

Understanding Acidification; Objectives of the
UK Environment Department's Research Programme.

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Introduction

Ideally, the basis for formulating policy on pollution issues is a complete understanding of each problem including;

- . identification of the damaging agents and the mechanism and extent of their impact.
- . identification of pollution sources and the mechanisms of transport, transformation and deposition of pollution between source and target.
- . evaluation of abatement options for both cost and benefit.

The Air Quality Management System approach discussed in session V of this conference, incorporating this understanding in a quantitative and mechanistic way, may then be used to quantify a range of policy options representing various levels of environmental benefit with their associated abatement costs.

Our understanding of acidification of the environment remains, however, incomplete. This is not to say that air quality management models and systems should not be formulated nor policy objectives identified until every element of the acidification process is fully understood and quantified. A project with objectives in many ways similar in concept to the IIASA RAINS system, presented in Session V, is included in the UK Department of the Environment's own Research Programme.¹ An important feature of the project is to include explicitly elements of uncertainty into the model. The UK has also announced policy objectives of 30% reductions in SO₂ and NO_x emissions by the end of the century. However, our ability to evaluate the consequences of actual or proposed policies will remain subject to considerable uncertainty until our understanding improves.

The purpose of this paper is to illustrate some of the areas in which the Department's Research Programme seeks to fill the

need for more detailed understanding of acidification of the environment and its effects. The projects mentioned are part of the Environment Department's overall air pollution research programme, currently costing about £4M per annum. Appendix 1 lists those projects specifically related to effects.

The Department's programme seeks to integrate its more applied projects with the basic research at Universities and research institutes, supported by Government funds, being carried out principally through the Natural Environment Research Council. Appendix 2 lists the effects related projects. The important work of the Energy Industries, with sponsorship from the Department of Energy, is also recognised. The Central Electricity Generating Board, for example, in the last year supported a programme of environmental impact research by about £5M.²

An important function of the programme is liaison and cooperation with other work, both in the UK and abroad. In this context we have already established arrangements to exchange details of research programmes with Government Departments and Agencies in the Federal Republic, Norway, Sweden, Finland and the USA. I would like to take this opportunity to invite other delegates at this conference to take part in similar exchanges of information.

Identifying Key Research Areas.

Air pollution problems demand an understanding of three basic components; atmospheric processes, effects and abatement. Projects within our Research Programme cover all three areas. Almost all the research is carried out under contract by universities, research institutes and private sector consultants and the formulation of new contracts in the light of results obtained is an important method of identifying key research areas.

International contacts also play a large part in determining the content of the Research Programme. In the context of acidification the Work Programme of the Executive Body for the ECE Convention on Long Range Transboundary Air Pollution is particularly important and the UK has played a full part in contributing to the work of the various groups.

The Department seeks independent assessments of air pollution problems through Review Groups, composed of National experts, who review specific topics to agreed terms of reference and report with recommendations. The first such group to report was the Acid Rain Review Group,³ and the present structure of the UK acid deposition monitoring network is based on the Group's recommendations. Very recently, the Acid Waters Review Group⁴ published its interim analysis of available data on the acidification of freshwaters in the UK. It identifies evidence for relatively recent acidification of freshwaters in a few geologically distinct areas of the UK, but also points to a past lack of good monitoring data specifically aimed at assessment of the problem as well as the potential importance of land-use practices in acidification. Other Review Groups due to report this year or early next year are concerned with the effects on terrestrial systems and buildings, and with the formation of photo-chemical pollutants.

In designing a research programme to reflect the key areas identified, the overall objectives remain the gathering of essential baseline data and the elucidation of those links in the chain between pollutant emission and environmental effects that remain poorly understood.

Research Programme Projects on Acidification.

Atmospheric Processes.

