CHAPTER 1

INTRODUCTION: OVERVIEW OF THE PROBLEM

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1.1 What causes the problem?

Acid waters are observed in areas with calcium-poor but quartz-rich soil and where acid precipitation occurs. It implies that acid waters are seen in Central Europe, Scotland, Scandinavia, Belgium, The Netherlands, a minor part of France, Canada and the Northeastern states of U. S. A, Australia, New Zealand and Japan, see Overrein et al. (1980).

Acid rain has probably been observed for centuries, although acidity was not measured until about 100 years ago. The problem has, however, increased during the last decades due to man-made emissions. Emissions of natural and anthropogenic acidic gases on a global basis are about equal, but in the more industrial Northern Hemisphere, man-made emissions account for 90% or more of total acidic emission.

In the presence of carbon dioxide at atmospheric pressure and at a temperature of $20^{o}C$, rain will have a pH of 5.6, and if we also include the presence of other natural generated gases, the background value of rain is probably about 5.0. It is therefore relevant to define acid rain as rain with a pH of less than 5.0. In industrial regions rain is, however, ten times more acidic, namely pH 4.0 and in some very polluted areas rain may be transiently even more acidic, to a pH of 3.5.

Only a minor part of the total precipitation will fall directly on the surface of lakes. The processes between the ions in the rain water and the soil are therefore significant for the over-all acidification of lakes, which will be determined by the following processes and factors: the carbon dioxide pressure in the soil, release and uptake of ions from the vegetation, dissolution of weak acids, oxidation and reduction of sulfur - and nitrogen compounds (nitrification produces hydrogen ions, while denitrification consumes hydrogen ions), accumulation and release of sulfur compounds, ion exchange processes and the retention time. The typical result will be, that ammonium-, nitrate- and hydrogen ions will be retained in the catchment area, while sodium-, chloride-, potassium- and magnesium ions will be released. Release will take place for either aluminum ions or hydrogen carbonate ions, dependent on the pH.

Table 1 shows typical observations from Norway, where acidification of lakes is considered a major problem. The results are approximate average values from SFT (1982). It is seen from the table that a significant amount of the hydrogen ions is being removed by the catchment area.

Table 1.1

Typical concentrations of rain and drainage water in areas with little buffer capacities.

Component	**Rainwater**	**Drainage water**
Water mm.	1000	700
Hydrogen ions keq/km^2	60	20
Sodium ions keq/km^2	50	100
Potassium ions keq/km^2	4	6
Calcium ions keq/km^2	10	35
Magnesium ions keq/km^2	9	20
Aluminum ions keq/km^2	-	15
Ammonium ions keq/km^2	24	low
Sulfate ions keq/km^2	40	52
Chloride ions keq/km^2	41	59
Nitrate ions keq/km^2	26	3
Cations total keq/km^2	118	118
Anions total keq/km^2	118	118

The acidity of drainage waters is therefore generally less than that of incident rains, but in some cases, however, where soils and vegetations generate acidity, such as in peat bogs or organic soils, the acidity of surface waters may exceed that of rain even by an order of magnitude, for instance in the Amazonian region, where rain is about 5.0, while pH of streams might be as low as 2.8. The removal of acidity by the catchment area is, however, not sufficient to eliminate acidification in areas with low buffer capacities.

The pH of the lake water is regulated by the hydrogen-carbonate buffer system for pH > 5.5, while the aluminum buffer system becomes active below pH 5.0. An iron buffer capacity will take over by even lower pH values (below 4.0). No

