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THE PRIME MINISTER

29 August 1986

ACID DEPOSITION

You will be chairing a meeting of E(A) on 10 September at which Ministers will be considering proposals concerning UK emissions of sulphur dioxide (SO₂). This follows earlier discussions at E(A) on 24 July. Unfortunately I shall be away at the time of the meeting and cannot comment directly on the papers. I hope you may find it helpful to have my comments in advance.

2. Ministers will be discussing policy options following the conclusion by the Chairman and Board of the Central Electricity Generating Board (CEGB) that the scientific evidence of damage to freshwater ecosystems by acid deposition now justifies action to reduce sulphur emissions from power stations.

3. I attach for your information an advance copy of the review of the scientific evidence prepared jointly by scientists from the Departments of Energy and the Environment and the CEGB at the request of E(A). I consider this to be a fair assessment of current knowledge. It does not present a straightforward picture; we still have a far from complete understanding of this extremely complicated issue. But I do attach great significance to the fact that the parties are in agreement over the key issues. These I summarise in the following paragraph.

4. Despite earlier doubt, there is now agreement that Scandinavian lakes have become more acid since the 1950s, and SO₂ emissions are accepted as a major contribution. Models of the relationship between any one country's emissions and deposition in Scandinavia are sufficient to confirm that UK emissions are deposited in Norway and Sweden; and now suggest the UK is the second largest

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What is Norway
doing about its
own contribution?

contributor in Norway, after Norway herself. Although acidity (decreased pH) alone is not critical for fish losses, fish die because (a) increased acidity leads to increased aluminium in the water, which is toxic; and (b) acid soils lead to calcium deficiency. We also understand now that while forestry, particularly coniferous, can of itself increase the acidity of soils, this is not a sufficient explanation of the acidity in Scandinavian lakes. Recent experiments have shown that a large chemical reservoir of sulphur in the soil buffers the inputs so that outputs are hardly affected in the short term. Reductions in emissions now will therefore take some time to show benefit in improved water quality.

5. The proposal for retrofitting of power stations represents a change in attitude by the CEEB. Although the precise details of the action to be taken will need further consideration, I think that Government should endorse this change of approach for the following reasons:

- (i) Revised forecasts of electricity demand indicate that instead of a continuing fall in emissions (consistent with Government policy to aim for a reduction of 30% on 1980 levels by 2000), the rise in emissions which started in 1985 will continue.
- (ii) Although there has been no dramatic breakthrough, I am satisfied that the weight of evidence is now sufficient to call for action. There has been a steady incremental strengthening of our understanding of the issues, pointing strongly to long-range sulphur pollution as a major contributor to acidification of freshwaters in Scandinavia and to the beneficial effects of reduction of sulphur emissions from the UK. Absolute certainty is not the currency in scientific issues as complex as this. Lack of such watertight certainty should thus not deter us from taking action when the evidence is as strong enough as I now believe it to be.

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(iii) The first report of the joint Royal Society/Norwegian and Swedish Academies' study of acidification of Scandinavian waters, commissioned and financed by the CEGB and the National Coal Board, will be published next year and will lend weight to the link between UK emissions of sulphur and acidification of Scandinavian waters. (Although I do not see a case for delaying any decision on installation until then, as CEGB is proposing).

(iv) The present proposal is based entirely on the link between UK sulphur emissions and damage to Scandinavian freshwater ecosystems. This is sensible as it is here that the scientific evidence is the strongest. But there is also evidence, albeit less strong and less robust, linking sulphur emissions with freshwater damage in the United Kingdom (particularly upland areas of Wales and Scotland). This evidence cannot be ignored.