A comprehensive inventory of pollutant emissions is the essential basis for understanding acidification. The Warren Spring Laboratory of the UK Department of Trade and Industry, under contract to the Department of the Environment, has a central role in collating information on UK emissions and developing spatially and temporally disaggregated inventories.⁵ These data have been used extensively in collaborative exercises with the UNECE and, through the OECD and EC, have formed part of the input data to the PHOXA programme described in Session V. Critical evaluation of emission factors, in particular for NO_x and hydrocarbons, is necessary to improve our confidence in emission estimates. Warren Spring Laboratory has recently incorporated new performance - related emission factors for motor vehicles in the National inventory as a result of the development of on-the-road in-service sampling systems.⁶

Warren Spring is also the centre of national air pollution monitoring which is currently being expanded to provide comprehensive data on precipitation chemistry, NO_x, SO₂, and ozone. 1986 will be the first complete year of operation of the new Acid Deposition network comprising nine primary sites with wet-only daily collectors and SO₂ measurement, and a secondary network of some 60 sites with bulk rain collectors.⁷ Monitoring is often regarded as a routine task, but for results to be worth while considerable effort and development is needed to ensure good quality control of data. Sample collection has also demanded new equipment development, particularly for the sampling of snow-fall.⁸

Networks of NO_x, NO₂, and SO₂ measurement are now being established using totally remote, automatic operation which will build to a total of about 17 sites by 1987/88. As well as providing complete coverage of the whole of the UK, including the remote rural areas of Wales, Scotland and Northern Ireland, these networks will supply the necessary data for the planned expansion of the European Monitoring and Evaluation Programme, (EMEP), to include NO₂ in 1986 and O₃ in 1987.

Many questions remain concerning atmospheric chemistry, in particular the reactions which govern the oxidation of SO₂ and NO_x in the atmosphere. The Environmental and Medical Sciences Division at Harwell has been involved in the investigation of such reactions for many years.⁹ The crucial role of hydroxyl radicals and hydrogen peroxide in converting SO₂ to sulphate is now well recognised and in addition to defining the reactions involved, Harwell has been developing measurement equipment for these species to enable the relationships between primary and secondary pollutants to be

observed in the atmosphere.

Deposition of acidity at high altitude is poorly understood, involving as it does the conversion of sulphur and nitrogen oxides within clouds and precipitation. It is, however, of potential importance for upland forests and streams. To study the processes involved a series of field experiments at Great Dun Fell in Cumbria is being undertaken by the University of Manchester Institute of Science and Technology, Harwell, the University of East Anglia and the Institute of Terrestrial Ecology.¹⁰ The peak of the Fell, at a height of 847m, is cloud-capped during some 200 days in the year and forms a natural laboratory where the chemistry of air pollutants can be followed as they pass through the cloud cap and into precipitation. The experiments include the detailed study of the pattern of acidic deposition and concentration at high altitude and the formulation of a mathematical model to describe the results.

Mathematical modelling brings together our knowledge of emissions, atmospheric transport, transformation processes and mechanisms of deposition. The main thrust of modelling work in the Research Programme, also centred at Harwell,¹¹ has so far been summer photo-chemical episodes. By using modelling techniques which allow chemical mechanisms to be included in detail this work has shown among other things the potential for increased sulphate formation as a result of reductions in NO_x emissions. More recent work on the development of NO_x deposition models has indicated significant differences in deposition pattern from that for SO₂.

These modelling results have already been used in the ECE LRTAP NO_x Working Group and through the OECD are contributing to the Netherlands/FRG PHOXA programme presented in Session V. The detailed photo-chemical modelling approach is an essential component in increasing our confidence in models to a level where they can be used for control strategy evaluation.

Effects - Freshwater systems.

The integrated study of freshwater catchments is central to our attempts to improve understanding of how water courses become acidified and the impact on freshwater biota. By comprehensive monitoring of complete catchments it is hoped to quantify the relative role of atmospheric acid input and of other influences, such as land use and management, soil type and history, and to estimate the effects of changes in these factors. The development of catchment classification and modelling techniques is a complementary part of this approach.

There are four catchment studies within the programme, two being undertaken in collaboration with local Water Authorities. They range in size from catchments in South Wales covering many hundreds of hectares and feeding the Llyn Briane reservoir,¹² to a 6.6 hectare catchment on a granitic outcrop at Charnwood in the English Midlands.¹³ Between them they cover water courses from small upland source streams which are most susceptible to the immediate effects of acid precipitation, through lakes in granitic basins to river systems which have shown the effects of high acidity during times of peak flow.¹⁴

The variety of land use represented includes moorland, afforested areas, agricultural land and managed uplands. The importance of soil type and the effects of weathering, past management and groundwater flow are being intensively studied in catchment systems in Aberdeenshire, Scotland.¹⁵ The small catchment at Charnwood, by virtue of its convenient location, size and fast response to rainfall events can be very intensively monitored.¹³ This gives a detailed picture of the relationship of rainwater and stream quality during individual rainfall events and their impact on freshwater biota.