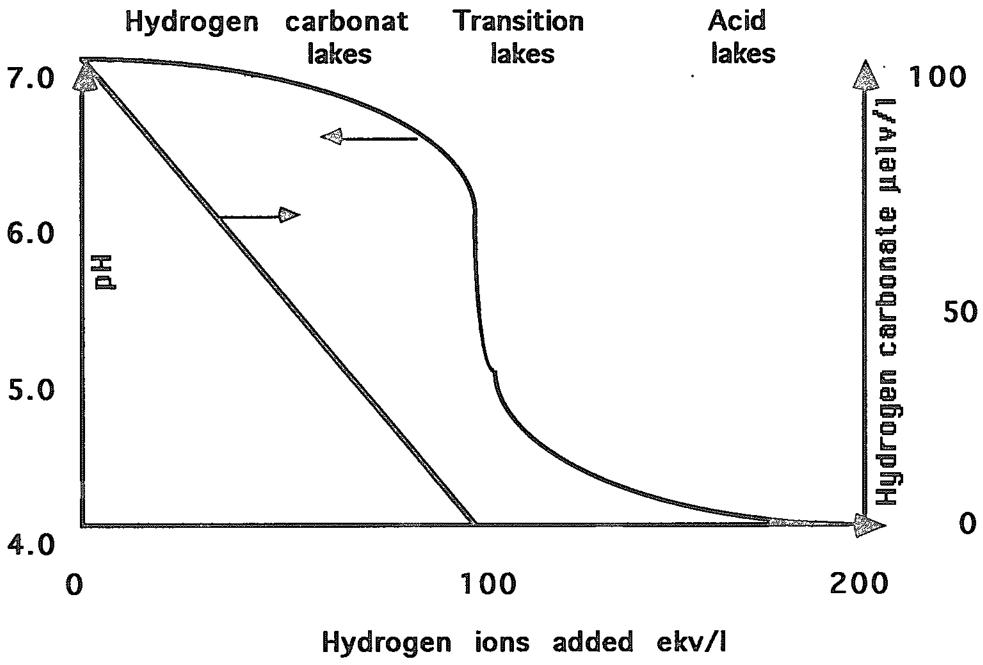

Fig. 1.1. A titration curve for lake water with 100 eq/ l hydrogen carbonate. The hydrogen carbonate buffer capacity explains that the pH is changed slowly between 7.0 and 6.0, while a rapid change will take place between 6.0 and 5.0. Below 5.0 the aluminum buffer capacity takes over. A classification of the lakes in accordance with the pH is shown. Above 6.0: hydrogen carbonate lakes, between 5.0 and 6.0: transition lakes and below 5.0: acid lakes.

biological changes will be observed, as long as the hydrogen-carbonate buffer system is active. When this buffer capacity has been used, seasonal fluctuations in pH will be observed with elevated aluminum concentrations.

The acidification process may be considered as an acid titration i large scale (Henriksen, 1980). Figure 1.1 illustrates such a titration plot for a hydrogen carbonate concentration of 100 μeq/l. Addition of 100 μeq/l hydrogen ions causes only a pH change from about 7.0 to about 6.0 due to the buffer capacity of the hydrogen carbonate system, while a further addition of only < 10 μeq/l is sufficient to provoke a pH change to 5.0. The aluminum buffer capacity becomes active below 5.0, which explains that the pH again is changed slowly.

This Guideline book focuses on the wide consequences of pH fluctuations and low pH-values on the lake ecosystem, i.e., the transition lakes and the acid lakes. Significant changes of water chemistry and in the lake ecology are observed in these lakes, which make acidification of lakes a determining pollution problem in environmental management. As an increasing number of lakes all over the world suffer from pH fluctuations and low pH values, the problem will show an increasing importance during the coming decades, unless plans for reduction of the emissions of acidic gases are launched.

1.2 Distribution and Frequency of Acid Lakes.

Extensive sampling in several regions of the world has been carried out during the last decade to identify the distribution and frequency of acid lakes.

In a survey in Northeastern U.S.A. in 1984, Linthurst et al (1986) observed that approximately 8% of the lakes could be declared acid, i.e., the pH was below 5.0.

In Canada, it is estimated that half of the 700,000 lakes in the six Eastern Provinces have alkalinity values below 50 eq/l. and thus are judged acid-sensitive. More than 7000 lakes in the Eastern Provinces have been sampled to evaluate chemical evidence for acidification. It was found that about 5% of the lakes had zero alkalinity (NAPAP, 1990).

In Sweden, of an estimated total of 85, 000 lakes, as many as 4000 lakes are classified as seriously acidified and 18, 000 lakes are reported to be acidic during some critical periods, such as snow-smelt (Monitor, 1985). A survey of the lakes in southern Norway (Henriksen et al, 1987 and 1988) shows that the highly acid waters are concentrated in the southwestern region, where pH of rain is 4.3 or less. In this area it is reported that thousands of lakes are acid and have zero alkalinity. In Finland a survey of 8000 lakes showed that 500 were acidified (Kamari, 1985).

Areas in Britain considered susceptible to acidification are western and upland areas, i.e., in northwest Wales, Cumbria and western Scotland. In these regions at least 24 major lakes are acidified - understood as pH < 5.6, (Battarbee et al., 1989).