6. If Ministers agree to a programme of retrofitting, I would advise that this is presented as an evolutionary approach. An initial programme might for example involve three plants in the first place, but with the possibility of retrofitting further plants deliberately left open. This is for two reasons. First, our scientific knowledge is not yet sufficient to predict with any precision what reductions in sulphur emissions are necessary to prevent future damage or allow recovery from past damage. Secondly, I believe that such an approach would be to the advantage of the relevant sectors of British engineering industry. I am sceptical about the costs of retrofitting supplied by the Department of Energy - I have seen no estimates independent of the CEGB. But if several British companies could be involved in an initial programme with the incentive of possible further work in the UK, it could encourage competition, with consequent cost-effectiveness and a national capability to compete in the international market.

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7. A decision on whether to join the "30% Club" is based only partially on scientific grounds. Certainly retrofitting power stations will increase the probability of the UK meeting the 30% target although the present scientific evidence does not itself constitute justification for that particular level. In any case the key determinant of future sulphur emissions is the demand for energy in the UK, and the proportion of this which is provided by fossil fuels. I do not believe that we will be able to see clearly until the turn of the decade what additional measures would be needed to meet the target if adopted.

8. I am copying this minute to Sir Robert Armstrong.

pp JOHN W FAIRCLOUGH
Chief Scientific Adviser

John W. Fairclough

SULPHUR EMISSIONS, ACID DEPOSITION AND FRESHWATER
ECOSYSTEMS : CURRENT SCIENTIFIC UNDERSTANDING.

Memorandum by the Chief Scientist, Department of Energy, Chief Environment Scientist, Department of the Environment, and Director of Technology, Planning and Research, Central Electricity Generating Board.

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SUMMARY

1. Research since acidification became an international issue in 1972, confirms that acid deposition has a major effect on the chemistry of certain soil/water systems.
2. The nature of the interaction is complex, involving detailed soil chemistry and the influence of other soil acidifying factors, most particularly coniferous forestry.
3. Acid deposition on acidified soil produces ground water of a quality unsatisfactory for fish.
4. It is not yet possible quantitatively to predict the rate or extent of recovery of affected soils, water and fisheries now that emissions are being reduced over much of Europe - and still less to be precise about the effect of particular future measures - but there are strong indications that sulphur stored in the soil, much of which must have come from past depositions, will continue to have adverse affects on water chemistry in acidified catchments for many years or decades.
5. In many areas, continued deposition at current rates would not allow the sulphur store to decrease. Where the soil depth and sulphur store are substantial, even reduced deposition will be unlikely to take effect for some considerable time.
6. Loss of calcium from acidified soils will require limestone additions to the soil if improvements are to be seen in any reasonable timescale.
7. The role of forestry in acidification needs to be reviewed alongside any emission reduction since in some areas it can contribute at least as much as acid deposition to the acidification of soil and the aggravation of effects on freshwater systems.

SULPHUR EMISSIONS, ACID DEPOSITION AND FRESHWATER ECOSYSTEMS :
CURRENT SCIENTIFIC UNDERSTANDING.

1. INTRODUCTION

This paper attempts to summarize current scientific understanding of the impact man-made sulphur dioxide emissions have on freshwater chemistry and biology.

In 1972, when the Swedish Government's case study for the UN/Stockholm Conference established acid deposition as a topic of international debate, freshwaters and forests were seen as the targets and the neutralization of limited alkalinity in soil and water by acid pollutants as the damaging mechanism. Since 1972, scientific inquiry has steadily modified that simple picture.

Research on tree damage has reduced perceptions of the potential significance of acid deposition. It remains implicated in some proposed damage mechanisms but a firm connection with acid deposition has yet to be established.

Studies of freshwater chemistry and biology have revealed the complexity of the interactions between ambient input, soil and ground water chemistry and effects on freshwater biota. It is clear that assessing the impact of acid deposition requires a level of detailed understanding far beyond the initial simple titration hypothesis. Nevertheless, and in contrast to tree damage, the scientific problem has remained one of quantifying the impact of acid deposition rather than assessing its significance in principle. This paper deals only with freshwater, and not forest, effects for this reason.

