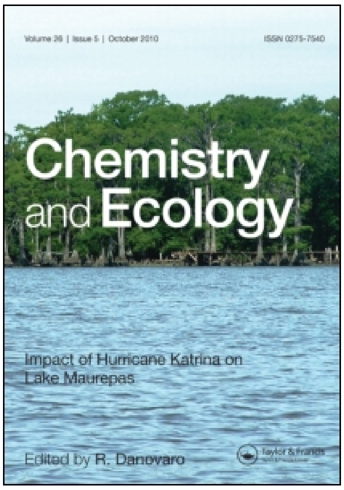

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NITRATE STATUS OF TWO MAJOR RIVERS IN N. E. SCOTLAND WITH RESPECT TO LAND USE AND FERTILISER ADDITIONS

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Land Use and the influence it has upon river water nitrate levels is discussed, for two large relatively unpopulated river systems in the N.E. of Scotland. The catchment areas for the rivers Dee and Don have been further subdivided into a number of sub catchments. Substantial differences in land use and agricultural potential exist both within and between the two areas. Greater agricultural production down stream is associated with increased river nitrate concentrations.

KEY WORDS Nitrate, rivers, land use

INTRODUCTION

There is considerable worldwide concern about increasing levels of nitrate-nitrogen (NO_3-N) in both river systems (ECETOC, 1988) and groundwater sources (Foster *et al.*, 1982). There appear to be strong links between these elevated concentrations and the rapid increased use of fertilizer N, which has occurred in the UK, for example, over approximately the last thirty years (Gasser, 1982). While claims of potential harmful effects to man are not fully understood (Owen and Jurgens-Gschwind, 1986) sufficient concern exists for guidelines on permissible NO_3–N levels in drinking water (11.3 $\mu g\, ml^{-1}$) to have been introduced (WHO 1984). A strong regional pattern of NO_3–N in river water is evident for England and Wales with highest values occurring in the Midlands and South-East (Marsh, 1980; White, 1983).

Significant amounts (possibly half) of any added nitrogen not utilised by crops may remain within the soil/plant system and are suceptible to leaching. The large seasonal and annual variations in the amounts of fertilizer required to maintain crop production present a real problem. Predicting adequate fertilizer N requirements is certainly not helped by the lack of a suitable widely applicable soil test with present recommendations being based heavily on previous cropping/fertiliser histories and expected yields. In addition, local factor, including soil type, rainfall amount and distribution, temperature and farm management practices add further complications. Fertilisers (both organic and inorganic) are of course not the only source of nitrogen. Atmospheric inputs, biological fixation

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and mineralisation of soil organic matter also make significant contributions in many situations.

In this study the authors highlight differences in NO_3–N content of the rivers Dee and Don (N.E. Scotland) with regards to differing land use and soil type within and between individual catchments. The data presented are combined from a variety of sources and were not specifically collected with the present aim in mind. For this reason the data are not as comprehensive as one might have wished. The authors are aware of these inadequacies, but feel that the unique blend and wide-ranging type of information presented here has many positive advantages. The results presented initially are expressed as NO_3–N concentration data and relate directly to guidelines for drinking water standards. By including river discharge data, estimates of actual NO_3–N loads are also presented which have relevance when considering current EEC proposals for reducing total NO_3–N loads to the North Sea.

SITE CHARACTERISTICS AND METHODS

Location

The North-East of Scotland offers an excellent site for an investigation of this type (Figure 1). Superficially the Rivers Dee and Don appear similar, both flowing rapidly in an easterly direction, and discharging only two miles apart to the North Sea within the city boundaries of Aberdeen. However, anyone familiar with the area will be aware of great differences between the character of each valley. Reasons for their individuality arise primarily as a result of contrasting geologies and more recent glacial influences which have resulted in a range of soil types, and consequently in agricultural diversity (Glentworth and Muir, 1963).

