decade (E. Gorham, pers. comm.). Hydrochemical investigations must take this 'assimilation capacity' of wetlands into consideration; that is, their ability to 'hide' or avoid short-term effects (Likens and Bormann, 1974).

Another temporal concern when studying wetlands is long-term change in hydrochemical cycles. These cycles can have different frequencies (diurnal, seasonal, annual, historical), and display several scales of time variability (Kadlec and Kadlec, 1979). Long-term changes in response to a factor like acid precipitation are difficult to assess, and may involve determination of a mean rate of change in the amplitude of the 'normal' cyclic variation.

Biological response to acid precipitation is also a function of time. This is particularly evident when studying the effects of acid precipitation on long-lived perennials in wetlands because, unless there are several effects, changes will be slow (Hutchinson and Havas, 1980). This is largely due to the deep rooting of these plants where changes in acidity may be less pronounced. They may therefore exhibit what Gorham (1957) has termed 'biological inertia'.

Thus, wetland sensitivity to acid precipitation is also a function of time because those criteria which are most important for describing sensitivity are themselves time-dependent. It is essential that this factor be taken into consideration when designing experiments to assess impact of acid precipitation on wetlands.

3.2 Wetland Sensitivity Rating

The five major wetland classes (bog, fen, swamp, marsh and shallow water) with nutrient "poor" or "rich" modifiers have been divided into four sensitivity categories based on the above intrinsic factors. This classification is a relative ranking of sensitivity to acid precipitation as proposed by Kessel-Taylor (1985). It is largely subjective in nature and requires verification by experimental and field observations. The four classes of sensitivity used are:

1 - low sensitivity
2 - moderate sensitivity
3 - moderate to high sensitivity
4 - high sensitivity

CLASS #1 - LOW SENSITIVITY
MARSHES, RICH SWAMPS, RICH FENS, AND SHALLOW WATERS

The effect of acid precipitation on marsh, rich swamp and shallow open water wetlands is likely to be negligible (E. Gorham, pers. comm.). Waters in these wetlands have circumneutral pH and have adequate buffering to neutralize incoming acid precipitation due to minerotrophic input of calcium, magnesium, sodium and potassium. Furthermore, the open flowing waters that are characteristic of marshes and shallow waters bring acid precipitation into contact with buffering sources.

The effect of acid precipitation on rich fens (i.e. those with high alkalinity and minerotrophic waters) is likely to be minimal because of the buffering capacity of the surface waters. Exceptions to this rule exist. Seasonal field measurements of surface waters in a southern Ontario fen indicated a drop in pH from 6.0 to 4.0 between fall and spring sampling time (J. Riley, pers. comm.). This observation suggests that the increased water flow due to thawing conditions, coupled with the inaccessibility of frozen minerotrophic sediments that could otherwise neutralize incoming acid waters, caused this temporary drop in pH. Longer-term alterations in water chemistry or plant and animal life due to such pH fluctuations is not likely. This demonstrates the importance of water flow in influencing change in wetlands in response to acid precipitation.

Under most circumstances, the neutralizing capacity of the hydrochemistry of marshes, rich swamps, rich fens and shallow waters receiving acid precipitation should prevent a significant change in either the wetland or in the discharge waters. The hydrochemical and hydrological regimes of these wetland classes are such that acid precipitation should have minimal impact.

CLASS #2 - MODERATE SENSITIVITY
BOGS

Bogs are inherently acid, but it has been suggested that they may be vulnerable to adverse effects of acid deposition (Gorham, 1958; Johnson, 1981; Bayley, 1983). Their pH levels are below 4.5; hence, bicarbonates are no longer available to accommodate incoming hydrogen ions in acid precipitation. However, organic acids and aluminum, at these low pH values, will neutralize incoming acidity (Johannesen, 1980). The peat cation exchange capacity is already largely saturated with hydrogen ions generated by Sphagnum mosses and would provide only limited neutralization. The slow movement of water in a well decomposed peat (Bulavko, 1971) increases the contact with these neutralizing sources. If the potential to reduce acidity within bogs should be exhausted, an increase in acidity in this low pH environment due to acid precipitation may mobilize toxic metals such as aluminium, zinc, mercury and cadmium and initiate the loss of nutrients or basic cations. Either event would result in an inhibition of plant growth which could be assessed by field observations. Bogs, then, may suffer some adverse effects from acid precipitation.

The internal neutralizing capacity of bogs should be able to reduce acid precipitation in the discharge waters, although aluminum solubilization will be high, and may increase with increased levels of acid deposition. These wetlands are therefore identified as moderately sensitive.

CLASS #3 - MODERATE TO HIGH SENSITIVITY
POOR SWAMPS

Certain nutrient poor swamps, have only minor minerotrophic input. Ion input for cation exchange and bicarbonate buffering are limited. Their pH is therefore circumneutral and acid deposition could quickly exhaust the available neutralizing capacity. Also, water flow in poor swamps can often be channelized restricting the interaction of incoming precipitation with plant and sediment substrates. In the event of a large influx of acid precipitation (e.g. heavy rain event, spring thaw), there may be a temporary drop in pH in those waters which have 'by-passed' neutralizing sources. Discharge waters would therefore not be neutralized and the potential to contribute to surface water acidification is high. Hence, some poor swamps could be ranked moderately to highly sensitive to acid precipitation. This scenario implies that the bicarbonate buffering capacity of the surface waters is saturated, which may or may not be true.