2. THE FACTORS AFFECTING ACIDIFICATION

2.1 GENERAL

It is now clear that the impact of acid deposition on freshwaters is much more complex than the simple hypothesis of sulphuric acid input exhausting a limited alkalinity of some soils and lakes. Research has led to 3 conclusions about the factors involved:

- i. that water quality and in particular the concentration of cations, notably calcium and aluminium, rather than acidity alone, is the factor affecting many freshwater species.
- ii. that soils and their interaction with ground water are cardinal in determining freshwater quality, particularly aluminium and calcium levels.
- iii. that land management practices, and in particular forestry, can alter soil chemistry and hence the quality of ground water.

2.2 SOIL CHEMISTRY

Three soil processes are particularly important.

The first is exchange of cations with the incoming rainwater which can either increase or decrease its acidity in the short term. Rosenqvist has drawn attention to the importance of this mechanism for episodes (2.1) and showed that runoff water could be more acid than incoming rain (2.2). Experiments on catchments in Aberdeenshire (2.3) have shown that adjacent water systems can react quite differently to the same rainfall event, one increasing rapidly in acidity while the other is hardly altered.

The second process is a long-term acidification of the soil that comes about if the ion-exchange system is depleted of base elements, e.g. calcium and magnesium. This can arise either by the natural take-up of these elements in vegetation, particularly trees, or by their displacement by hydrogen ions from acid deposition. In either case the soil acidity is increased. In the long term, the rate of change of soil acidity will depend on the extent to which weatherable minerals are present whose decomposition can both neutralise acidity and replenish the exchangeable cations. Soils which have a low cation-

exchange replenishment capacity could show a rise in acidity by as much as 1 pH unit in a few decades of typical acid deposition. (2.4). Examples of increasing soil acidity associated with particular nearby sources of acid deposition have been documented in the UK (2.5). The cation-exchange regions of strongly acidic soils are dominated by aluminium ions. They may be displaced by percolating acidic solutions (2.6) contributing to the soluble aluminium content of surface waters.

The third process is the storage in the soil of sulphur compounds deposited from the atmosphere, and their subsequent release as sulphuric acid. Deposited sulphur can be retained in wet organic soils by chemical reduction to sulphide and incorporation into humus (2.7) (2.8). If such soils subsequently dry out, re-oxidation can lead to leaching of sulphuric acid by later rainfall (2.9).

Measurements of total soil sulphur content in the Norwegian RAINS programme show that it is equivalent to many decades of acid deposition. One hypothesis of sulphate retention is that it takes the form of aluminium and ferro-hydroxy sulphate (2.10, 2.11). In this model the aluminium and ferro-hydroxy sulphates can be formed in the soil when the concentrations of the constituent ions exceed a solubility limit. Conversely it can be leached from the soil when the concentrations fall below the solubility limit. Another retention and release process is adsorption of sulphate on soil material. This then acts as a buffer. During the times of high sulphate input, sulphur is effectively stored up to some equilibrium level, together with cations including aluminium from minerals in the soil. Continued addition of sulphate at the equilibrium level would pass straight through the soil while, if the concentration in the input fell below the equilibrium level, sulphate and aluminium would be leached out until a new equilibrium was established.

A direct demonstration is provided by the Norwegian RAIN project where catchments are subjected to controlled inputs of, in one case, sulphuric acid at five times present atmospheric deposition levels, and in the other to deacidified water or artificial snow. In the first case, some 80% of the sulphate added during the year was retained and acidity in the output only doubled. The catchment subjected to deacidified input, however showed a sulphate output well in excess of input, and virtually unchanged acidity over a period of 18 months.

Qualitative hypotheses to explain these results are now being developed, although definite identification of the mechanisms actually operating and quantification of the role played by acid deposition remains the objective of further work.

1.3 LAND MANAGEMENT

Land use and management can have important impacts on soil and drainage water quality.