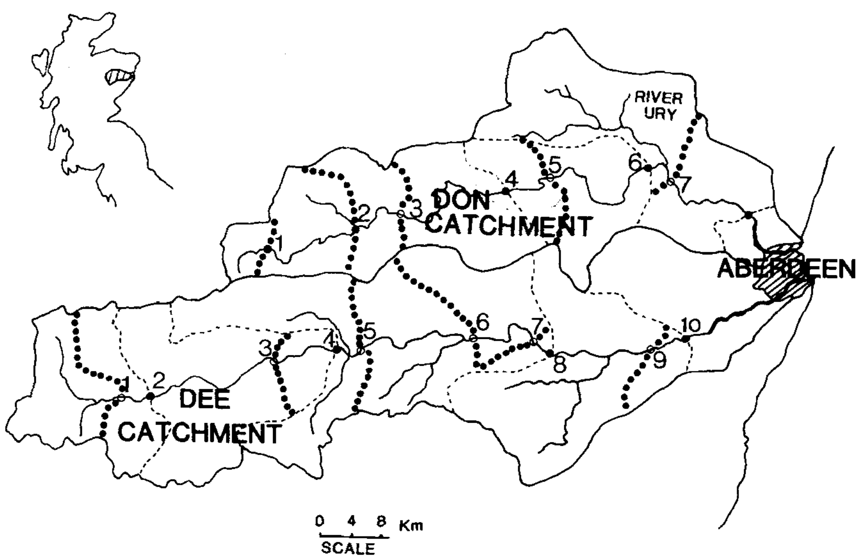

Figure 1 Location map showing water sampling points and the gauging stations together with their respective sub-catchments.

Climatic Conditions

The monthly mean air temperature range tends to increase with distance from the coast and also with altitude (Glentworth and Muir, 1963). Inland areas can suffer severe winters with an extensive frost period (mid-November to the end of March). There is a sharp decline in rainfall amounts from west to east with over 1500 mm on higher ground, down to 750 mm in Aberdeen, a significant proportion of which can fall as snow (average 35 days on which snow falls each year). Prolonged snow showers can occur from December to March, but again, the amounts of snow, and length of time it lies, are higher inland.

Physical Aspects

The catchment areas of the Dee and Don are approximately 1900 and 1400 km^2 respectively. Both contain elements of highland and lowland terrain, uplands to the west and lowland to the east with a number of valleys cutting back into the hill masses. The river Dee is 145 km long with its source relatively high up in the Cairngorms (well over 1300 m). The source of the Don is at lower altitude ($\simeq$760 m) and it is also shorter than the Dee, 135 km. The area lies to the north of the Highland Boundary Fault where the basement rocks are the extremely variable folded metamorphics of the Highland schist formation (Glentworth and Muir, 1963). Acidic (granites and basic gabbros) igneous rocks were intruded into these during the Palaeozoic. Only small remnants of a much greater area of Old Red Sandstone (Devonian) remain as isolated outlines.

The importance of these geological formations are two-fold. The resistant nature of igneous and metamorphic rocks to erosion has greatly influenced the current landscape and differences in relief. Evolution of the soil types has been greatly affected by the recent Pleistocene glaciation and subsequent re-working by rivers. Variations in the character of till derived from different ice sheets closely reflect the rocks over which the glaciers passed (further information Glentworth and Muir, 1963).

The result is a range in soil characteristics between the Dee and Don catchments. In Table 1 a division has been made into three broad groups reflecting the contrasting chemical composition of the parent materials. The soils derived from granites (acidic) have a relatively low base status compared to those

Table 1 Proportion of soils classed[a] as ultra-basic (UBR), basic or acidic as a percentage of total catchment areas.

	Dee	*Don*
1. UBR	—	0.6
2. Basic	65.4	95.8
3. Acidic	34.6	3.6

[a] Classified using data for representative soil profiles (R. E. F. Heslop, Soil Survey of Scotland and B. Smith, Department of Mineral Soils, Macaulay Institute for Soil Research).

from gabbros (basic) which are inherently richer in calcium, phosphorus and iron. Over 96% of soil types in the Don catchment are classed as "basic" compared to only 65% for the Dee. A small area of ultra basic material is present in the upper Don area.

It is apparent from the climate and altitude data described that the growing season is limited to the period April–October, declining sharply inland, and greatly influencing the type and success of agriculture possible.

Scottish Soil Fertility Information System

Data on farm type, crops, area under different crops and N fertiliser rate in the different sub catchment areas of the Dee and Don were obtained from the Scottish Soil Fertility Information System (SSFIS). The essential features of SSFIS are described by Sinclair *et al.* (1988). SSFIS is based on data from soils that are analysed for advisory purposes as a result of requests from individual farmers and not as a result of systematic sampling. However, the data used were only from "routine" sampling and not from "problem" fields.