CLASS #4 - HIGH SENSITIVITY
POOR FENS

Certain forms of fen are likely to be quite sensitive to acid precipitation. It has been suggested that poor fens which are characterized by low alkalinity, low floristic diversity, slow water movement, low mineral input from surrounding soils, and having cation exchange complexes available only at the surface of the fen peat, are highly sensitive to acidification (Gorham et al., 1984). With low alkalinity and limited carbonate input, the bicarbonate buffering capacity would be rapidly consumed by acid precipitation. An influx of hydrogen ions in acid precipitation would leach bases from surface peats and cause the pH in surface waters to drop. Subsequent alterations in floristic composition of a poor fen may involve the invasion of acidophilic Sphagnum species. The resulting natural acidification of these fens would result in biological changes in response to the change in the chemical environment initiated by anthropogenic acidification as the fen shifts to bog conditions. Discharge waters would become increasingly acidic, contributing to surface water acidity.

3.3 Conclusions

The sensitivity criteria and classes discussed above are summarized in Table 2. These represent a 'first approximation' of intrinsic factors determining wetland response to acid precipitation. Investigation of these factors in field and laboratory studies would provide the evidence necessary to support or reject the proposed sensitivity ratings. The study of the moderately to highly sensitive wetland classes (e.g. bogs, poor swamps, and poor fens) may produce the information needed to reveal the effects of anthropogenic acidification in wetlands.

4.0 CURRENT RESEARCH ON WETLANDS AND ACID PRECIPITATION

The effects of acid precipitation on wetlands are receiving extensive attention from federal, provincial, and state governments and university researchers (Table 3). A brief review of current studies at seven institutions in eastern North America is presented. These include:

1) University of Minnesota, Minneapolis;
2) Freshwater Institute, Winnipeg;
3) Canadian Wildlife Service, Ottawa;
4) National Water Research Institute, Burlington;
5) Ontario Ministry of Environment, Toronto;
6) University of Toronto, Toronto; and
7) Lands Directorate, Ottawa

In addition, remarks on two scientific workshops examining aspects of acid

Table 2: Wetland Classes and their Relative Sensitivity to Acid Precipitation (Kessel-Taylor, 1985)

Wetland Class	Soil Characteristics	Chemistry of Dominant Water Source	Water Movement	Hydrochemistry	General Range In Acidity (pH)	Sensitivity of Wetland to Acid Deposition
Marsh	Predominantly Mineral: Some Peat Filled Depressions	Minerotrophic	Open Standing Water; Flowing Water	Mineral Rich - Dependent on Groundwater Sources	>6.0	Low
Shallow Water (<2m Deep)	Mineral	Minerotrophic	Flowing and Standing Water	Mineral Rich - Dependent on Groundwater Sources	>6.0	Low
Rich Swamp	Peat or Mineral	Minerotrophic	Gently Flowing to Standing Water	Mineral Rich - Dependent on Groundwater Sources	6.0-6.5	Low
Poor Swamp	Peat	Ombrotrophic With Minor Minerotrophic	Slow	Moderate Mineral Inputs	4.5-6.0	Moderate to High
Rich Fen	Peat	Minerotrophic	Gently Flowing	Mineral Rich - Dependent on Groundwater Sources	>6.0	Low
Poor Fen	Peat	Ombrotrophic With Minor Minerotrophic	Standing Water to Slow	Moderate Mineral Inputs	4.5-6.0	High
Bog	Peat	Ombrotrophic	Standing Water to Slow	Mineral Poor	<4.5	Moderate

This table is a summary of the general characteristics of each wetland class. There will be exceptions to each class.

Table 3: Highlights of Wetlands Acid Precipitation Research in Eastern North America to 1985

Agency	Study Location	Focus of Study
Dept. of Ecology and Behavioral Biology, University of Minnesota	Transect Minnesota to Newfoundland	. Ecology and Biochemistry of Sphagnum bogs in North America versus Europe . Monitoring of specific bog sites for long-term trends
Freshwater Institute Fisheries and Oceans Canada	Experimental Lakes Area, Ontario	. Monitoring of effects of artificial acidification of a bog and a poor fen
Canadian Wildlife Service, Environment Canada	Ranger Lake and Wanapitei Regions, Ontario	. Comparison of wetland biota variations in two acid precipitation loading zones . Characterization of wetland habitats
Inland Waters Directorate, and Canadian Wildlife Service, Environment Canada	Southwest Nova Scotia	. Impact of organic waters from peatlands on surface waters chemistry
Lands Directorate, Environment Canada	Southwest Nova Scotia	. Evaluation of role of land use management, fisheries management and wetlands in the salmon decline of rivers
Aquatic and Terrestrial Ecosystems Section, Ontario Ministry of Environment	Muskoka Region including Plastic Lake, Central Ontario	. Catchment monitoring to evaluate impact of acid precipitation on aquatic systems . Role of organic acids in water chemistry
Institute for Environmental Studies, University of Toronto and Canadian Wildlife Service, Environment Canada	Ontario: Dryden, Turkey Lakes, Sudbury and Muskoka	. Metal accumulation in mink and otter

precipitation research and wetlands are presented.