The draining of peats (which is often an essential prelude to afforestation) can result in the oxidation of organic sulphides, to which atmospheric inputs will have contributed, and lead to subsequent leaching of sulphuric acid. Regular burning of vegetation on organic-rich soils leads to a release of neutralising elements. (2.1). Liming will both restore the cation exchange capacity of soils and give some short term direct neutralisation of incoming acidity.

It is now generally accepted that forestry is probably the most significant aspect of land management to affect areas sensitive to acid input. Observations in Sweden (2.12) and in the UK (2.13), amply demonstrate the effect with densely forested catchments showing levels of sulphate and acidity in run-off water several times that for lightly or non-forested areas.

There are a number of mechanisms by which forestry, in particular with conifers, can affect soil and ground water quality;

- i. ploughing prior to planting can lead to organic sulphur oxidation.
- ii. trees extract base cations from the soil, reducing its capacity for acid neutralisation and increasing its acidity.
- iii. forest litter is a source of organic acid.
- iv. harvesting trees removes the base capacity of the cations incorporated into the tree material.
- v. clear-felling leads to a surge in nitric acid generation in the soil as root systems decay. This may displace stored sulphur (2.14, 2.15, 2.16).

- vi. enhanced deposition of pollutants to branches and leaves can occur either by dry deposition or the interception of mists and fog. (2.17, 2.18).

Tamm has attempted to distinguish the affects of tree growth on the acidification of soils from other causes (2.19, 2.20) by comparing pH versus depth profiles of soils with corresponding measurements made in the same place, using the same techniques, some 57 years previously. He found a systematic decrease in pH over the period independent of the acidification due to tree growth, which suggests that the effects of tree growth and acid deposition are about the same for the upper soil horizons at these sites.

2.4 THE RELATIVE IMPORTANCE OF ACID DEPOSITION.

Within the complex picture that has now emerged acid deposition and coniferous forestry both constitute major perturbations to the chemistry of certain soil/water systems. Their effects are interactive - coniferous forestry evidently both enhances acid deposition and reduces the neutralising capacity of the soil. The prime objective of further research is to quantify what is yet a predominantly qualitative picture in order to predict the effect of changes in acid input or land management practices. Models so far developed (2.21, 2.22, 2.23) have currently to rely on many broad, simplifying assumptions. Before they can be used with confidence in a predictive way they will need to incorporate both extensive hydrological pathway and soil chemical mechanisms, fully quantified by further fieldwork, as well as reliable data on past land management practices. Large scale acid-exclusion experiments, like the RAIN project, will be necessary to confirm model predictions.

3. EFFECTS ON AQUATIC LIFE

3.1 GENERAL

Just as the processes of acidification themselves are now revealed to be complex, so it is clear that the mechanisms leading to the deterioration of fisheries and changes in other aquatic life forms involve in many cases detailed chemical water quality, rather than simple acidity.

Ideally, studies of fisheries status should be combined with comprehensive analyses of water quality over the period of decline but this has never been fully achieved. Inevitably, therefore, the relationship between decline and acidification is generally circumstantial rather than clearly proven in the field.

3.2 FISHERY DECLINE

During the 1970s, evidence of fishery decline accumulated in Scandinavia, the USA and Britain. (3.1, 3.2). The source of much of the data is fishery records and therefore is not associated with parallel water quality data. The time scale of decline varies from 80 years for salmon in Southern Norway and Nova Scotia (3.1) to 20 years in mid-Wales (3.3, 3.2) and South West Scotland (3.4, 3.5).

The clearest evidence for a relationship between acidification effects and fishery decline comes from the La Cloche mountain region of Ontario. (3.1). Here, the acid input is due mainly to the emissions from the Sudbury smelters some 65 km away and therefore is not an example of long range transport influence. The region has however been closely monitored over some 15 years.

3.3 EFFECTS ON OTHER SPECIES.

Freshwater invertebrates can be used as pollution indicators (3.6, 3.7, 3.8). Mayfly abundance decreases as freshwater acidity increases. Omerod (3.9) has reported the decline of dippers, which feed extensively on mayfly larvae, along stretches of Welsh streams that have shown an increase in acidity over the last 14 years.