Farm and field data which include farm type, soil series, cropping and lime and fertiliser use are collected at the time of soil sampling and compiled by computer along with the analytical results. The information presented here is based on samples collected between January 1985 and March 1987.

There were 1664 fields sampled from the Don catchment, covering 8500 hectares, and 1155 fields from the Dee, covering about 5000 hectares which represent approximately 10% of agricultural area of the respective catchments.

Hydrological Characteristics of the River Systems

Discharge is monitored continuously at a number of locations on each main river channel (Figure 1) by the North East River Purification Board (NERPB) i.e. 3 sites on Don, 4 on Dee. Daily read gauging board records were also available and have been used to estimate flow for the Ury which is the main tributary of the Don. One of the most striking features of both rivers is their response time to individual storm events. This becomes particularly exaggerated upstream towards the headwater tributaries (Edwards *et al.*, 1984).

Seasonal variations in discharge are apparent, low flows being associated with summer months and high flows as a result of autumn storms and spring snowmelt. Retention of water as snow, particularly on higher ground, can be considerable, and results in a later period when total river discharge may far exceed the amount of precipitation collected over a similar timescale. It is, however, apparent from Table 2 that the mean discharge values for the seven year period (1980–86) being used in this study are close to the long-term (30 yr) averages for each site.

River Water Sample Collection and Analysis

The river samples were collected approximately monthly over the seven year period (1980–1986) as part of the NERPB's routine water quality control and monitoring remit. Samples were collected on the same day at a number of locations for each river system. Nitrate-nitrogen was determined using standard

Table 2 Discharge data and site characteristics for the gauging stations located on the Dee and Don.

Station		*Catchment area (km²)*	*Altitude (m)*	*Estimated[c] long-term rainfall (mm)*	*Discharge long-term average[b] ($m^3 s^{-1}$)*	*Discharge (1980–1986) Mean ($m^3 s^{-1}$)*	*Max.*	*Min.*
Don								
Alford	(NJ 566170)	513	140	964	11.1	11.5	196	2.23
Haughton	(NJ 756201)	779	55	1018	15.2	16.7	189	3.03
Parkhill	(NJ 887141)	1267	35	964	21.5	23.6	216	3.2
Dee								
Mar Lodge[a]	(NO 098895)	289	275	—	—	12.7	214	0.65
Polhollick	(NO 343965)	699	220	—	23.3	23.3	280	2.09
Woodend	(NO 635956)	1384	70	1156	37.7	38.6	720	3.75
Park	(NO 798983)	1829	30	1136	46.8	48.4	922	4.08

[a] 4 years only 1983–1986.
[b] Data from NERPB Annual Report 1985 (from 1973–1985 or longer).
[c] Institute of Hydrology (1941–1970).

automated colorimetric procedure (Technicon No. 487-77A). Nitrite and ammonium values were also obtained but have not been included in this discussion because of their low levels of concentration (<1% NO_2–N and 5% NH_4–N respectively of the N present as nitrate).

RESULTS AND DISCUSSION

The catchment areas, each with a relatively low population density, have similar geographical characteristics but markedly different patterns of land use (Figure 2). The Don catchment appears to have a greater agricultural potential than the

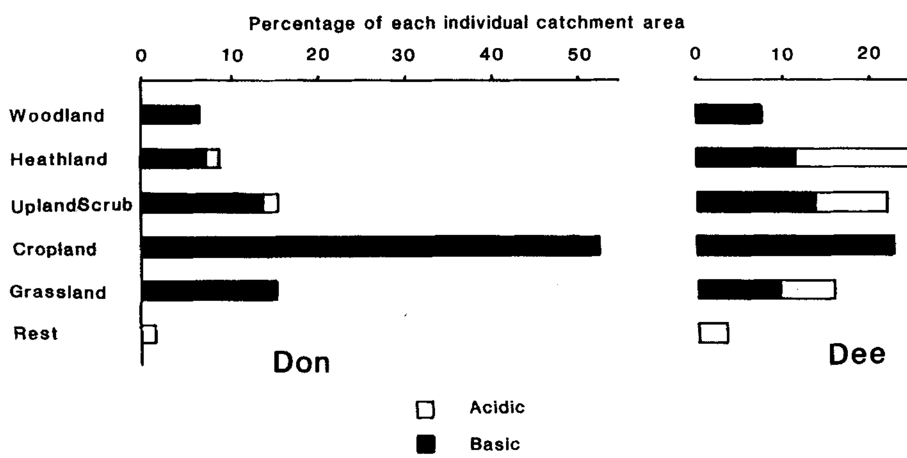

Figure 2 A comparison of broad land use categories between the Dee and Don catchments.