4.1 University of Minnesota, Department of Ecology and Behavioral Biology. (Dr. E. Gorham)

Two research projects have been designed to investigate the vulnerability of peatlands to acid precipitation. The first is a proposal to assess the vulnerability of peatland ecosystems to acid deposition and associated pollutants (Gorham *et al*., 1984). The project was submitted for funding to the National Science Foundation (United States), but, to date has not received financial support.

The objectives of this project would be to investigate: (1) the chemical processes involved in both natural and anthropogenic acidification of peatlands; and (2) the most significant responses of plant and plant communities to acidification. The approach would be a comparison of peatland development in poor fens with and without exposure to substantial acid deposition. Conclusions drawn from the study would then be tested by a second study involving the experimental acidification of a poor fen.

The second project, underway since 1981, examines the ecology and biochemistry of *Sphagnum* bogs in North America with specific detailed studies at several sites including the Luther Bog in Minnesota. While this study does not specifically address the effect of acid deposition on wetlands, observations of the general influence of air pollution on bog water chemistry have been made (Gorham *et al*., 1985).

The objectives of this research are to: (1) examine the environmental factors controlling the chemistry of bog waters; (2) compare the chemistry of bog waters in the mid-continental and the eastern oceanic regions in North America with those in Ireland and England; and (3) investigate the causes of their acidity.

Twenty-eight bog sites were selected along a transect from Manitoba to Newfoundland. For comparison, three bogs in northern England (in the Southern Pennine Mountains, where the air pollution is severe) and two maritime bogs in Ireland were included in the study. Water samples were analysed for various chemical parameters (e.g. pH, ion concentrations, dissolved organic carbon). A complete flora of the vascular plants, bryophytes, and lichens was made of each site, as well as estimates of cover and dispersion of each species. Bogs were cored to basal mineral soil in order to investigate peat accumulation rates, paleoecology, and chemical stratigraphy. Surface water was sampled and analysed for major ions and trace metals.

The hydrochemical data was interpreted in terms of acid deposition input. It was found that elevated levels of pollutants were not detected in bogs receiving urban/industrial emissions of sulphur and nitrogen oxides. This was attributed to several factors. First, nitrogen, an essential plant nutrient that is often limited in bog environments, likely is being taken up by plants, as well as undergoing microbial reduction and denitrification. These processes would account for the fact that nitrate was usually undetectable in bog water samples, despite high concentrations in the precipitation along the transect. Second, concentrations of sulphate are likely being lowered by microbial reduction close to the water table. This would explain why the average sulphate measurement was appreciably less than that of the precipitation across the transect (Gorham et al., 1985).

Further interpretations of the sulphate and acidity data have recently been undertaken (Urban et al., 1985). A trend toward increasing sulphate concentrations from west to east across the same transect was observed, and was shown to be correlated to the gradient in sulphate deposition. However, the small amount of sulphate input retained within bogs was shown to be highly dependent upon hydrological factors. The fraction of sulphate retained decreases as the fraction of precipitation going to run-off increases. It was recognized that this interaction between water movement and sulphate reduction makes it impossible to define a fixed sulphate loading that would result in the acidification of bogs. It was suggested that bogs sampled in Maine may be experiencing anthropogenic acidification.

Acidity balances were compared across the transect. A subtle shift in organic versus mineral acidity production was observed, with the importance of mineral acidity increasing eastward along the transect. It was concluded that eastern bogs were predisposed to further acidification by acid deposition due to: (1) decreased water retention times in these maritime bogs which results in a corresponding decrease in sulphate reduction; and (2) high rates of organic and mineral acidity production which neutralize the low input of alkalinity.

In summary, it can be stated that bogs have a large capacity for sulphate reduction. This becomes an increasingly important source of alkalinity as rates of sulphate deposition increase. It was this finding that prompted Gorham et al. (1985) to conclude that sulphate reduction made the effect of anthropogenic sulphate negligible. The ability of bogs, however, to counter the affects of acid deposition appears to be limited (Urban et al., 1985). Specific monitoring studies of the Luther Bog in Minnesota by Dr. N. Urban are continuing.

4.2 Fisheries and Oceans Canada, Freshwater Institute. (Dr. S. Bayley)

The project by Fisheries and Ocean Canada is designed to provide background data for the future experimental acidification of a wetland. The study is located in the Experimental Lakes Area (ELA), northwestern Ontario, an area receiving low levels of acid precipitation. The project consists of base line data collected prior to the acidification of a bog, and data collected during the acidification process.

The initial study provides quantitative and comparative information on the vegetation of selected bogs. These data were analysed with respect to chemical and hydrologic variables prior to artificial acidification (Bayley, 1983; Bayley and Schindler, 1985; Vitt and Bayley, 1984).