Experimental acidification of lake water (3.1) leads to a gradual loss of species as acidity is increased.

In none of these studies has water quality factors other than pH been monitored.

3.4 MECHANISMS OF DECLINE

As fishery status and simultaneous water chemistry data became available in the 1970s it became clear that in many instances, neither acidity nor sulphate concentration could alone provide an adequate explanation for the observed fishery status. (3.10). Parallel laboratory and field work revealed the importance of soil-derived elements in determining fish viability. Calcium emerged as a critical element for survival (3.11) enabling fish to live despite low pH (3.12), 3.13). Aluminium, on the other hand, mobilised from the soil by acid water was identified as a major toxic agent, (3.14). Furthermore, the toxicity of aluminium was itself modified by other chemical constituents, being reduced by complexation with organic materials and fluorides and by the presence of calcium (3.15, 3.16).

Episodic stream flows, either following heavy rainfall episodes or during times of snow melt, have been correlated with sudden fishkills in rivers and commercial hatcheries served by rivers. Where coincident water quality data are available they are usually restricted to pH (Prigg 1983) but under snow melt conditions there is evidence of a substantial influence of soil in modifying the chemistry of acid rain and snow (3.17). It seems likely that even during such episodes the mixing of water from different hydraulic pathways may result in exposure of fish to toxic levels of aluminium (3.18).

Failure of fish stocks to be renewed resulting from acid-induced mortality of eggs and juvenile fish or from reduced spawning performance, is a possible mechanism of fishery decline suggested by controlled studies (3.19, 3.20, 3.21, 3.22) but the operation of this mechanism in actually affected waters has yet to be clearly established. The influence of reduced food availability on fisheries seems however to be relatively unimportant (3.1).

3.5 THE ROLE OF ACID DEPOSITION

It now seems clear that the influence of acid deposition on aquatic life is linked with its ability to contribute to changes in chemical water quality and in particular to its influence on calcium and aluminium concentrations. The task of quantitatively assigning the degree of responsibility of acid deposition for decline of freshwater species is therefore essentially the same as that described for soil in Section 1. The role of acid deposition needs to be evaluated in the context of other influences. This is emphasised by the strong circumstantial evidence of the correlation of fishery status

with afforestation in some areas of Wales and Scotland. (3.2).

3.6 REMEDIAL ACTION

The Swedish Fisheries Board has embarked on a pragmatic programme of limestone additions to many lakes to neutralise incoming acid and reduce lake acidity. This also has the effect of raising calcium levels and depressing those of aluminium. The programme has been generally successful for lakes, but less so for streams because of the episodic nature of the flow and the proximity to ground sources of toxic aluminium (3.23). A more fundamental approach is seen to be the replacement of calcium in the soil surrounding lakes, with the aim of suppressing aluminium mobilisation and neutralising acid from whatever source. This approach is being tried in Scandinavia and in the UK with promising results (3.24, 3.25).

4. HISTORIC EVIDENCE FOR ACIDIFICATION

4.1 ANALYSIS OF LAKE SEDIMENT CORES

Undoubtedly, one of the key developments in the study of the history of lake water quality has been the use of techniques of estimating past levels of acidity by studying the remains of diatoms in lake sediment cores. (4.1, 4.2). Results from lakes in sensitive areas of South West Scotland show that acidification began to accelerate sharply at various times over the last 100 - 150 years, but in no case did the onset of acidification precede the industrial revolution. Furthermore, in the lakes with the earliest onset of acidification, the appearance of combustionash particulates and increased heavy metal concentrations occur at the same time. While the technique has yet to be widely employed, it has provided the clearest evidence yet of an association between man-made emissions of acidic pollutants and water acidification.