Acidified lakes are reported in many other surveys, for instance in Denmark, northern Germany, the Netherlands, Austria and Switzerland. The acidified lakes are in many cases found where acidic waters drain sandy soil and afforested terrain.

Historic data for lake chemistry have been invoked to demonstrate a progressive acidification in many areas. These studies are often flawed, inevitably, by inconsistent methods of sampling and analysis. Even so there is strong evidence, that many lakes demonstrate a decline in pH over the past 100 years. As much as two pH-units are reported in several lakes. In Sweden, where thousands of lakes have been acidified, the best documented and reliable examples suggest that the pH changed from above 6.0 to below 5.0 from the 1940s to the 1970s, changing rather little since (Sanden et al., 1987).

1.3. Outlines.

This introduction to the guideline book on acidification has defined the problem, showed and explained why it is concentrated in certain regions and demonstrated the vast extent of the problem in these regions.

The following chapter focuses on the sources of the problem. Which emitted gases can cause acidification, and what is the relative importance of the various gases in relation to their acidification effects? The major parts of the acidifying gases arise from the use of fossil fuel, but the different types of fossil fuel, i.e., heavy fuel oil, gas oil, gasoline, natural gas and so on, are contributing very differently to acidification. The chapter gives an overview of these relations to be able to link acidification with the energy policy of industrialized countries.

Chapter three is the core chapter, as it deals with the effects on lake ecosystems. The effects may be classified in three groups: the effects on the chemistry of lake water, the effects on the biota of the lakes and the effects on the lakes as ecosystems. The effects on the biological components of the lakes are particularly important and are also unfortunately very pronounced. The effects on the various trophic levels: phytoplankton and macrophytes, zooplankton, planktivorous fish and carnivorous fish, are a natural classification of the biological effects.

Chapter four focuses on restoration methods. It has been widely acknowledged that environmental problems can only be solved by the use of a combination of environmental technology, alternative technology and ecotechnology. The first mentioned type of technology is covered in chapter five. The use of alternative technology implies that we, in the long run, switch to alternative energy, which does not emit acid gases, and ecotechnology implies that we attempt to solve the problems in the ecosystem once they have appeared. The chapter will present the available methods to bring the lake ecosystems back to normal - it means, in this case, to repair the damages due to acidification and to bring the pH back to above 5.0. Cases on the use of ecotechnological methods will be presented in this chapter, both successful and less successful ones.

The fifth chapter gives information on environmental models available to obtain an overview of the problems of acidification. Environmental management is increasingly using models as a synthesizing tool to compare different management strategies. It is, therefore, not surprising that a whole series of models have been developed to solve the problems related to acidification of lakes. A chain of models is available to link the source with the pH of the precipitation with the pH of soil with the pH of drainage water with the change of lake water chemistry with the biological changes in acidified lakes. The entire chain will be presented, although most details will be given for the later links of the chain as they are directly involved in lake management problems. However, the entire chain is needed to develop a proper environmental management strategy. Political decisions should ultimately be dependent on all the models in the model chain.

The fifth chapter is furthermore devoted to a brief review of the abatement methods available to reduce the emission of acid gases. The proper abatement of this pollution problem requires that we go to the roots of the problems. The models presented show how it is possible to link emissions with the effects on the lake ecosystems, while chapter five attempts to answer the crucial question: To what extent is it feasible to reduce the emissions of acidic gases with the present energy pattern? A detailed answer to this question will require a comprehensive treatment of uptodate air pollution technology, which is beyond the scope of this guideline book. This chapter can therefore only give an overview of what it is possible to obtain with the technology of today to enable the reader to understand what can be achieved in trying to solve the problem. Chapter Six and Seven are devoted to two case studies, where the detailed measurements, observations in general on the effects of acidification and the problem solving initiatives are included in the presentation. Chapter Eight is devoted to a review of the problems associated with the acid rain in Canada, where the problem is almost on the same level as in Europe.

The volume has two appendices. The first appendix presents the concepts of double logarithmic representation, which is very useful to get an overview of the relationships between pH and the chemical composition. The second appendix gives information on the global emission of acidic gases. The present problems of acid rain are concentrated in Europe and North America, but it can be foreseen, that several other regions will meet this crucial pollution problem within one or two decades.

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