Table 3 Farm type expressed as a percentage of total area sampled for each individual subcatchment

River	Sub Catchment[a]	Area Sampled (ha)	% of total area sampled (b) 2	(b) 2–5[c]	(b) 2–5[d]
Dee	4	nd	nd	nd	nd
	8	1320	22	70	8
	10	3539	48	37	15
Don	4	1001	44	27	29
	6	1417	57	33	10
	7	4156	81	9	10
	8/sea	1892	82	10	8

[a] Numbers represent the sub-catchments above each sampling point (see Figure 1).
[b] Years in 5 that fields are in grass.
[c] N fertiliser rate to grass was greater than 125 kg ha^{-1}.
[d] N fertiliser rate to grass was less than 125 kg ha^{-1}.
nd: insufficient data (i.e. under 100 ha sampled).

Dee catchment, having relatively twice the area under crops and less than half the area of unproductive heath and scrub. These changes in land use within and between catchment areas are substantiated using the SSFIS. Table 3 shows a division of data into a classification of farm type based upon the number of years that fields are in grass with a further subdivision into high and low nitrogen usage. The largest proportion of short-term leys are located throughout Donside while much of Deeside typically has longer-term grass leys. Decreasing the proportion of grass in a rotation is indicative of more intensive arable agriculture with an associated greater use of fertiliser. If there is a link between agricultural intensity and NO_3–N leaching the Don might be expected to have overall, higher NO_3–N concentrations than the Dee. This is in fact the case; volume-weighted means of monthly samples collected over seven years for the Dee and Don (lower reaches) respectively are 0.77 and 2.63 $\mu g\ ml^{-1}$ NO_3–N.

Additional information regarding differing land use and NO_3–N concentrations is provided upon subdivision of the catchments into smaller sub units. This is achieved by using the location of individual river sampling points (Figure 1) and calculating their respective catchment areas. A cumulative picture reflecting differing land use patterns and water quality is the result. Figure 3 shows the two dominant forms of land use (which also represent the opposite extremes of agricultural intervention) for the area upstream of each sampling point and the mean river NO_3–N concentrations for both catchments. The domination of the upland areas where headwaters arise by heathland and scrub is associated with relatively low NO_3–N concentrations. A significant proportion of the annual nitrogen requirements of the native vegetation will be supplied by atmospheric inputs (bulk deposition approximately 10 kg N ha^{-1}) (Edwards *et al.*, 1985) plus dry deposition of a similar amount of about 20–25 kg N ha^{-1} (Royal Society Report, 1983). The difference in importance of heathland and scrub is much more significant for the Don compared to Dee catchment. Cropland makes an earlier and much more significant contribution to the overall land use pattern for the Don (Figure 3). The relative proportion of area under woodland and grass remain reasonably constant along the length of each catchment. However, the quality,

