The Distribution of Nitrate in the UK Surface Water and its Implication for Calculating Critical Loads: A Preliminary Assessment


A Report for the DoE from the Critical Loads Advisory Group, Freshwaters Sub-Group

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Environmental Change Research Centre
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THE DISTRIBUTION OF NITRATE IN UK SURFACE WATERS AND ITS IMPLICATION FOR CALCULATING CRITICAL LOADS: A PRELIMINARY ASSESSMENT.

Report for the Department of the Environment from the Critical Loads Advisory Group, Freshwaters sub-group.

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Table of Contents

1 Introduction 1
2 Methods 1
3 Results 1
4 Discussion 2
5 References 12

List of Figures

1 Distribution of nitrate values in surface waters 3
2 Distribution of nitrate values in 'sensitive' (Ca++ <200 μeq l⁻¹) surface waters 4
3 Distribution of nitrate values in surface waters where the critical load for S is exceeded (diatom model) 5
4 Nitrate as a proportion of nitrate & excess sulphate against critical load exceedance (diatom model) 6
5 Distribution of nitrate values as a proportion of nitrate & excess sulphate where critical load for S is exceeded (diatom model) 7
6 Magic model scenario for the Round Loch of Glenhead showing effect on critical loads for sulphur of a reduction in nitrate uptake 8

List of Tables

1 List of sites sampled (grid reference plus name) with nitrate >10% of nitrate plus excess sulphate where critical load (diatom model) is exceeded (see categories >0.1 in Figure 4). 9
1. Introduction

Although increased nitrogen deposition is likely to have most serious consequences for soils and vegetation in the United Kingdom, surface waters are also affected, especially in areas of very high N deposition and where uptake by vegetation is reduced. In these areas high nitrate levels contribute significantly to lake acidity and may independently cause changes to the structure of aquatic communities.

2. Methods

As a preliminary assessment of this problem we have used the water chemistry data for UK surface waters being collected for sulphur (S) critical loads (CLAG 1992). So far data are available for Scotland, Wales and parts of England and Northern Ireland. A complete dataset should be available later in 1992.

3. Results

Figure 1 shows surface water nitrate distribution based on a single water sample from either a standing water or headwater stream in each 10 km grid square sampled. Values range from >200 μeq NO₃⁻ l⁻¹ to <5 μeq l⁻¹. The most striking patterns are the very low levels of nitrate across most of Scotland north of the central lowlands, with the exception of the Angus area, and the higher values to the south. The low values (<5 μeq l⁻¹) are in good agreement with the recent decision at the Løkkeborg meeting to fix background nitrate values at <4 μeq l⁻¹) (Kämäri et al. 1992). The higher values are a combination of catchment and atmospheric sources of N because these data do not differentiate between lowland sites, with agricultural catchments, and upland sites, sensitive to acid deposition, with moorland and afforested catchments.

Figure 2 shows the distribution of nitrate values after the removal of non-sensitive sites, conservatively taken here as sites with >200 μeq Ca²⁺ l⁻¹. The values now range from >30 μeq l⁻¹ down to <5 μeq l⁻¹. On this map only a few sites with relatively high nitrate values remain in Scotland, and these are principally in the Galloway region. Many more sites occur further south in Cumbria, the Pennines, north, central and south-west Wales.

Although it is probable that the nitrate at these sites is predominantly derived from atmospheric sources the main concern about nitrate is its influence at acidified sites. Figure 3, consequently, shows surface water nitrate distribution at sites where the critical load for sulphur is exceeded, according to the diatom model (CLAG 1992). The Henriksen model (CLAG 1992) exceedance plot would be similar, but with somewhat fewer sites. The general distribution of values is not unlike that in Figure 2 except that there are more sites in the Pennines and less in south-west Wales, illustrating the difference in S deposition between those two regions. It is clear in the majority of cases that high nitrate occurs where high excess sulphate also occurs.

In Figure 4 the relative importance of nitrate to the strong acid anion total is shown for all the exceedance sites. This is an indication of the extent to which nitrate levels might interfere with the successful reduction of acidity based on sulphur abatement. Again the values are for the diatom model with exceedance for sulphur plotted against the ratio of nitrate to nitrate
plus excess sulphate. Typically nitrate contributes less than 25% to the total acid anion concentration, but 37 squares have values over 20%.