Of particular interest is the surface water chemistry data. Water samples were analyzed for pH, corrected conductivity, alkalinity, Ca, Mg, Na, Mn, K, Fe, Cl, N_2O_3, and SO_4. These describe hydrochemical characteristics of bogs which receive low levels of acid precipitation. In addition to this general qualitative data, surface water samples from one bog in particular were analysed weekly during an ice-free season from stations at inflows and outflows of the bog. In this way, changes in water chemistry brought about by bog vegetation were established. Results indicate that concentrations of Ca, Mg, SO_4, N_2O_3 and alkalinity were significantly lower leaving the bog than entering it, while hydrogen ion concentration was significantly higher leaving the bog. Associations between physical and chemical parameters and species dominance patterns were revealed. Vegetation communities exist as a series of gradients with individual plant species occupying overlapping habitat ranges.

The information on the pre-acidification state of these wetlands is a reference to which changes resulting from the artificial acidification are being compared. Extensive physical and chemical baseline data are available on other wetlands in the ELA (Wickware and Rubec, 1976). Both of these studies have valuable descriptions of wetland ecosystems in an area receiving minimal acid input; such information could provide essential reference material with which to compare data from affected wetlands.

The purpose of the second stage of the acidification project is to determine the effects of known concentrations and volumes of sulphate, nitrate and hydrogen ions on the vegetation and chemistry of a poor fen in an area that currently receives low levels of atmospheric pollutants (Bayley and Schindler, 1985). Acidification was accomplished by using a 50/50 equimolar mixture of concentrated H_2SO_4 and HNO_3, added to water pumped from a nearby lake, and sprayed from small irrigation nozzles over the 2.66 ha of wetland each month during the ice-free season in 1984 and three months in 1983. Each time the irrigation water (pH 3) was sprayed for a 4-5 hour period. This was followed by a 30 minute rise of lake water at pH 5-7.

To date, results indicate that all sulphate and nitrate additions to the wetland disappeared rapidly. Sulphate returned to background concentrations within seven days and nitrate after one day. Laboratory experiments confirmed these field observations, for it was shown that _Sphagnum_ spp. were able to remove additions of sulphate and nitrate within 12 hours of application. It was observed that sulphate reduction occurred in the top 10 cm of saturated moss. This was subsequently simulated in minerotrophic areas by addition of sulphate during acidic rain events. Addition of acid to _Sphagnum_ spp. in the field caused a measurable increase in growth. There was no change in decomposition of _Sphagnum_ litter in bags embedded in the bog exposed to acid spray. Birch leaves, however, did undergo greater decomposition in the acidified area. In general, trace metal (Al, Cu, Fe, Mn, Zn) concentrations did not increase due to acidification. There was no effect of acidification on the emergence of insects.

Future plans are to continue the wetland acidification program. A major observation thus far is that the bog appears to be a sink for both sulphate and nitrate with no obvious or early detrimental effects. It is suggested that the effect of acidification on wetlands is a long-term phenomenon which manifests itself only after extended exposure to the pollutants.

4.3 Environment Canada, Canadian Wildlife Service, Ontario Region. (Dr. P. Blancher)

The Canadian Wildlife Service is undertaking a study of the effects of acid deposition on wetland wildlife in the Ranger Lake and Wanapitei areas of northeastern Ontario. These two areas have different mean annual amounts of acid loading (Blancher, 1984, 1985a, 1985b). Wanapitei, northeast of Sudbury has a much higher rate than Ranger Lake, northeast of Sault Ste. Marie, Ontario. The project began in 1984 and is expected to continue through to 1986.

A preliminary field survey was done in 1984 to locate wetlands and characterize their vegetation, aquatic invertebrates, and water chemistry in preparation for an intensive 1985 field survey (Blancher, 1984). Results from this initial survey indicate that high input of acid deposition in wetlands at Wanapitei is reflected in the water chemistry of the wetlands. These wetlands are more acidic and have higher concentrations of sulphate and metals than those in the Ranger Lake study area.

Research is continuing in order to further characterize wetland habitats in these two areas. Data have been collected on peatland morphology, hydrology, physiognomy, peat type, water chemistry, flora, and fauna. Of particular interest is the response of selected groups of peatland fauna to acid deposition. Comparisons will be made between the two areas of aquatic invertebrates, cyprinid fish, breeding amphibians, waterfowl, insectivorous birds, and shrews.

This project is specifically designed to determine whether or not acid deposition input can be detected in areas receiving low acid loading. Preliminary results, which agree with the findings of Urban et al. (1985), suggest that regional differences are discernable.

4.4 Environment Canada, Inland Waters Directorate, National Water Research Institute. (Dr. R. Bourbiniere)

The Inland Waters Directorate is examining the impact of organic waters from peatlands on aquatic ecosystems by investigating the contribution of organic acids to surface water acidity. Sampling of selected lakes and rivers throughout Nova Scotia began in 1984, and will continue through 1986.