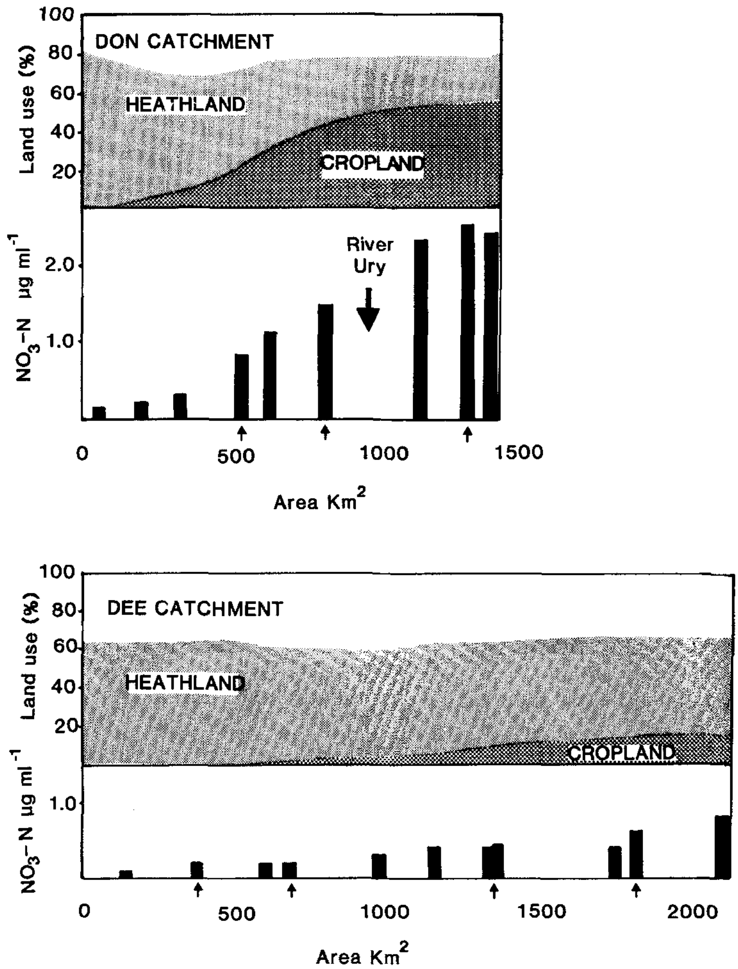

Figure 3 Cumulative areas under different land use heathland and scrub i.e. unfertilised (light shading) and cropland i.e. fertilised (dark shading) for the Don and Dee catchment areas. Position of gauging stations (↑) are also shown. Remaining unshaded area represents grass and forested land.

and therefore presumably productivity, of the grass should increase downstream on the agriculturally better soils (as indicated in Table 3). The mean NO_3–N concentrations in river waters at the various sampling points strongly reflects the increased proportion of cropland ($r^2 = 0.94$) between and within each catchment area (Figure 4). Maximum NO_3–N concentrations ($\mu g\, ml^{-1}$) observed during the sampling period were 2.1 for the Dee and 5.9 for the Don. A further important consideration concerns the increase in NO_3–N concentrations downstream as the result of input from water sources (e.g. tributaries) with much higher concentrations mixing with the main stream. This point is particularly well displayed by the Don's major tributary, the River Ury (Figure 1). Only 11% of its total 175.5 km^2

Table 4 Distribution of spring and winter sown crops in each sub catchment and average nitrogen application rates (kg ha^{-1})

River	Sub Catchment[a]	*% of total area reported* Spring sown[b]	Winter sown	*N application rate (kg ha^{-1})* Spring sown	Winter sown
Dee	4	95	nd	nd	nd
	8	83	17	nd	nd
	10	71	29	nd	nd
Don	4	74	25	82	191
	6	61	39	93	204
	7	53	47	97	209
	8/sea	47	53	106	213

[a] Numbers represent the sub-catchments above each sampling point (see Figure 1).
[b] Barley most dominant spring sown crop.
[c] nd: insufficient data.

catchment area is identified as heathland and scrub, whereas 60% is cropland. The NO_3-N concentrations in the Rivery Ury are comparatively high, with a mean value of 4.7 $\mu g\,ml^{-1}$ (maximum observed 8.0 $\mu g\,ml^{-1}$), which has a significant effect on the River Don's chemistry in the lower reaches (Figure 3). Areas where elevated NO_3-N concentrations are likely to be encountered, such as intensively farmed land and where there are also households with local well water supplies (e.g. for Grampian Region approximately 5% of the population), of which quality is less easy to monitor routinely, are particularly worthy of attention.

