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**Surface Water Acidification:  
I. the Increasing Importance of Nitrogen**

**Abstracts of a one day symposium held at the ECRC,  
11th September, 1997.**

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**Environmental Change Research Centre  
University College London  
26 Bedford Way  
London  
WC1H 0AP**

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## Introduction

Rick Battarbee

ECRC, 26 Bedford Way, UCL, London.  
WC1H 0AP.

### Abstract

There are three principal reasons for holding the conference *Surface Water Acidification: the increasing importance of nitrogen*.

1. There is a danger that the Government believes the problem of "acid rain" and surface water acidification has gone away simply because the UK signed up to the UNECE's second sulphur protocol in Oslo (June 1994).

On the contrary, and despite substantial reductions in S emissions across Europe, there has been little change in the quality of our upland waters over the last decade, and much of the evidence we have suggests that recovery in many regions of the UK will be patchy and slow, and in some cases continued acidification may even occur. So acid deposition probably remains today, and is likely to remain for some time, the single most serious pollution issue facing Britain's upland ecosystems, both terrestrial and freshwater.

2. In this context, we specifically want to bring attention to the nitrogen problem. For many parts of the UK, especially Wales, the Pennines, the Lake District and parts of Scotland, the acidifying impact of increased N deposition may offset improvement expected from reduced S deposition, and if nitrate leaching increases to the extent that some of the models suggest then further acidification could result. The phrase sitting on a time bomb has been used with some justification.

3. The third reason for holding the meeting is simply to present ongoing research, almost all of it funded by the Department of the Environment, Transport and the Regions (DETR), to a wider public, to make sure interested parties are kept informed of what's going on, and have an opportunity to discuss the issues.

When acid rain research started gathering momentum in the UK in the early 1980s, *The Royal Society* hosted a famous meeting sponsored by the CEGB - not on "acid rain" - the phrase was far too emotive in Britain at that time - but on the *Ecological effect of deposited sulphur and nitrogen compounds*.

However, the focus was almost entirely on sulphur, then, and for the next 10 years. Despite nitrogen emissions contributing 30% or so to acid deposition, we believed that N was retained quite effectively in naturally N limited terrestrial ecosystems, and that freshwater ecosystems were only threatened by sulphur.

Indeed this was probably the case, but there is good evidence now that some upland catchments are saturated by N and others are becoming saturated.

This first became clear following our initial 'critical loads' research. In this project, we sampled the most sensitive lake or headwater stream in each 10 km grid square in the UK. A by-product of this survey was a water chemistry map for the UK.

For nitrate, and for the country as a whole, the sites with high concentrations were located mainly in the lowlands, related to areas with intensive agriculture.

However, when these sites were removed by including only sites sensitive to acidification (i.e. those with low base cation concentrations), the nitrate map

showed a different distribution, with sites with high values (up to  $50 \mu\text{eq l}^{-1}$ ) found in the uplands of England, Wales and south-west Scotland. In the absence of agricultural sources in these largely moorland regions, these high values could only be the result of N deposition. The expected natural background is close to zero and certainly less than  $5 \mu\text{eq l}^{-1}$ .

Following these observations we have in the last 3 years been focusing much of our DoE/DETR work on nitrogen, looking at seasonal patterns in nitrate concentrations at sites in the Acid Waters Monitoring Network (AWMN) and at sites in a specially selected series of catchments across Britain that spans a gradient of N deposition from low values in the north of Scotland to very high values in northern England.

The results confirm the view that N is leaking from catchment soils in areas of high N deposition, seasonally (in the winter) at some sites (e.g. in south-west Scotland), and throughout the year at others, especially in the Pennines.

The problem now is understanding the nitrogen dynamics in these and other catchments, sufficiently well to model accurately the timing and extent of nitrogen saturation and nitrate leaching.

Current model outputs suggest that many catchments should already be saturated. However, we must now determine whether catchments can immobilise and / or denitrify N compounds more effectively than we currently believe, or whether we can expect major substantial increases in nitrate leaching in the near future.

Only when these issues are more fully understood can we then assess what optimum combination of sulphur and nitrogen reductions are needed at

individual sites if recovery targets are to be met.

## Acid deposition monitoring in the UK

Glenn Campbell & Keith Vincent

National Environmental Technology Centre, E1 Culham Laboratory, Abingdon, UK. OX14 3DB.