Seasonal samples were taken from coloured bog, creek and river waters at Barrington Bog, Beaverskin and Pebbleloggitch Lakes and at river sites in Kejimkujik National Park, Nova Scotia. Laboratory work involved the fractionation of dissolved organic matter into humic acid and six sub-fractions of fulvic acid. Results indicate that bog waters generally contain acidic fractions of fulvic acid, while lake waters associated with bogs have both acid and neutral organic components; it is suggested that the neutral fraction is due to soil runoff. Rivers sampled some distance from their source had high proportions of humic acid, indicating that chemical changes had occurred under these more aerated conditions.

Reports addressing aluminium fractions in water samples from selected acid stressed sites are currently underway (R. Bourbiniere, pers. comm.). Work in the future will monitor the Mersey and Clyde Rivers, and Beaverskin and Pebbleloggitch Lakes in Nova Scotia.

This work is being done in cooperation with Dr. J. Kerekes (Canadian Wildlife Service, Atlantic Region) who is involved in the Kejimkujik calibrated catchments program, investigating the aquatic and terrestrial effects of long range transport of air pollutants. Between 1978 and 1983, data were collected in this area on three lake basins which are sensitive to acid precipitation. The influence of peatland drainage on the chemical composition of the lakes in these drainage basins is currently being studied.

An analysis of water quality data in the tributaries of the Kejimkujik catchments indicates that while considerable organic acidity is present in coloured waters, anthropogenic sulphur further increases the acidity of these waters, particularily at times of high discharge (Kerekes et al., 1985a). A study of sources of sulphate ions and acidity in wetlands and lakes in Nova Scotia, discovered that during the ice free period, sea salt corrected sulphate concentrations range from approximately 45 meq/L in the south end of the province, to 30 meq/L in the Kejimkujik area, to less than 17 meq/L in the northern areas, and average 85 meq/L in the Halifax area. These reflect the atmospheric deposition pattern of sulphate (Kerekes et al., 1985b).

4.5 Ontario Ministry of the Environment, Aquatic and Terrestrial Ecosystems Section. (Dr. P. Dillon)

Dr. P. Dillon leads a project monitoring ion fluxes in twenty-four catchments in Ontario in order to determine the effects of acid deposition on these lake systems. While the focus of this work does not deal directly with wetlands, a few of the watersheds under study do contain wetland areas and in this way specific information about acid precipitation and wetlands has been obtained.

The research has evaluated the importance of organic acids relative to mineral acids entering Plastic Lake, a lake surrounded by *Sphagnum*-conifer swamps. Water flowing into the lake was sampled biweekly during the spring run-off season in 1982 and analysed for major ion concentrations. The results indicate that, at certain times throughout the season, inflow to the lake that drains the swamps contributes significantly to the acidity of the system. However, on an annual basis, organic acids are not the major source of acidity for this catchment; anthropogenically-derived sulphuric acid is the primary source. During peak flow, sulphate anions (from acid deposition) dominate the anion chemistry, accounting for 83% of the total anions. This percentage drops during low flow in the summer months due to the seasonal anoxia in upstream *Sphagnum*-conifer swamps at this time. It is only then that organics become the largest source of acidity (LaZerte and Dillon, 1984).

Monitoring of these catchments will continue in the future. Information pertaining to the influence of wetlands on the total acidity of these catchments should continue to emerge from such data.

4.6 University of Toronto, Institute for Environmental Studies. (Dr. C. Wren)

Dr. C. Wren is conducting a study for the Canadian Wildlife Service, Environment Canada, evaluating metal accumulation in wild mink and otter in Ontario as a result of environmental loading and availability (Wren and Stokes, 1985). While mink and otter inhabit wetlands only as part of larger home ranges, this study will be useful for the identification of the possible biological effects of acid precipitation on wildlife associated with wetlands. Work began in 1983 and is expected to continue through 1986. Field work has been completed and current efforts are being directed towards completing the analysis of metal content of tissue and food samples.

Four areas in Ontario were selected for this study: Dryden (English-Wabigoon Rivers), Turkey Lakes, Sudbury, and Muskoka. Preliminary data indicate that regional differences occur in metal concentrations. The final report will address the problem of the potential for toxic metals (from atmospheric deposition and their increased mobility due to acidification) to accumulate in wildlife and will also assess the toxicity hazard of present metal levels to mink and otter populations in Ontario.

4.7 Environment Canada, Lands Directorate (Ms. I. Kessel-Taylor)

The decline and eventual extinction of Atlantic salmon (*Salmo salar*) in southwest Nova Scotia has been attributed to surface water acidification as a result of increasing levels of acid precipitation. Upon closer examination of this region, it is possible to identify several unique local factors which could have had significant effect on the local salmon population and surface water acidity. These are: (1) historic salmon harvesting practices; (2) changes in land management practices; and (3) the occurrence of acid soils and wetlands which contribute to the natural acidity of surface waters. Examination of these local factors and consideration of their role in affecting fishery decline and surface water acidification can aid in evaluating the relationship between acid precipitation, surface water acidification and salmon decline in this region.