Palaeoecological Studies, involving the study of lake cores for the remains of diatom populations, pollen, heavy metals and particles, enable the water quality history of water bodies to be assessed on a time scale of hundreds and even thousands of years, compared with the tens of years of direct water quality measurement. The work of Battarbee and his group at University College London,¹⁶ initially supported by the CEGB, indicates that water bodies in geologically sensitive areas of South West Scotland have become acidified as a result of acid deposition since the Industrial Revolution. This work is now being extended within the Research Programme to include lakes in other parts of the UK, both to provide further tests of the method and to investigate the geographic extent of the phenomenon.

The method has a precision of a year or two for the most recent sediment layers and may therefore be useful for indicating a response to reduced acid input by a method and on a timescale consistent with the long-term lake record.

Effects - Crops, Trees and Vegetation.

In contrast to the acidification of freshwaters, it remains open to question if acid deposition has any significant effect on the growth and yield of crops, trees or vegetation. The importance of factors, such as other air pollutants and the natural stresses of drought and temperature fluctuations, have always to be taken into account.

Laboratory studies on the mechanisms of air pollution damage to trees and crops are carried out at Lancaster and Newcastle Universities.¹⁷ The response of plants to other stresses (low temperature, decreased levels of irradiance) and the potential for interaction with pollutant effects are important elements of the work.

Chamber studies of effects on plants and trees are carried out at Nottingham and Lancaster Universities, at Imperial College London and at the Institute of Terrestrial Ecology, Edinburgh.¹⁸ Both open top and closed chambers are used, the latter being specially designed to incorporate facilities for climate adjustment. The Nottingham open top chamber facility forms part of their lead role in the CEC COST 612 programme.

These programmes also reflect the need to take into account not only pollutants in combination and their direct effects, but the possibility that pollutant exposure might predispose plants to injury through water or temperature stress.

Field experiments with crop plants, growing as far as possible

under normal conditions, are carried out at Nottingham University, where cereal crops are fumigated with SO₂ in the field, and at Imperial College, where the emphasis is on ozone exposure, ozone and acid mist, and the combined effects of ¹⁹ urban pollutants on a wide range of crop and forage plants. Sensitive legumes are being used in a transect study of plant growth and yield carried out across Southern England.

These approaches to evaluating the effects of air pollution on terrestrial systems represent an integrated approach designed to facilitate the transfer of quantitative dose-effect relationships from controlled experiments in laboratories and environmental chambers, through open-top chamber and field studies to estimates of effects on growing crops and trees.

Forest Surveys in the UK have so far been carried out by the Forestry Commission. ²⁰ Conifers were studied in 1984 and 1985 with a study of beech in 1985. Damage syndromes reported in the Federal Republic were not apparent in the UK trees surveyed. In 1986 the Department will be collaborating with the Commission in an extension of the annual survey to include deciduous species in hedgerows and amenity trees. Although not a direct part of the Research Programme, there are also strong links with the ITE and Lancaster University contributions to the Early Warning Forest Damage experiment of the European Community. ²¹ The interlinking of these programmes is important in ensuring that damage assessments are made using methods which are comparable throughout Europe.

Studies of the decline of blanket peat bogs (ombrotrophic mires) by Dr. Lee at the University of Manchester ²² have highlighted a pollution related problem that particularly affects some upland areas of the UK. This work is important since it is one of the few cases where damage is related particularly to the nitrogen input from air pollution, of which the nitrate fraction of acid rain would form a part.

Effects - Buildings and Monuments

The Building Effects Review Group, which is due to report by the end of this year, is charged with reviewing the evidence for damage to monuments, buildings and building materials. An important question still to be answered quantitatively is the extent to which current pollution levels are causing damage and how far deleterious effects are the legacy of past pollution levels.

The Building Research Establishment of the Department of the Environment plays a central coordinating role in the programme of research on buildings, monuments and materials. ²³ Intramural work carried out at the Building Research Station includes controlled laboratory exposures on modern building materials, and environmental exposure with the National Materials Exposure Programme. This work provides the basis for an important input to the UNECE International Exposure Programme. The interaction of microclimate and air pollution is studied in projects at Wells and Lincoln Cathedrals and at Bolsover Castle. The Establishment is also a centre of expertise on stone preservation techniques.