### Abstract

The four reports of the Review Group on Acid Rain, the latest of which is available from the DETR, summarise UK monitoring of acidifying pollutants since 1973. In 1986, the then Department of the Environment established a national acid deposition monitoring network of 59 sites. This was reduced to 32 sites in 1989. Wet deposition is monitored at all the sites. Concentrations of gaseous and particulate species are monitored at a subset of sites.

Precipitation-weighted mean concentrations of sulphate and nitrate in rainfall can be mapped using these data. Concentrations of both species in precipitation are correlated in both time and space. Events of polluted rainfall tend to show elevated concentrations of all anthropogenic species. Concentrations are smaller in the north and west, since much of the rainfall in these regions is associated with Atlantic airflow and air masses that have not passed over the main sources of UK and European emissions. In the east, concentrations are elevated both because the rainfall volume is generally smaller, and because the air mass origin is more polluted.

The concentrations of sulphate in precipitation has fallen over the whole of the UK since 1978. The decrease is most marked in eastern England where the precipitation-weighted mean concentrations has fallen from 100 to 120  $\mu\text{eq l}^{-1}$  to 60 to 70  $\mu\text{eq l}^{-1}$ . In more sensitive upland areas, the decline is less marked. There is little

change in nitrate and ammonium concentrations and the S:N ratio in precipitation has therefore markedly declined.

Measurements have taken place at Eskdalemuir since the 1950s and to modern protocols since 1973. There are more data on sulphur species than nitrogen:

- daily sulphate in precipitation, sulphur dioxide concentration and particulate sulphate concentration 1973 -
- daily nitrate and ammonium in precipitation 1979 -
- monthly nitrogen dioxide concentration 1987 -
- daily nitric acid + particulate nitrate concentrations 1989 -
- daily ammonia + particulate ammonium concentration 1989 -
- monthly ammonia concentration 1996-

The availability of daily data allowed a sector analysis to be carried out. Back trajectories kindly supplied by the Norwegian Meteorological Institute were used. These show marked reductions in concentrations of sulphur species in air and precipitation, associated with flow from all sectors. The shorter time series of nitrate and ammonium in air showed no significant trend.

## Modelling future N deposition in the U.K. using 'HARM'

Sarah Metcalfe<sup>(1)</sup> and J. Duncan Whyatt<sup>(2)</sup>

<sup>(1)</sup> Department of Geography, University of Edinburgh, Edinburgh EH8 9XP

<sup>(2)</sup> Department of Geography, University of Hull, Hull HU6 7RX

### Abstract

Although the focus of this presentation is modelled changes in N deposition across the UK in response to a range of possible emissions scenarios, it must be remembered that atmospheric N comes from a wide range of sources and has a wide range of effects, including those on human health. Based on deposition data for 1992 - 1994 from the RGAR (1997), in terms of  $H^+$ , total N deposition exceeded S deposition across much of the UK, with  $NH_x$  contributing more than  $NO_y$ . A similar situation prevails over much of north-west Europe. While emissions of  $SO_2$  have fallen sharply over the last twenty years,  $NO_x$  emissions have been much more stable with only a gradual decline in both the UK and across Europe since 1990. Policies with respect to future  $NO_x$  emissions are being developed within 2 fora: the UNECE and the European Commission. These two institutions are developing policy within different frameworks: the multi-pollutant, multi-effect approach of the UNECE 2nd  $NO_x$  protocol and the Acidification strategy of the EC. A range of possible emissions targets have been suggested: CRP (current reduction plans) and REF (reference)

within UNECE and B1 (or STRAT) by the EC. The effects if these proposals on UK emissions are summarised over, in Table 1.

Modelling the transformation, transport and removal of atmospheric nitrogen is more complex than for S, given the nature of the sources, the complex chemistry, and elements of non-linearity as pollutants interact. Here we use the recently developed 10 km version of the HARM model to explore the possible effects of reductions in emission of  $SO_2$ ,  $NO_x$  and  $NH_3$  on future N deposition. Under both the CRP and REF scenarios, the apparent decline in reduced N deposition is far greater than the reduction in emission and may be attributed to the effects of continuing major cuts in  $SO_2$  emissions.