The geographical distribution of sites plotted in Figure 4 is shown in Figure 5, and these are listed in order of relative importance in Table 1. There is a scatter throughout the country but some of the highest values occur in Cumbria and north Wales.

4. Discussion

Although some of these data are provisional and the map for the whole UK has not yet been completed, the data so far support the view that nitrate values in sensitive upland waters, where the main N sources are atmospheric, are well above background levels for many parts of the country. In some cases, they constitute an important fraction of the total acidity.

These observations have both indirect and direct consequences for critical loads research. At some sites an achievement of critical loads for sulphur by the year 2005 may not be possible without a complementary reduction in nitrogen deposition. Moreover as S deposition declines the relative importance of N as a cause of acidity will increase. If the net retention of nitrate within the catchment decreases, the critical load for sulphur will be further decreased, as indicated by the MAGIC model scenario for the Round Loch of Glenhead in Figure 6. Moreover future climate warming might increase the rate of organic nitrogen mineralisation and so decrease the relative net retention of N in catchments, thereby accelerating this process.

The data also suggest that nitrate concentrations in some upland waters may be sufficiently elevated to cause changes to the structure of aquatic ecosystems, not only in contributing to high H⁺ and Al³⁺ (especially from mature forest catchments) but also in altering the nutrient balance between nitrate and phosphate. In P limited systems it is unlikely that additional N will cause any major increase in primary productivity but the shift in nutrient ratios might well alter the composition of some communities.

In view of these conclusions we consider it important:

- to incorporate nitrogen in our calculations of critical loads for acidity (already recommended at the recent Løkeborg conference),
- to develop further the MAGIC model to incorporate explicitly nitrogen processes within the catchment and to cater for projected changes in N deposition,
- to measure total P levels at selected sites to assess the likely impact of elevated nitrate levels on primary productivity,
- to evaluate the need to measure reduced forms of N in upland waters, in the context of expected future increases,
- to carry out exploratory studies of the biology of high nitrate streams and lakes in selected regions of the country to assess the impact of high nitrate concentrations on community structure.
Figure 1  Distribution of nitrate values in surface waters

- > 200 μeq l⁻¹
- 50 - 200 μeq l⁻¹
- 10 - 50 μeq l⁻¹
- < 10 μeq l⁻¹
- < 5 μeq l⁻¹
Figure 2  Distribution of nitrate values in 'sensitive' (Ca$^{++} < 200$ μeq l$^{-1}$) surface waters

- > 30 μeq l$^{-1}$
- 20 - 30 μeq l$^{-1}$
- 10 - 20 μeq l$^{-1}$
- 5 - 10 μeq l$^{-1}$
- < 5 μeq l$^{-1}$
Figure 3 Distribution of nitrate values in surface waters where the critical load for S is exceeded (diatom model)
Figure 4  Nitrate as a proportion of nitrate & excess sulphate against critical load exceedance (diatom model)
Figure 5  Distribution of nitrate values as a proportion of nitrate & excess sulphate where critical load for S is exceeded (diatom model)
Figure 6  Magic model scenario for the Round Loch of Glenhead showing effect on critical loads for sulphur of a reduction in nitrate uptake.
Table 1  List of sites sampled (grid reference plus name) with nitrate >10% of nitrate plus excess sulphate where critical load (diatom model) is exceeded (see categories >0.1 in Figure 4).

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5. References


RESEARCH PAPERS

1981-1991: Palaeoecology Research Unit

The influence of sanitary and other social changes on the eutrophication of Lough Erne since 1850: project introduction and a consideration of the potential role of metabolic wastes.

No. 2  Battarbee, R.W.  1983
Diatom analysis of River Thames foreshore deposits exposed during the excavation of a Roman waterfront site at Pudding Lane, London.

No. 3  Patrick, S.T. & Battarbee, R.W.  1983
Rural sanitation in the Lough Erne catchment: history and influence on phosphorus loadings.

No. 4  Patrick, S.T.  1983
The calculation of per capita phosphorus outputs from detergents in the Lough Erne catchments.

No. 5  Patrick, S.T.  1983
Phosphorus loss at sewage works in the Lough Erne region.