4.2 RESPONSE OF ACIDIFIED WATERS TO REDUCED ACID INPUT

The only direct indications to date are from the RAIN experiment. Here, after 18 months' shielding from acid precipitation, the pH of the run-off water from a mini-catchment barely changed. The ratio of calcium to acidity, which is broad indicator of the acceptability of water quality to fish, remained unchanged. It is not clear if, with continued low-acid input, acceptable surface water quality can be achieved at this location without soil treatment, or on what timescale.

Given the buffering effect of sulphur in the soil and the year-to-year variability of the meteorological and biological factors involved, it should not be surprising that there is no convincing evidence from field measurements in Europe of a relationship between reduced ambient input and water quality. Sorensen (4.3), using data supplied by the Swedish Environmental Protection Board, finds no discernable trend in sulphate flux in the major rivers of southern Sweden over the period 1965 to 1981.

It has been suggested that the rapid rise and fall of sulphate levels in three lakes in south west Sweden over the period 1970 - 1983 reflected changing atmospheric deposition over that period. However, it appears more likely that the effect was due to release of stored soil sulphur by forestry operations. (4.4, 4.5, 4.6).

In Canada, one closely monitored lake in the Sudbury region of Ontario, which had been subject to decades of heavy acid deposition from the smelters there, has shown clear reductions in acidity and sulphur levels since 1972, paralleling a decline in smelter emissions (4.7, 4.8).

The Sudbury situation is, however, exceptional in its high sulphate levels and a direct translation of this observation to the different European context is not justified. It does suggest that, in some cases an improvement in water quality might be seen within years of reducing acid input but clear answers on the rate of response of European surface waters to reduced acid deposition are most likely to be found in direct experiments of the RAIN type. The acceptability to fish of the resulting surface water cannot be assessed by its sulphate content or pH measurement alone and aluminium speciation and calcium levels at least are vital.

5. LONG-RANGE TRANSPORT, TRANSFORMATION AND ATTRIBUTION OF DEPOSITION

5.1 LONG-RANGE TRANSPORT AND TRANSFORMATION

Clear evidence for Long-Range Transport on the scale of hundreds and even thousands of kilometres comes from measurement.

First, and most simply, sulphur deposition can be measured in regions remote from sources. (5.1). Secondly, in particular meteorological conditions, direct measurements from aircraft have tracked pollution plumes from cities and power stations for hundreds of kilometres. Plumes from power stations in the North of England, for example, have been identified as they reached the Scandinavian coasts (5.2, 5.3). Most recently, the dispersion of radioactive material from the Chernobyl accident has provided a dramatic demonstration of the power of winds to disperse airborne material across continents.

Mathematical modelling attempts to simulate the transport and chemical transformation of pollutants and ultimate deposition patterns. The Norwegian Meteorological Institute carries out mathematical studies of sulphur emission and deposition in Europe under the UN ECE Convention on Long-Range Transboundary Air Pollution (EMEP Programme.) (5.4). In broad terms, the results show that while the major emitting countries, including the UK, are responsible for most of the deposition, mainly dry, within their own boundaries, in more remote areas transboundary pollution makes a substantial contribution, mainly wet. However, the model predictions for wet deposition over the north west fringe of Europe are unable to explain the measured depositions and attempts at improvement are continuing. The EMEP model does not in fact explicitly include the chemical processes leading to acidity in rainfall but represents them by simple physical parameters. Different types of models are likely to be necessary to take into account these factors. (5.5).

The geographic scale of the EMEP model covers the whole of NW Europe and Scandinavia, but it has become clear that transport distances may be considerably longer than previously estimated, (5.6, 5.7) and sources outside the current modelled area may need to be considered. This "ultra-long range transport" opens up the possibility of significant amounts of sulphur from North America, or from natural oceanic sources, reaching Europe and Scandinavia and of

European emissions reaching previously unconsidered regions or of being recirculated and contributing to a general European "background".