Through these scenarios, the areas of Britain where N deposition predominates increase. The B1 scenario yields a 55% decrease in total N deposition to the UK compared with 1994 (modelled). High wet depositions remain in some upland areas and the general pattern of high dry deposition over central and eastern England is very resilient. Although N deposition dominates acidic deposition over most of Britain under the B1 scenario, the implications of this for emission reductions to achieve ecosystem protection depend upon the ecosystem of interest and the format of the critical load function being applied. The emissions reductions being suggested by the EC are significant, but appear to be of the order required to meet other environmental targets such as air quality guidelines for  $NO_2$  and  $O_3$ .

Table 1: Summary of modelled changes in N deposition:

	<b>% change UK NO<sub>x</sub> emission</b>	<b>Deposited NO<sub>y</sub>-N in k tonnes</b>	<b>Deposition as % of 1994</b>	<b>% change UK NH<sub>3</sub> emission</b>	<b>Deposited NH<sub>x</sub>-N in k tonnes</b>	<b>Deposition as % of 1994</b>
<b>1994</b>		150.3			67.7	
<b>CRP</b>	-44	103.4	69	0	53.4	79
<b>REF</b>	-44	89.8	60	0	49.7	73
<b>B1</b>	-64	67.5	45	-30	32.3	48

**An empirical method of predicting nitrate leaching from upland catchments in the United Kingdom using deposition and runoff chemistry.**

**Ron Harriman**

**Freshwater Fisheries Laboratory,  
Pitlochry, Perthshire, Scotland. PH16  
5LB, UK.**

**Abstract**

The signing of the European sulphur protocol in June 1994 committed the United Kingdom government to a 70 % reduction in sulphur emissions by the year 2005. Since then there has been mounting concern that the perceived improvements to ecosystems will not be achieved because of nitrate leaching resulting from nitrogen emissions. Most European studies of nitrogen cycling have concentrated on the effects of nitrogen additions or exclusions to forest plots or small forest catchments, e.g. the NITREX project, but this requires detailed information on soil and vegetation status, thus making it difficult to develop a regional assessment which would include both forest and non-forested catchments.

Therefore, to provide a UK assessment of the potential effects of increasing N deposition, the freshwater group of the DoE Critical Loads Advisory Committee (CLAG) set up a nitrogen network (NGS) of 13 sites along an N-deposition gradient of 12-50 kg.ha<sup>-1</sup> y<sup>-1</sup> to determine the key catchment characteristics which influence nitrogen status and nitrate leaching. Five large lochs with multiple sub-catchments (LLS) were later added to the network. The aim was to evaluate the potential for using water chemistry from catchment outputs as a cheap and simple method of predicting N-leaching on a regional basis.

A preliminary evaluation of the data showed little relationship between N-deposition and mean nitrate leaching, but a negative correlation was found between nitrate leaching and mean C:N ratios and dissolved organic carbon (DOC) in runoff. Nitrate leaching was well predicted in each catchment using a deposition function which incorporated DOC flux and, when combined with C:N ratios in runoff, provided an empirical assessment of the N-status of catchments.

Nitrate leaching from the LLS sites was successfully predicted apart from mature forest sub-catchments which were predicted to have lower nitrate leaching than measured values.

If N-assimilation in catchments is a 'capacity' effect, regulated by carbon supply, then many upland catchments in the UK may experience increased nitrate leaching in the future at current levels of N-deposition.



## Nitrate leaching in Welsh upland catchments

Brian Reynolds

Institute of Terrestrial Ecology, Bangor Research Unit, UWB, Deiniol Road, Bangor Gwynedd, LL57 2UP.

### Abstract

Factors controlling  $\text{NO}_3$  leaching in Welsh upland catchments have been investigated using data from the 1995 Welsh Acid Waters Survey (WAWS) and results from the NITREX nitrogen manipulation experiment. The former involved monthly sampling of stream-water for one year at 102 upland catchments located in the acid-sensitive parts of Wales. A set of catchment attributes was also compiled for each site. Atmospheric N deposition to Wales during 1995 was modelled using data from a network of 21 bulk deposition collectors supplemented by UK national data on  $\text{NH}_3$  and  $\text{NO}_x$ . The NITREX study comprised 7 ecosystem scale nitrogen manipulation experiments in mainly forested sites across Europe. Manipulations included both addition and removal of N at sites experiencing atmospheric N deposition ranging from 13 to 59  $\text{kg N ha}^{-1} \text{yr}^{-1}$ .