A case study of the decline in Atlantic salmon was undertaken for the Clyde River, southwest Nova Scotia. Results indicate that (1) historically, fish management practices have repeatedly depleted the salmon stocks of the river; (2) land management changes have increased soil acidity through reforestation of previously burned and cut-over areas; and (3) wetlands significantly influence surface water acidity. Acid precipitation and its resultant impact on surface water acidity has been superimposed onto these factors. It is the combination of all these factors which have contributed to the decline and extinction of Atlantic salmon from this region (Kessel-Taylor, 1986).

The study also correlates the area of wetland within a watershed to surface water quality measurements. To do so, nine additional rivers from Nova Scotia were selected to permit statistical correlations. It was found that in seven of the watersheds selected, highly coloured water and wetland area within the watershed are generally related. In the remaining three watersheds with clear water rivers, wetlands did not appear to significantly influence water quality and no relationship to wetland area is evident.

4.8 NATO Advanced Research Workshop on Effects of Acid Deposition on Forests, Wetlands and Agricultural Ecosystems. Toronto, Ontario. May 12-17, 1985

Participants directly involved in the discussion of acid deposition and wetlands were Eville Gorham (USA), John Lee (UK), Richard Clymo (UK), Noel Urban (USA), Steven Norton (USA), John Jeglum (Canada), Magda Havas (Canada), David Schindler (Canada), Suzanne Bayley (Canada) and Joseph Kerekes (Canada).

At the outset of the meeting, it was decided that the more specific term 'peatlands' should be used instead of the general term 'wetlands' when discussing the impact of acidic deposition, because little stress is expected to occur in well-buffered systems such as marshes and rich swamps. Problems deserving of study were identified and the following research recommendations were made.

(1) Continued study of the acidity/alkalinity budgets of peatlands is needed to identify sources and sinks of acidity and to enable the relative rating of the importance of acid deposition in ecosystem acidification. The hydrologic budget, cation/anion balance and microbiological changes associated with the geochemical regime are equally important factors involved in peatland acidity that are in need of further investigation.

(2) More peatland acidification experiments should be initiated. They should be continued long enough to identify changes in community composition, biogeochemical cycling and general metabolism.

(3) Paleoecological studies are needed to determine patterns of change in ecosystem properties that occurred prior to the onset of monitoring. These analyses are an important supplement to short- and long-term monitoring of sites at which acidification experiments are under way.

(4) Continued experimentation with *Sphagnum* moss species to study gaseous pollutants and their transformations are needed.

(5) Determination of the effects of acid precipitation on forest trees in bogs is essential; in particular, a search should be made for symptoms similar to those observed in some terrestrial coniferous forests receiving acidic deposition.

(6) Trace metal speciation and mobility should continue to be examined. More information is needed on the influence of acidity on metal speciation and on the interaction of metals with organic acids.

4.9 Organic Acidity Workshop, ESSA Environmental and Social Systems Analysts Limited. St. Andrews, New Brunswick December 3-5, 1985

This workshop sponsored by Environment Canada and Fisheries and Oceans Canada, provided a forum for discussion and a structured review of the sources and importance of organic acidity in surface waters and its effects on aquatic biota (ESSA, 1986). The focus was on processes which contributed to the production of organic acidity, interactions between organic and mineral acidity, and their effects on aluminum solubility and speciation. Wetlands were discussed in terms of their contribution to overall aquatic acidity and modification.

The workshop identified several specific research needs:

(1) a re-examination of existing data on wetlands and surface waters. Valuable information on wetland vegetation, chemistry and distribution is currently available. Such information can be used as a basis for future studies;

(2) further characterization of the dissolved organic carbon component of surface waters by use of a method that does not overlook important differences between fractions or classes of compounds;

(3) research on the role of wetlands in controlling surface waters chemistry;

(4) characterization of wetland types, measurement of internal and export chemistry; and

(5) development of surface water acidification models that include organic acidity.

5.0 EXAMPLE OF A WETLAND DATA BASE FOR REGIONAL RESOURCES AT RISK ASSESSMENT: ONTARIO

Regional assessments of the effects of acid precipitation on wetlands and degree of resources at risk could be made by comparing existing chemical and biological data from sites with and without exposure to substantial acid deposition. This section presents a review of an available peatland data base in Ontario, which could be useful as a basis for a wetland sensitivity assessment. It is intended only as an example of a data base application. Similar peatland and wetland data bases in New Brunswick, Nova Scotia, Newfoundland, and elsewhere may also be appropriate as examples for an assessment of all of eastern Canada. The objective of this review is to examine the parameters of data sources needed to produce a geographical comparison of the status of abiotic and biotic variables in wetlands receiving a range of acidic input.

It should be emphasized that results from such a geographical survey would only establish a correlation between measured acidic input and observed impact; conclusions from this type of investigation must be tested by experimental methods (i.e. artificial acidification) in order to establish a causal relationship between biotic changes and decreased pH (or secondary ecosystem interactions, such as elevation of trace metals). Such surveys should be viewed only as preliminary steps when determining the impact of acid precipitation, providing initial evidence of sensitive components in the ecosystem.