Among the extra-mural contracts coordinated by the Establishment are laboratory studies of pollutant effects on materials and a field study of damage to stone buildings situated along a transect in SE England covering a range of pollutant exposure conditions. Finally, the programme recognises the difficulty of assessing the scale and value of building damage and therefore includes a study of methodologies for assessing the building stock at risk from air pollution damage.

Abatement

The Department's programme on abatement and control does not at present include development of technologies. The important programme of the power generating industries and the Department of Energy is therefore briefly summarised here.

The assessment of the suitability of existing technologies for abatement of pollution from UK sources is carried out by the end users and the energy industries. In this, the Central Electricity Generating Board have a major effort. The development of new and improved technologies is sponsored principally by the CEGB, the National Coal Board, the British Gas Corporation and the Department of Energy.

Atmospheric fluidised bed combustion systems have been developed and are available for industrial boilers and dryers. The main focus of current work is on the design, development and comparative assessment of advanced designs of power generation systems which hold promise of significant improvements in costs and in operating efficiency compared with present conventional plant equipped with flue gas desulphurisation.

A major programme has been started on the development of a pressurised fluidised bed combustor, employing a heat exchanger immersed in the bed, with the addition of limestone sorbents for SO₂ capture. A design study is in progress on the use of PFBC systems in conjunction with gas and steam turbines for power generation.

British Gas has already developed to a commercial size a gasifier which abstracts the coal ash as a molten slag. A parallel study is being made for a power station using combined gas and steam turbines, using clean gas from this slagging gasifier.

Compared with the desulphurisation of gases, the scope for economic sulphur removal from coal is limited, but research is being carried out on both the improvement of conventional coal preparation techniques and on the separation of a high sulphur stream from pulverised coal by high gradient magnetic flux.

Substantial reductions of NO_x emissions are now possible on new plant equipped with suitable new burners. Retrofitting of existing plant can however pose problems of corrosion and loss of efficiency and a stepwise approach is necessary to establish the operational limits with the different types of combustion equipment of UK power stations. Fiddler's Ferry power station has been equipped with low NO_x burners as part of such a programme of testing and retrofitting. Trials will be extended to other power stations as the suitability of the equipment is

demonstrated.

The Department's Research Programme focusses on assembling information on control and abatement technologies that can be used in evaluating strategies and policies. In order that the emission performance, environmental impact and cost implications of the application of abatement and low emission technologies can be evaluated, performance and cost estimates need to be available on a consistent and well defined basis. An agreed basis for such figures is not currently available, as pointed out in a recent OECD study.²⁴ As a first step in filling this need the Fellowship of Engineering is undertaking a review of abatement technologies with the central objective of deriving performance and cost information on a consistent and well defined basis. The study will include all the major sources of SO₂ and NO_x emissions and is due to be completed in 1987.

Summary and Conclusions.

The Research Programme of the Department of the Environment seeks, in the context of other work going on in the UK and abroad, to improve our understanding of the phenomenon of acidification and its effects. The emphasis wherever possible is on quantification of processes which will enable the environmental benefits of emission changes to be assessed against their costs.

In many areas, a better quantitative understanding should become available over the next 1-3 years, specifically;

- i) Improved, disaggregated emission inventories will form a more reliable and detailed input for modelling studies.
- ii) Improved estimates of performance and cost for abatement technologies and low emission processes on a consistent basis will become available.
- iii) Comprehensive monitoring systems are being established, alongside similar systems in the rest of Europe, suitable for better defining the phenomenon of acid deposition and for validation of modelling programmes.
- iv) Improved mechanisms of pollutant transformation and deposition will be developed for inclusion in models.
- v) Large field experiments capable of testing models and the assumptions they incorporate are being undertaken. Integrated studies of land use, soil and freshwater systems and the development of catchment models should lead to better quantitative estimates of the contribution of acid deposition to freshwater acidity and hence the potential effectiveness of abatement and amelioration policies.
- vi) The detailed study of effects on crops, trees

and vegetation should clarify the relative importance of all stresses, both those due to pollution and those due to natural factors, and lead to realistic dose/effect relationships.