The WAWS data show that the acid-sensitive upland regions of Wales are receiving relatively large inorganic-N inputs in the order of 20-25  $\text{kg N ha}^{-1} \text{yr}^{-1}$ . Long-term monitoring data from Beddgelert Forest show that non-seasalt  $\text{SO}_4$  deposition has declined since 1984, whilst  $\text{NO}_3$  inputs have remained approximately constant. Thus,  $\text{SO}_4 / \text{NO}_3$  ratios have halved, from 3 in 1984 to 1.5 in 1995, indicating that  $\text{NO}_3$  has become an increasingly important component of acid precipitation.

A subset of 91 WAWS sites with winter hardness values less than 20  $\text{mg l}^{-1} \text{CaCO}_3$  was selected for analysis. These catchments are varied in relation to topography, area, altitude and land-use, including extent of conifer cover and amounts of land improvement. Despite this, however,  $\text{NO}_3$  concentrations were significantly larger in streams containing conifer forest (0.16  $\text{mg N l}^{-1}$ ) compared to those without conifers (0.09  $\text{mg N l}^{-1}$ ). The contrast between winter and summer means was also larger in the forested catchments. Within the forest catchments there was a broad increase in  $\text{NO}_3$  concentration with both forest age and percentage forest cover. Simple linear regression, between log  $\text{NO}_3$  and these attributes, explained 35-40 % of the variance in the log  $\text{NO}_3$  concentration data, although there was considerable scatter in both relationships. Some of this scatter could be explained in terms of other attributes, such as the extent of agricultural improvement within the catchments (defined from the ITE Landcover map) and the amount of peat. For the moorland catchments,  $\text{NO}_3$  concentrations increased with areal extent of improved land. In both moorland and forest catchments,  $\text{NO}_3$  concentrations were low in catchments with extensive areas of peat, but much more variable in catchments with no peat cover. A possible confounding factor is that areas of land improvement and forestry also decline in the peat dominated catchments.

The results from the NITREX study show that, for forest sites, the  $\text{NO}_3$  leaching response to increasing N deposition is determined by the site N status. Thus, at the N-poor Gårdsjön site in Sweden (forest floor C/N ratio = 32), the leaching response to added N was minimal compared to that at Aber in the UK (forest floor C/N = 22) where there was a large and immediate increase in  $\text{NO}_3$  leaching. Site N status appears to reflect historical N deposition, site management and soil factors. At Aber,

relative to the control plot, there was a sustained decrease in soil solution ANC of c.  $-70 \mu\text{eq l}^{-1}$  in response to the increase in  $\text{NO}_3$  leaching following addition of  $35 \text{ kg N ha}^{-1} \text{ yr}^{-1}$  as ammonium nitrate. A simple two-component mixing model applied to a hypothetical catchment comprising 50% 'Aber forest' and 50% unimproved acid grassland (assumed not to respond to N additions), predicts that stream water ANC under stormflow conditions will decline from  $-61 \mu\text{eq l}^{-1}$  under ambient N deposition to  $-86 \mu\text{eq l}^{-1}$  following addition of a further  $35 \text{ kg N ha}^{-1} \text{ yr}^{-1}$  of ammonium nitrate.

In conclusion, the studies have shown that land management is a major factor influencing nitrate leaching in upland catchments, and must be incorporated into any predictions of stream-water  $\text{NO}_3$  response to increased N deposition. For conifer forests, the current site N status provides a basis for predicting the  $\text{NO}_3$  leaching response to increased N deposition. Where increased N deposition leads to enhanced  $\text{NO}_3$  leaching, soil and stream-waters become acidified.

#### **Acknowledgements**

The WAWS and NITREX projects involved large teams of scientists from a number of universities and institutes, and their contributions are gratefully acknowledged. From amongst the teams, particular thanks are due to Bridget Emmett and Paul Stevens of ITE Bangor and Steve Ormerod of UWCC. The WAWS study was funded by the Welsh Office, the Environment Agency, the Forestry Authority, the Countryside Council for Wales and NERC. The UK component of NITREX was funded by the National Power / Powergen Joint Environment Programme, the European Union, the DETR and NERC.

## The use of the First-Order Acidity Balance model (FAB) for the prediction of nitrate leaching and calculation of critical loads for total acidity in Great Britain.