5.2 ATTRIBUTION OF DEPOSITION

Estimates of the relative responsibility for deposition in one country due to the emissions from another are still subject to considerable uncertainty and are entirely dependent on models. Revision of the UN ECE EMEP model, including taking account of changed emission patterns since 1980 and the incorporation of more realistic deposition mechanisms, has led to a steady reduction in the estimate of UK responsibility for deposition in Norway. (5.7). From being the largest single contributor, the UK is now estimated to be second with Norway herself becoming first. More dramatically, however, is the increase in the proportion of deposition that the model is unable to account for (the "unattributable" portion).

In Norway the proportion "unattributable" has risen from about a quarter to over half the total deposition in the latest calculation. This must be due in part to the increased transport distance of sulphur pollutants out of Europe, now included in the model. It also in part reflects the inability of the EMEP model to allow for sources outside the modelled area or more than four days upwind. Some of the discrepancy may also lie in the crudeness of the treatment of the complex chemistry.

The probable origins of the unattributed deposition are three-fold; North America, recirculated European emissions and natural emissions from the sea (5.8).

The reliance that can be placed on emitter/receptor tables, at the present state of knowledge, is clearly limited. However, there is no indication that any one particular source is likely to emerge as dominant for southern Norway.

6. EFFECTS OF REDUCED EMISSIONS ON DEPOSITIONS

6.1 GENERAL

Taking the widest global view it is clear that depositions would fall linearly with emission reductions. However, research has demonstrated the complexity of the chemical transformation and meteorological processes governing the deposition of sulphur compounds in rainfall which at present prevent adequate quantification of the emission/deposition relationship for specific emitter and receptor areas.

Since the early 1970s, sulphur emissions in Europe have fallen on average, including by some 40% from the UK. The same period has seen the development of methods for measuring rainfall quality and the establishment of monitoring networks.

6.2. THEORETICAL STUDIES

The dry deposition of sulphur is a relatively straightforward and well understood process and over a wide range of distances it will fall in proportion to emission reductions.

In remote areas however, most of the deposition is by rainfall and the pathway from emissions of sulphur dioxide to wet deposition of sulphur compounds involves highly non-linear chemical transformations, principally the oxidation of SO_2 to sulphate by oxidants such as ozone and hydrogen peroxide in cloud water droplets (6.1). These in turn involve meteorological processes, advection of oxidants, cloud formation and rain production.

In certain situations, for example, in a slowly dispersing power station plume, the supply of oxidants to transform SO_2 to sulphate may be a limiting factor. In many situations the acidity of the cloud droplets will inhibit further oxidation of SO_2 until they are diluted in a precipitation event. Over the long term and at sufficient dilutions the meteorological and chemical factors conspire to render the system substantially linear and we do not necessarily need a complete understanding of the detailed mechanisms (6.2). The difficulty with this approach is to define limiting ranges in particular situations of most interest.

In the industrial core of Europe, SO_2 concentrations are high enough to expect non-proportionality in the conversion of SO_2 to sulphuric acid in cloud water droplets. However, in this core area, dry deposition dominates and a non-proportionality of wet deposition

will not have a large influence on total deposition. At distances from sources of about 1000 - 2000 kms, concentrations of SO₂ are low enough to expect substantially linear conversion of SO₂ to sulphuric acid. At the present stage of semi-quantitative understanding it is not possible to define precisely the circumstances of deposition in Scandinavia and their relation to European emissions between these limiting cases.

If the unattributed contribution from the EMEP calculation is indeed due to ultra-long range transport from very distant sources, we may expect proportionality to apply to reductions in the contributing anthropogenic emissions. This would leave a contribution from natural sources whose size remains to be determined.

6.3 MEASUREMENT

Several workers (6.3, 6.4) have suggested that a downward trend of acidity or sulphate in rain water measured at some sites parallels the general reduction in UK emissions since 1973. However, over the time-series of data so far available, the year-to-year changes in meteorology, especially trajectory distributions, will tend to mask any reduction in deposition at a point due to emission changes.