5.1 Ontario Ministry of Natural Resources, Ontario Geological Survey, Peatland Inventory Project. (Mr. J. Riley)

The main objective of the Ontario Peatland Inventory Project has been to evaluate the resource potential of the province's peat deposits. Of particular relevance to acid precipitation impact assessment is the fact that this study has obtained extensive floristic, hydrochemical and peat chemistry data on wetlands located throughout the province. The project was initiated in 1982 and is expected to continue until 1986. Study areas were selected to be representative of areas of considerable peat resources. Peatlands in these areas were surveyed to provide information on the following: elevation and depth contour mapping, volume calculations, peatland classification, peat type profiles and peat humificiation profiles. Types of peatland vegetation were also mapped at individual sites. Extensive reports on these study areas have been published as open file reports by the Ontario Geological Survey (Riley, 1983, 1984). Further summary reports on peat chemistry and hydrochemistry should be available in 1986.

Since 1982, a total area of over 107 000 ha have been investigated, within which 152 sites were studied in detail and 264 other sites were selected for study at a reconnaissance level in order to generate recommendations for possible detailed investigations in the future.

Detailed wetland sites were characterized in terms of substrate, percentage tree cover, stump content, cover type, microtopography and peatland classification. As well, peat core analyses included data on cation exchange capacity, conductivity, pH-H_2O, pH-$CaCl_2$, nitrogen, sulphur, hydrogen and several trace metals (Hg, Ca, Fe, Pb, Al, P, K, Mg, Mn, Cu, and Zn).

These same data would be useful in a comparative, geographical survey investigating potential sensitivity to acid precipitation of the chemical and biological characteristics of wetlands. The study areas are located throughout Ontario and thus receive varying loadings of acid precipitation. Vegetation and hydrochemical characteristics from this study could be compared with gradients of acid loading using data from deposition monitoring networks (e.g. CANSAP/CAPMON) to determine whether or not correlations exist between measured input and impact. Selected key wetlands could also be used as a basis for long term monitoring.

Information in this Ontario project could be used as follows:

(1) Identification of areas in the province that receive low, moderate, and high acid precipitation loading;

(2) Selection of wetlands of approximately equal size and comparable peatland types in each of the different acid precipitation loading zones;

(3) Comparison of floristic data among these wetlands, noting presence or absence of indicator species that could correspond to changes in chemistry due to acid loading; and

(4) Comparison of chemical data, such as concentrations of sulphate, nitrate, and trace metals, to determine whether levels of incoming acidity are reflected in wetland chemical characteristics.

5.2 Conclusions

While the data in the Ontario Peatland Inventory Project were collected to characterize peat resources and not the impact of acid precipitation, they may assist in regional sensitivity assessments and selection of long term monitoring sites for wetlands. Conclusions from these studies could be a starting point for the assessment of the impact of acid precipitation on wetlands and as such, would assist in development of more precise indices of sensitivity.

6.0 SUMMARY AND RECOMMENDATIONS

The importance of studying the impact of acid precipitation on wetlands is well recognized, although the role of wetlands in the environment and their vulnerability to acid deposition is still poorly understood.

Reports indicate that nutrient poor wetlands are strong sinks for sulphate, nitrate and ammonia ions found in acid precipitation. There are assumed limits to the amount of acidic input which can be assimilated without changes occurring in the hydrochemical regime of these sensitive wetlands. Poor fens, poor swamps and bogs are cited as being the wetland classes in Canada most vulnerable to acidification.

Only initial evaluation of the responses to acid precipitation of wetlands has been under taken. Some examples are the artificial acidification experiment of a bog at the Experimental Lakes Area in Ontario and monitoring studies at Plastic Lake in Ontario, the Luther Bog in Minnesota, and in Kejimkujik National Park in Nova Scotia. Regional surveys of wetlands within areas affected by acid precipitation (Blancher, 1985b; Gorham *et al*., 1985; Urban *et al*., 1985) have also been attempted but more comprehensive studies in eastern Canada would be valuable.

Further work needs to be initiated to determine the kinds of alteration which might be expected from acidic input, to identify early-warning indicators of damage, and to counter the effects of acid precipitation on wetlands.

Recommendations

Specific recommendations that can be drawn from the conclusions outlined in each section of this paper include the following in terms of (i) wetland functions and (ii) wetland sensitivity.

Wetland Functions

(1) More detailed acidity/alkalinity budget and cation/anion balance studies in wetlands are required to evaluate the impact of acid precipitation on these ecosystems.

(2) Further artificial acidification experiments of wetlands are important to elucidate the response of non-acid stressed wetlands to acid precipitation.

(3) Documentation of the effects of acid precipitation on the normal functioning of vegetation in wetlands is needed, particularly in field situations in relations to alterations and stress on these species.

(4) Study of the effects of acid precipitation on indicator floristic species needs to be expanded, particularly with *Sphagnum* spp.

(5) Evaluation of indirect effects of acid precipitation on wildlife through the impact on habitat and food chains is needed.

(6) Further studies of wetland hydrological budgets are needed, in particular the role of waterflow, water depth, flushing rates, and seasons.