C.J. Curtis<sup>1</sup>, T.E.H. Allott<sup>1</sup>, M. Kernan<sup>1</sup>, D. Bird<sup>1</sup>, B. Reynolds<sup>2</sup>, R. Harriman<sup>3</sup> & J. Hall<sup>4</sup>

<sup>1</sup>Environmental Change Research Centre, University College London, 26 Bedford Way, London, WC1H 0AP, UK.

<sup>2</sup>Institute of Terrestrial Ecology, Bangor Research Unit, Deiniol Road, Bangor, Gwynedd, LL57 2UP, UK.

<sup>3</sup>Freshwater Fisheries Laboratory, Faskally, Pitlochry, Perthshire, PH16 5LB, UK.

<sup>4</sup>Institute of Terrestrial Ecology, Monks Wood, Abbots Ripton, Huntingdon, PE17 2LS, UK.

### Abstract

The relative contribution of nitrogen deposition to the acidification of freshwaters in Great Britain has increased over the last few years as sulphur deposition has fallen in line with reduced emissions, while N deposition has remained relatively constant or even increased slightly in some areas. Lake-water chemistry data from a network of sites across Great Britain has shown that in high deposition areas (e.g. North Wales, Lake District) nitrate based acidity can approach the levels of sulphate based acidity on a seasonal basis, especially during the spring. At one site in Snowdonia, Llyn Nadroedd, nitrate concentrations can exceed those of sulphate (CLAG Freshwaters, unpublished data). The need for the incorporation of N into models of critical loads of acidity for fresh waters is therefore evident. Such models are currently being tested for the production of national critical load maps to be submitted for use in international negotiations on transboundary pollution.

Given the dynamic nature of N cycling processes in catchments, it is not sufficient to assume that long-term, steady-state conditions apply or that existing empirical models of critical loads, for example the Steady-State Water Chemistry Model (Henriksen *et al.*, 1992) and diatom model (Battarbee *et al.*, 1996) are adequate. Although these models have been adapted for the calculation of critical load exceedance under current N deposition loads by the inclusion of current measured nitrate leaching data (Harriman *et al.*, 1995; Allott *et al.*, 1995), they cannot be used for testing different scenarios under predicted, or proposed, changes in N deposition. The complexity of catchment processes which affect the retention or leaching of nitrogen species is such that only very detailed dynamic models (e.g. MAGIC-WAND, Ferrier *et al.*, 1995) can predict the timing and magnitude of nitrate breakthrough. Such models cannot be easily applied for national scale mapping however, because of the huge data requirements in order to calibrate and run them. A compromise can be provided by incorporating the major nitrogen sinks into the steady-state models in order to predict future nitrate leaching when N inputs are in steady state with sinks and outputs.

The first-order acidity balance model (FAB) is a simple process-oriented model which can be applied to predict the maximum nitrogen leaching from a catchment at steady state, and hence can be used to construct a critical load exceedance function for sulphur and nitrogen deposition for a site (Posch *et al.*, 1997). The FAB model has been applied in several European countries, and has been modified for national mapping of critical loads across Great Britain. Application of the model requires catchment soils and land cover data, in addition to the water chemistry and deposition data used in the empirical models. In Great Britain, these have been obtained by overlaying digitized catchment outlines (derived from O.S. 1:25,000 maps) onto national soils (1:250,000) and landcover

(25m pixel resolution) maps. The FAB model incorporates the major N sink processes in order to predict maximum N leaching. It is assumed that the major net sinks, for N which can operate sustainably over the long-term are:

- 1) N uptake and removal in harvested or grazed vegetation - usually forest
- 2) N immobilisation in catchment soils
- 3) denitrification losses of N from waterlogged catchment soils
- 4) in-lake retention of N.

Preliminary runs of the FAB model at a small network of 13 sites have used recommended default values for terrestrial N sink terms (Hall *et al.*, 1997). These sites are all unafforested, so it is assumed that N removal in vegetation is negligible, although there is some extensive sheep grazing which may account for minor net losses of N from the catchments. Comparison of lake inflow and outflow chemistry has shown that there appears to be little in-lake retention of N at these sites. The major modelled N sinks are therefore N immobilisation and denitrification. Literature default values for these parameters vary, but for the UK are given as 1-3 kg N ha<sup>-1</sup> yr<sup>-1</sup> for immobilisation and 1-4 kg N ha<sup>-1</sup> yr<sup>-1</sup> for denitrification (Hall *et al.*, 1997). Using default values from within these ranges for British soils, the FAB model predicts nitrate leaching at much higher rates than are currently being measured in surface waters. On a national basis, the model shows that reductions in S emissions will have no beneficial effects, in terms of achieving non-exceedance of critical loads, for large parts of the country where N leaching alone could cause critical load exceedance.