No. 6  Flower, R.J. & Battarbee, R.W.  1983
Acid lakes in the Galloway uplands, south west Scotland: catchments, water quality and sediment characteristics.

No. 7  Patrick, S.T.  1984
The influence of industry on phosphorus loadings in the Lough Erne region.

No. 8  Battarbee, R.W. & Flower, R.J.  1985
Palaeoecological evidence for the timing and causes of lake acidification in Galloway, south west Scotland.

No. 9  Raven, P.J.  1985
The use of aquatic macrophytes to assess water quality changes in some Galloway Lochs: an exploratory study.

No. 10  Anderson, N.J. & Battarbee, R.W.  1985
Loch Fleet: bathymetry and sediment distribution.

No. 11  Battarbee, R.W.  1985
Diatoms and acid lakes: proceedings of a workshop.

No. 12  Battarbee, R.W. & Renberg, I.  1985
Royal Society Surface Water Acidification Project (SWAP) palaeolimnology programme.
No. 13  Raven, P.J. 1986
Occurrence of *Sphagnum* moss in the sublittoral of several Galloway lochs, with particular reference to Loch Fleet.

No. 14  Flower, R.J., Rippey, B. & Tervet, D. 1986
34 Galloway lakes: bathymetries, water quality and diatoms.

No. 15  Flower, R.J. & Nicholson, A. 1986
Bathymetries, water quality and diatoms of lochs on the island of South Uist, the Outer Hebrides, Scotland.

Palaeoecological evaluation of the recent acidification of Welsh lakes. I, Llyn Hir, Dyfed.

Palaeolimnological evidence for the recent acidification of Loch Fleet, Galloway.

Palaeoecological evaluation of the recent acidification of Welsh lakes. II, Llyn Berwyn, Dyfed.

No. 19  Patrick, S.T. & Stevenson, A.C. 1986
Palaeoecological evaluation of the recent acidification of Welsh lakes. III, Llyn Conwy and Llyn GamalIt, Gwynedd (site descriptions, fishing and land use/management histories).

Palaeoecological evaluation of the recent acidification of Welsh lakes. IV, Llyn Gynon, Dyfed.

No. 21  Patrick, S.T. 1987
Palaeoecological evaluation of the recent acidification of Welsh lakes. V, The significance of land use and land management.

Palaeoecological evaluation of the recent acidification of Welsh lakes. VI, Llyn Dulyn, Gwynedd.


No. 28 Jones, V.J., Stevenson, A.C. & Battarbee, R.W. 1987 A palaeolimnological evaluation of peatland erosion. Report (First phase) to the NCC.


No. 31 Patrick, S.T., Flower, R.J., Appleby, P.G., Rippey, B., Stevenson, A.C., Cameron, N., Darley, J. and Battarbee, R.W. 1988
Palaeoecological evaluation of water quality change in Loch Urr, Galloway, Scotland.

Palaeoecological evaluation of the recent acidification of Loch Tanna, Arran, Scotland.

No. 33 Rose, N.L. 1989
A method for the extraction of carbonaceous particles from lake sediment.

Palaeoecological evaluation of the recent acidification of Lochnagar, Scotland.

No. 35 Rose, N.L. 1989
An extraction technique for mineral ash particles in lake sediment.

No. 36 Battarbee, R.W. 1989
The acidification of Scottish lochs and the derivation of critical sulphur loads from palaeolimnological data

No. 37 Flower, R.J., Patrick, S.T. & Munro, M.A.R. 1989
Surface sediment diatom assemblages and water quality in welsh lakes: brief descriptions of 33 sites selected for study

No. 38 Patrick, S.T. (Ed.) 1989
Lake acidification in the United Kingdom II: a preliminary report to the Department of the Environment under contract PECD 7/10/167

No. 39 Raven, P.J. 1989
Short-term changes in the aquatic macrophyte flora of Loch Fleet, S.W. Scotland, following catchment liming, with particular reference to sublittoral Sphagnum.

No. 40 Rose, N. & Battarbee, R.W. 1991
Fly-ash particles in lake sediments: extraction and characterisation
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Palaeoecological evaluation of the acidification status of lakes in the north-west and west of Ireland.

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