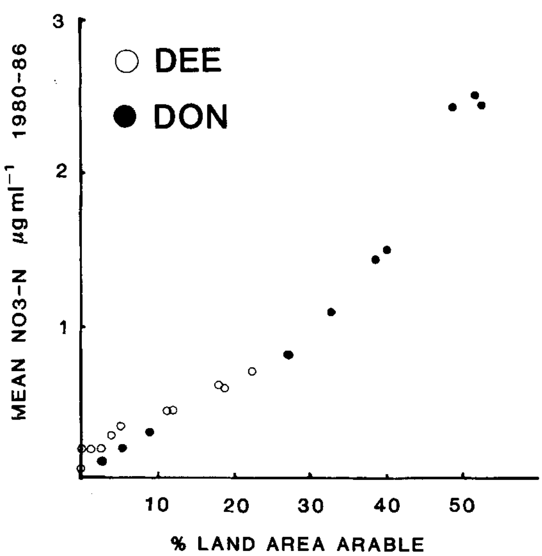

Figure 4 Relationship between mean NO_3-N concentration over a seven year period and the percentage of arable land.

River discharge is monitored continuously at various locations (Figure 1) so that NO_3–N loads can be estimated. River discharge and precipitation characteristics for the gauging stations are presented in Table 2. The limited amount of water quality data requires some prediction for those days when no sample is collected. A log load on log flow relationship (Smith and Stewart, 1977) has been used to provide a means for comparison; this equation has been used successfully by others (e.g. Oborne *et al.* 1980). Estimates of N input from the atmosphere (calculated using annual rainfall volume and appropriate rain chemistry (Edwards *et al.* 1985)) are always greater than N losses in river water (Table 5). Amounts of NO_3–N lost (via leaching and subsequent runoff) from upland headwater regions (particularly Deeside) are especially low, and reflect the rather N deficient nature of these areas.

Nitrogen cycling in upland pastures has been discussed by Batey (1982) who suggests that 20–60 kg N ha^{-1} is mineralised annually with a further 5–10 kg N ha^{-1} a^{-1} supplied by biological fixation. Atmospheric input ($\simeq$14 kg ha^{-1} a^{-1}) makes a substantial contribution to the overall nitrogen budget of these pastures and becomes relatively more important to moorland where biological fixation is low.

Increased agricultural productivity downstream is associated with substantial application of fertiliser-N and animal returns with intensive dairy and beef systems. Timing of fertiliser application is also an important variable, in particular its relation to the different nitrogen requirements of spring and winter sown crops. Table 4 indicates the proportion between spring and winter sown crops in the two catchments; spring sown crops are greater for Deeside with both Dee and Don areas showing a greater incidence of winter sowing downstream. The amounts and timing of fertiliser additions show considerable differences, with double the amount of N for winter crops than for spring sown crops (Table 4). Fertiliser timing may have important consequences for N leaching with respect to both soil moisture status and crop uptake (Edwards *et al.* 1990). Spring barley

Table 5 A comparison of estimated atmospheric ($NO_3 + NH_4$) and fertiliser N inputs with NO_3–N outputs (all in tonnes) in river water. Values in parenthesis expressed as kg N ha^{-1}.

Sub catchments	*Bulk precipitation inputs*	*Estimated fertiliser inputs*	*Output via river*
Dee			
2	555 (19.2)	0	51 (1.8)
4	1342 (19.4)	1478 (21.1)	218 (3.1)
8	2411 (17.4)	4568 (33.0)	642 (4.6)
10	3105 (17.0)	6925 (37.9)	1537 (8.4)
Don			
4	966 (19.2)	3054 (59.5)	274 (5.33)
6	1405 (18.0)	5399 (69.3)	881 (11.3)
8	2177 (17.2)	10785 (85.1)	1893 (14.9)

[a] Numbers represent the sub-catchments above each gauging point (see Figure 1). The data therefore applies to an accumulative area downstream.

[b] Calculated using a general application rate from the fertiliser statistics for North-East Scotland (Survey of Fertiliser Practice, 1986).

would receive all its applied N (80–100 kg ha^{-1}) during late March/early May compared to winter barley where 15 kg ha^{-1} would be applied in September, 65 kg ha^{-1} late February/early March and the remainder in late March/early April. Figures of typical nitrogen usage (principally ammonium nitrate) for a particular crop type within N.E. Scotland (Survey of Fertiliser Practice, 1986) in conjunction with the relevant land use data, allow estimates of expected fertiliser inputs (Table 5) to be calculated. Losses of NO_3–N in river water tend to be an order of magnitude less than the estimated fertiliser inputs. Both figures do, however, show a considerable increase downstream reflecting increasing agricultural activity.