While the predictions of severe N leaching across the country are not borne out by current observations in all areas, it does appear that nitrate leaching has become a major problem in certain regions. Two possible explanations are proposed for the discrepancy between observed and predicted

nitrate leaching. The first possibility is that the FAB model overlooks other processes affecting the catchment N budget, for example N retention in riparian wetland zones or streams, enhanced riparian denitrification and losses to groundwater. A second explanation is that the model has correctly identified the major N sink processes, but that the literature default values are too low. There is some evidence that over the short term, very high rates of both immobilisation and denitrification are possible, and this would account for the current levels of nitrate leaching being lower than model predictions which use *sustainable* rates. However, it is the long-term steady-state situation which is relevant to the definition of critical loads, and it is not known whether current elevated rates of immobilisation or denitrification are sustainable.

The national application of the FAB model in Great Britain demonstrates the need for further research on the rates at which N can be sustainably removed from, or immobilised in, catchment soils. The current predictions of increased nitrate leaching, if accurate, indicate that prospects for the recovery of freshwaters under declining S deposition will be severely reduced, and the implications for national emissions policy would be significant. It is therefore vital that the long term sinks for N in catchments are identified and that reliable figures are obtained for the relevant processes at steady-state.

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## Reduction requirements for Nitrogen and Sulphur deposition to Norwegian lakes

Arne Henriksen

Norwegian Institute for Water Research,  
Pb. 173 Kjelsås,  
0411 Oslo, Norway

### Abstract

Both sulphur and nitrogen can contribute to the acidification of soils and surface waters, and thus the critical loads of S and N are interrelated. The First-Order Acidity Balance (FAB) model allows for the simultaneous calculation of critical loads of acidifying N and S deposition and their exceedances, and can make predictions of effects of both S and N deposition scenarios. This model has been applied to the data from a regional 1000-lake survey carried out in Norway in the autumn of 1995. The lakes were selected statistically to express the properties of the total Norwegian lake population > 4 ha. (38.000 lakes). Today, with present N-leaching, 29% of the lakes (11.000 lakes) are exceeded, while 44% percent are exceeded at maximum N-leaching (16.700 lakes). In the year 2010 (the scenario of the Second Sulphur Protocol) the number of exceeded lakes will be reduced to 6.800 lakes at present N-leaching, while 13.000 lakes will be exceeded at maximum N-leaching. Today, 50% of the *exceeded* lakes require both N and S reductions; for 31% of these lakes we can chose between S and N reduction. Only 12% of the lakes will reach non-exceedance with S-reduction only, indicating the strong potential threat of N-deposition to the critical load exceedance of Norwegian lakes. After the Second Sulphur Protocol has been implemented, only 3% of the lakes will reach non-exceedance with further reductions of S-deposition, for 24% we can chose between

S- and N-deposition reduction. This implies that for about a quarter of our lakes we can reach non-exceedance by S-reduction only, while for the remaining three quarters of our lakes, reductions in N-deposition are required to reach non-exceedance. This shows the great importance of knowing whether the nitrogen leaching will increase in the future with current high N-deposition levels.

## Modelling nitrogen in surface waters

Alan Jenkins<sup>(1)</sup> & Bob Ferrier<sup>(2)</sup>

<sup>(1)</sup>Institute of Hydrology, Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire, OX10 8BB.

<sup>(2)</sup>MLURI, Craigiebuckler, Aberdeen, AB9 2QJ.

### Abstract

A dynamic model (MAGIC-WAND), capable of predicting the timing and magnitude of NO<sub>3</sub> leaching from catchments, has been formulated. The model builds on the sulphur based MAGIC model to provide a tool for assessing scenarios of future coupled sulphur and nitrogen deposition.