- vii) Similarly reliable exposure/effect data for buildings and materials will become available.
- viii) The improved data bases from the new monitoring and modelling programmes will allow dose/effect relationships to be translated into damage/cost estimates.

The incorporation of these new, quantitative data into air quality management models is an essential step towards the goal of estimating the costs and benefits of abatement policies within defined confidence limits.

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Appendix 1

Acid Deposition Effects-Related Projects of the Department of the Environment's Air Pollution Research Programme. 1985/86.

Research Project	Total Cost £
1. The effects of acid rain on upland soils and streams.	244,200
2. Chemical inputs from precipitation and their effect on a catchment.	129,000
3. Effects of acidification on lakes and streams in Scotland.	147,000
4. Effects of acid rain on plants and soils.	569,000
5. Effects of afforestation and land management on the acidity of 5 catchments in Wales.	272,000
6. Effects of acid rain on freshwater eco-systems in north-west England.	176,000
7. Effects of acid deposition and photo-oxidants on trees.	184,000
8. Aspects of pollutant attack on limestone buildings.	49,000
9. Degradation of building materials in the presence of air pollution.	70,000
10. Identification and assessment of materials damage by air pollution.	25,500
11. Effects of atmospheric nitrogen compounds on natural vegetation.	87,200
12. Effects of low temperature fluctuation on the sensitivity of crops and trees to air pollutant damage.	67,000
13. Effects of air pollution on metallic materials.	150,000
14. Pollutant take-up and stone decay in southern Britain.	27,000
15. Effects of acid deposition on vertical surfaces.	19,500
16. Development of methodologies to evaluate stock at risk from air pollution.	10,700
Total	2,227,600

Appendix 2

Acid Deposition Effects-Related Research Receiving Government Support. 1984/85.

Project	Cost in 1984-85 £
Natural Environment Research Council.	
1. Acidification of run-off from melting snow pack.	16,500
2. Effects of ambient air pollutants on plant growth in and around London.	24,300
3. Assessment of likely concentrations of toxic products of SO ₂ and NO _x fumigation of plants at their site of action.	4,400
4. Effects of gaseous pollutants on the interaction between plants and invertebrate herbivores.	3,600
5. Physiological effects of SO ₂ pollution in water stressed plants.	6,000
6. Physiological Biochemical and ultra-structural role of calcium in the fills of freshwater teleosts and arthropods with respect to survival at low pH.	16,000
7. Interception of wind blown fog by vegetation and pathways for pollutant deposition.	13,700 27,700
8. Chemical speciation of Aluminium.	(50 per cent from EEC) 12,000
9. Diatom survey related to pH and water chemistry.	(50 per cent from EEC)
10. Measurement of pH in freshwaters.	19,000
11. Trophic relationships and effects of acid waters on stream invertebrates.	15,000 9,000
12. Acid deposition and ground water.	(50 per cent from EEC) 29,000
13. Effects of different forest canopies on the gross precipitation passing to the soil.	(50 per cent from EEC) 23,700
14. Effects of acid precipitation on river catchments.	(50 per cent from DoE) 102,000
15. Effects of polluted atmospheres on crops.	(40 per cent from MAFF)

Project	Cost in 1984-85 £
16. Interaction of airborne pollutants with natural surfaces in particular epicuticular wax of scots pine.	5,000
17. Interaction of grazing and air pollution.	26,500
18. Measurement of the rate of dry deposition of SO ₂ on a Scots pine forest.	13,000
19. Chemical composition of rainfall through Northern Britain.	33,900
20. Effect of acid rain on the extension growth of Sitka spruce.	3,800
21. Influence of rainfall acidity on transport and exchange of gases between plants and atmosphere.	3,200
22. Hydro-chemistry of run-off from upland catchments.	26,500
23. Transient acid surges in upland streams.	54,000
Total	488,400
Scottish Office: acid deposition at Loch Dee	75,000
Welsh Office: ecological monitoring of acid rain in Wales.	32,000
Ministry of Agriculture, Fisheries and Food: the response of barley to sulphur dioxide at concentrations controlled by fumigation.	65,200
Forestry Commission: effects of ambient levels of air pollution on tree growth in rural areas.	*

This work is being undertaken directly by the Forestry Commission. The capital cost of equipment is £190,000 and about 2½ man years effort a year will be required.