(7) The role of organic acids in wetlands and their interactions with heavy and trace metals needs to be examined in much more detail, in particular as it affects or contributes to aquatic ecosystem acidity and modification.

Wetland Sensitivity

(1) Field testing is needed on the assumptions and initial criteria used in developing the wetland sensitivity classification presented in this report.

(2) Regional evaluations and synthesis for eastern Canada of information on the distribution of sensitive wetland classes is needed to assist in assessing aquatic resources at risk and in developing aquatic response models.

(3) The role of natural variations in hydrological regimes in relation to wetland sensitivity needs to be addressed.

(4) Studies on wetland biota and flora along acidity gradients in the various wetland classes in Canada would be useful in identification of acidification indicator species. These may include bryophytes, microalgae, small invertebrates, and amphibians.

(5) Identification of regional and natural variations in wetland flora and biota in individual wetland classes is important to properly separate anthropogenic versus natural influences in wetlands.

(6) Temporal aspects of impacts on wetlands, such as a temporary "assimilation capacity" to mask short-term effects, must be considered in design of wetland monitoring and impact studies.

(7) Moderate and high sensitivity wetland classes, specifically bogs, poor fens and poor swamps, should be the focus of more site specific monitoring experiments and of regional wetland distribution surveys wherever possible.

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APPENDIX I
WETLAND DEFINITIONS AND WETLAND CLASSES IN CANADA

WETLAND DEFINITION AND WETLAND CLASSES IN CANADA

The National Wetland Working Group of the Canada Committee on Ecological Land Classification has established the following wetland definitions and descriptions for the five major classes of wetlands in Canada (Tarnocai, 1979).

WETLANDS have been defined by this Group as "lands having the water table at, near, or above the land surface or which is saturated for a long enough period to promote wetland or aquatic processes as indicated by hydric soils, hydrophylic vegetation, and various kinds of biological activity adapted to the wet environment.

PEATLANDS are forms of wetlands in which the depth of peat accumulation exceeds 40 cm, with organic soils (excluding Folisols). In permafrost environments depth of peat moss only exceed 10 cm.

BOG is a peat-covered, or peat-filled wetland, generally with the water table at or near the surface. The bog surface, which may be raised or level with those of the surrounding wetland, is virtually unaffected by the nutrient-rich groundwaters from surrounding mineral soils and is thus generally acid and low in nutrients. The dominant peat materials are weakly to moderately decomposed and underlain at times by fen peat. The soils are mainly Fibrisols, Mesisols, and Organic Cryosols. Bogs may be treed or treeless, and they are usually covered with *Sphagnum* spp., feather mosses, and ericaceous shrubs.

FEN is a peat-covered or peat-filled wetland with a water table usually at or above the surface. Internal waters are generally nutrient-rich. The dominant materials are well to moderately decomposed fen peat of variable thickness. The soils are mainly Mesisols, Humisols, and Organic Cryosols. The vegetation consists dominantly of sedges, grasses, reeds, and brown mosses with some shrub cover and, at times, a sparse tree layer.

MARSH is a mineral wetland that is periodically inundated by standing or slowly moving waters. Surface waters may fluctuate seasonally, with declining levels exposing drawdown zones of matted vegetation of mudflats. The waters are rich in nutrients. The substratum usually consists of mineral material, although occasionally it consists of peat deposits. The soils are dominately Gleysols, with some Humisols and Mesisols. Marshes characteristically show zonal or mosaiced surface patterns comprised of pools or channels interspersed with unconsolidated stands of emergent sedges, grasses, rushes, and reeds, bordering grassy meadows and peripheral bands of shrubs or trees. Where open water areas occur, a variety of submerged and floating aquatic plants flourish.

SWAMP is a mineral wetland or peat-filled area with standing or gently flowing waters occurring in pools or channels. The water table is usually at or near the surface. There is strong water movement from the margin or other mineral sources, hence the waters are rich in nutrients. If peat is present, it is mainly well decomposed forest peat, underlain at time by fen peat. The associated soils are Mesisols, Humisols, and Gleysols. The vegetation is characterized by a dense tree or shrub cover of deciduous or coniferous species, herbs, and some mosses.

SHALLOW WATER is characteristic of intermittently flooded or seasonally stable water regimes, featuring large open expanses of standing or flowing water which are variously called ponds, pools, shallow open lakes, oxbows, reaches, channels, or impoundments. Shallow water is distinguished from deep water by mid-summer water depths of less than two meters, and from other wetlands by summer open water zones occupying 75 per cent or more of the wetland diameter. Large open water areas, greater than eight hectares, should be classified separately as open water units, despite the area or extent of bordering vegetation zones. Periodic flooding may increase water depths, but during droughts, low flows, drainage or intertidal periods, drawdown flats may be exposed. Shallow open waters are delineated from uplands and bordering wetland complexes by water-eroded shorelines, or by the landward margins of mudflats, floating mats, emergents, or shrubs. In the open water zone, living vegetation, if present, is confined to submerged and floating aquatic plant forms.