The model is based upon a simplification of the current understanding of N cycling in non-agricultural ecosystems and utilises three main processes to describe NO<sub>3</sub> leaching to surface waters:

- (i) uptake of N into vegetation
- (ii) immobilisation of N into the soil
- (iii) deposition of N (past, present and future)

Over and above the data requirements of the MAGIC model, MAGIC-WAND requires:

- specification of the changes in soil C pool through time
- specification of total N flux through time
- specification of the relationship between soil C and N pool and the proportion of N leached

Data to parameterise the model can be derived from experiment and from field sampling / observation.

Preliminary applications of the model to sites in the UK AWMN indicate that:

- future N breakthrough will offset the anticipated recovery in response to S reduction at UK sites
- the timing and magnitude of N breakthrough will vary in space and time across the UK.

Further process understanding may well be necessary to represent the N dynamics of non-forested catchments.

## **Defining and mapping critical loads for abatement strategies**

**Keith Bull**

**Monkswood Experimental Station,  
Institute of Terrestrial Ecology, Abbots  
Ripton, Huntingdon, Cambridgeshire.**

### **Abstract**

While it has become traditional to map critical loads to provide the information for developing abatement strategies, the mapping itself should reflect the science and use to which maps are put. Thus, the scale of critical loads maps is often determined by that of the available pollution data which usually necessitates summarising the critical loads data in an appropriate way. For the Oslo (sulphur) Protocol various simplifications, such as the sulphur fraction and gap closure, were also introduced to provide a practical tool for integrated assessment (IA) modelling. For the current Nitrogen Protocol discussions, consideration of several pollutants and other effects further complicate the IA modelling requirements.

There are no simple solutions to considering exceedances of critical loads in such an approach. It is not even known if it is more sensible to identify the magnitude of an exceedance or the excess in relation to the critical load value itself; could the latter be considered a suitable 'damage function' for assessing exceedance? While the so called critical loads function does provide a means for considering exceedances of sulphur and nitrogen simultaneously, even for this there are different ways that exceedances might be identified, especially when data have to be summarized for many ecosystems within a grid area. Because it will not be possible to achieve critical loads in the immediate future, there will still be a need to consider

gap closure approaches, though these are more complex for a multi-pollutant, multi-effect protocol.

Nevertheless, as abatement of emissions is increased and lower critical loads are met, there is an increasing need to be certain of our lower critical loads estimates, and the science that underpins them, to ensure that the higher sums of money involved are spent effectively.



## Closing Remarks

**John Murlis**

**Jackson Environment Institute, 5 Gower Street, University College London, London.**

### Abstract

It is often being said that environmental problems are never anticipated, but that society deals with them one at a time as their impacts are felt. On the basis of evidence presented today we have an opportunity to do better than this, and to take action now to avert damage from a potential threat to our environment.

Today, evidence was presented that, in at least some sensitive upland catchments, nitrogen breakthrough is occurring and that the resultant nitrate levels reflect the pattern of nitrogen deposition as it increases from north to south. Measurements from the nitrogen gradient network show that, in some catchments, nitrogen is breaking through during the winter and that in some extreme cases, there is year round nitrogen breakthrough. This is clear evidence that deposition loads are beginning to exceed the capacity of eco-systems to retain nitrogen and that we are therefore on the brink of a major nitrate problem in the United Kingdom.

Clearly there is much to be done to substantiate this evidence and to understand the mechanisms at work. We do not start from a blank piece of paper, however. The papers we have heard today represent a tremendous advance on work reported at the meeting held on environmental acidification at UCL in 1994 (Battarbee, R.W. (ed.) 1995) and on the work reported by the ITE in 1992 (Hornung & Skeffington (eds.) 1993). The considerable progress in monitoring

systems reported by Glen Campbell and particularly, the very welcome denuder network for ammonium has provided us considerably better understanding of ambient levels both of oxidised and reduced nitrogen in the UK. David Fowler reported how these data have been used to provide budgets for deposition of sulphur and nitrogen and how they have been used to validate procedures for orographic enhancement of deposition data.

The role of nitrogen species, and in particular of reduced nitrogen, now appears to be crucial to the understanding of environmental acidification. Yet there appears to be a mis-match between estimates of ammonia deposition and emission estimates amounting to some 100 kilotons.

Sarah Metcalfe showed the developments in deposition modelling using the HARM model and showed how vital this will be for policy makers examining impacts of different future emission scenarios.