The need for a time-series of consistent measurements over a period of at least 10 years to identify trends in acid deposition has been pointed out (6.5). Such a reliable time-series of measurement data is now being built up as a result of the quality control of measurement practice that has been a feature of the latest monitoring networks. Future results will be crucial to the direct determination of emission-deposition relationships.

7. DISCUSSION

Acid deposition is seen as constituting a major perturbation to the chemistry of sensitive soil/water systems. However, the interaction of soils with incoming deposition is a cardinal factor in determining the effect of acid deposition on freshwaters. Qualitatively, that effect is now clearly seen in terms of total chemistry, in particular the release of calcium and aluminium. In fact, the term "acidification", laying as it does all emphasis on only one aspect of the chemical changes that may follow deposition of acidity, now appears as inadequate as "acid rain", which poorly reflects the many processes that are involved in wet and dry deposition.

A key concept which has emerged from research on soil/water interactions is that of delayed response to changes in deposition. This is exemplified by the soil sulphur reservoir model. If the soil sulphur reservoir is in equilibrium with current atmospheric depositions, the output of sulphate will approximate the input. Decreasing the annual deposition of sulphate will have a less than proportional effect on run-off, but will tend to reduce the size of the sulphur reservoir. Conversely, an increase in annual deposition would have a less than proportional effect on run-off but would tend to add to the size of the sulphur reservoir, thus prolonging the problem.

Land management, and in particular coniferous forestry, can in its own right produce changes in soil and water chemistry of the same magnitude as acid deposition. By extracting neutralising elements, tree growth can influence the subsequent interaction of soils and deposited acidity. By enhancing the capture of acidic species, branches and foilage can increase their deposition rate.

The response of fisheries to "acidification" processes is in fact a response to the total chemistry, particularly aluminium and calcium levels, rather than acidity alone. The restoration of surface water quality acceptable to fish in areas such as Southern Norway requires a decrease in inorganic aluminium, a decrease in acidity and an increase in calcium. Following a reduction in sulphur deposition, the first two conditions will only be met after a delay which depends on the nature and size of the sulphur pool in the soil. If the total sulphur pools that have been measured in Scandinavia are involved, the delay could be many decades. There may be a distribution of pool sizes and of response times, with some waters recovering more quickly than others. This is consistent with the partial recovery of some highly impacted lakes in the Sudbury area of Canada over a period of years following reductions

in emissions from the strong local sources.

Recovery in terms of a rise in calcium concentration could be considerably delayed if acidic leaching or biological uptake resulting from afforestation has severely depleted the neutralising elements in the soil and if replenishment by mineral weathering is slow or inadequate. Experience so far is that there are areas where recovery will depend on replacing the base cation content by the addition of limestone to the soil.

It is becoming evident that the concept of a single, universally applicable "acceptable loading" for sulphur deposition, below which problems would not be experienced, is not in keeping with the complexity of the situation. This illustrates the value of research in guiding policy since the early 1970s by building up the qualitative picture of the many complex processes which occur in the atmosphere and in soil and water courses that together determine the eventual change in water quality and the health of aquatic life.

The future tasks for research are to quantify the processes identified in order to refine policy making on remedial measures and to continue the measurements that alone will verify their effectiveness.

8. CONCLUSIONS

The action of acid deposition is modified, but not nullified, by soil chemistry and the influence of land management practices, in particular coniferous forestry.

The extent to which surface water quality and fishery status in Scandinavia and other sensitive areas will be improved as a result of reduced sulphur emission in Europe depends on a number of factors which are as yet not quantified. These include the degree to which non-European and natural sources contribute to depositions, the extent to which soil has been depleted of base cations by acid deposition or biological extraction and the size and nature of the soil sulphur pool. The future effects of forestry, where they are independent of acid deposition, will depend on forestry practice and policies. There will be areas where soil and water calcium levels will not recover unless limestone is added to the soil.

The route to recovery is likely to require a combination of emission reductions, land management practice revisions and soil treatment. The timescale and targets for emission reduction must be determined in this context.