The importance of land management as a determinant of nitrate leaching was demonstrated both by Brian Reynolds and Ron Harriman and, here again, the advances in the last four years are dramatic. It seems that we are now beginning to understand the forces behind these impacts and in particular the vital role carbon sequestration is expected to play in the future.

Work on lakes within the catchments in the nitrogen gradient network by Martin Kernan showed the importance of characterising catchments accurately and understanding the small scale variability which occurs between lakes even in the same catchment. Chris Curtis described advances in modelling critical loads and showed how important it is in making assessments to move from steady state to

mass balance models. Arne Henriksen demonstrated the value of the new understanding of nitrogen critical loads in an assessment of the scale of further emission reductions required. He showed that, in the case of Norway, much more now needs to be done to reduce nitrogen emissions following the expected gains from the second sulphur protocol.

Alan Jenkins work in modelling nitrogen has developed, so that using newly-quantified dynamic processes, it is possible to follow, in greater detail, the long term changes of acid balance in water bodies. Using the model to predict how the balance will adapt to changes in deposition, it is possible to estimate the impacts of future emissions policy. The new models prove less optimistic in their assessment of the future for many catchments and clearly policy makers will wish to reconsider emission reduction plans in the light of these new results.

Keith Bull showed how the improved understanding of the respective roles of sulphur and nitrogen in environmental acidification has been incorporated into policy analysis tools. In 1992, the combined critical loads function appeared purely as a schematic diagram. It is now possible to quantify it, putting numbers to the disposition axes of the function. This is now a powerful tool in determining where further action on sulphur, or on nitrogen, or both will be required. The map of these areas shows how complex the future will be for policy development.

Policy response to these environmental pressures was outlined by John Rea and, he made it clear that policy beyond current reduction plans will be difficult to achieve. In particular, he suggested that it would be unlikely for the UK, in company with other European nations to meet the proposals from the European Commission to

implement their proposed future European Acidification Strategy.

The final impression from this meeting is that in order to make progress, policy will have to be more carefully targeted and the need for action beyond current reduction plans will need to be fully substantiated. In particular, it now seems crucial to understand the mechanisms involved in retaining nitrogen in catchments. On present evidence, it seems that retention exceeds what can reasonably be expected according to current understanding of biological processes. It is important to determine the validity of this observation and, if it turns out to be true, what processes are responsible. This will make it possible to determine how these catchments might behave in the future, and in particular, how best to characterise the horizon beyond which significant breakthrough will occur. For the assessment of policy over a wider geographic scale it will be essential to have a far better understanding of sources and sinks of ammonia. Firstly, to ensure that what is an apparent missing source of ammonia is identified and then to understand the geographically small scale mechanisms of emission and deposition in ammonia cycling. This will involve work at the scale of hundreds of metres as opposed to tens of kilometres, and will be demanding. There is also scope for incorporating the new understanding of orographic enhancement and its role in sulphate deposition into the critical loads mapping programme.

What was particularly important though about the days proceedings, was that it represented the effort of a broad community of research workers drawn from a wide range of Institutions supported over significant time periods, starting with funding from the DETR Atmospheric Pollution Effects Programme, but with

significant contributions from the Research Councils. The sense of community seems particularly valuable today where the next stage of research will require close co-operation between Geographers, Chemists, Biologists and Geologists with their counter-parts in DETR and the Research Councils.

It is important to maintain momentum particularly with the development of the nitrogen gradient network. This might be used to form the backbone of a programme to understand nitrogen retention. It would be possible, for example, to identify a number of marginal catchments, spanning the range from those where breakthrough is beginning to appear in winter, to those where it is appearing in small quantities throughout the year. A detailed study of such catchments, with full instrumentation to capture flows through essential pathways, should be made. This could be supported by a well targeted supplement to the existing umbrella contracts and it is greatly hoped that DETR will now consider this. At the same time, the message needs to go to the Research Councils that this work is of strategic importance to the UK and should be considered, perhaps within a further stage of the environmental diagnostics programme, as a priority.

**Battarbee, R.W. (ed.) 1995.** *Acid rain and it's impact: the critical loads debate.* London: Ensis Publishing.

**Hornung, M. & Skeffington, R.A. (eds.) 1993.** *Critical Loads: concepts and applications.* ITE Symposium No. 28, London: HMSO.