The output figures in Table 5 were calculated with regard to the total land area of each sub-catchment and consequently reflect the fact that not all the land area receives fertiliser inputs. If, however, 1.8 kg ha^{-1} NO_3–N (equivalent to the typical loss from a heathland/scrub area of Upper Deeside from Table 5) is subtracted from the total river NO_3–N losses and the remaining value is divided by the agricultural land area (grass plus cropland) the resulting figures are 21.6 and 21.5 kg ha^{-1} for the Dee and Don respectively. These values are consistent with those reported (24 kg ha^{-1}) for other British catchment areas (e.g. Webb and Walling, 1985).

CONCLUSIONS

Elevated river NO_3–N concentrations downstream appear to reflect the general increase in overall agricultural productivity and intensity. There are significant differences in river NO_3–N levels between the Dee and Don. However the similarity of figures for overall losses from agricultural land suggests these catchment differences are simply related to the greater percentage of agricultural land and consequently fertiliser applications on Donside.

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References

Batey, T. (1982). Nitrogen cycling in upland pastures of the UK. *Philosophical Transactions of the Royal Society London. B.* **296,** 551–556.

Edwards, A. C., Creasey, J. and Cresser, M. S. (1984). The conditions and frequency of sampling for elucidation of transport mechanisms and element budgets in upland drainage basins. *Proceedings of the International Symposium on Hydrochemical Balances of Freshwater Systems.* Uppsala, Sweden: 187–202.

Edwards, A. C., Creasey, J. and Cresser, M. S. (1985). Factors influencing nitrogen inputs and outputs in two Scottish upland catchments. *Soil Use and Managenment,* **1,** 83–87.

Edwards, A. C., Dyson, P. and Ross, J. A. M. (1990). The consequences for nutrient uptake efficiency of farm practices such as crop rotation. *Journal of the Science of Food and Agriculture* (In press).

Edwards, A. M. C. (1973). The variation of dissolved constituents with discharge in some Norfolk rivers. *Journal of Hydrology*, **18**, 219–242.

ECETOC. Nitrate and Drinking Water. Report No. 27, Brussels, 1988.

Foster, S. S. D., Cripps, A. C. and Smith-Carington, A. (1982). Nitrate leaching to groundwater. *Philosophical Transactions of the Royal Society London B*. **296**, 477–489.

Gasser, J. K. R. 1982. Agricultural productivity and the nitrogen cycle. *Philosophical Transactions of the Royal Society London B*. **296**, 303–314.

Glentworth, R. S. and Muir, J. W. (1963). The soils round Aberdeen, Inverurie and Fraserburgh. *Soil Survey Scotland Memoirs, Macaulay Institute for Soil Research.*

Heslop, R. E. F. and Smith, B. Personal communication.

Marsh, J. J. (1980). Towards a nitrate balance for England and Wales. *Water Services*, **84**, 601–606.

North East River Purification Board 1985 11th Annual Report.

Oborne, A. C., Brooker, M. P. and Edwards, R. W. (1980). The chemistry of the river Wye. *Journal of Hydrology*, **45**, 233–252.

Owen, T. R. and Jurgens-Gschwind, S. (1986). Nitrates in drinking water: a review. *Fertiliser Research*, **10**, 3–25.

Royal Society Report (1983). The nitrogen cycle of the UK. A study group report. Royal Society, London.

Sinclair, A. H., Reaves, G. A. and Brown, K. W. M. (1988). Design of a Scottish Soil Fertility Information System. *Analytical Proceedings*, **25**, 120.

Smith, R. V. & Stewart, D. A. (1977). Statistical models of river loadings of nitrogen and phosphorus in the Lough Neagh System. *Water Research*, **11**, 453–459.

Stewart, W. D. P., Preston, T., Peterson, H. G. and Christofi, N. (1982). Nitrogen cycling in eutrophic freshwaters. *Philosophical Transactions of the Royal Society London B*. **296**, 491–509.

Survey of Fertiliser Practice (Scotland) 1986. Rothamsted Experimental Station (SFPS/4/1986).

Webb, B. W. and Walling, D. E. (1985). Nitrate behaviour in streamflow from a grassland catchment in Devon, UK. *Water Research*, **19**, 1005–1016.

White, R. J. (1983). Nitrate in British waters. *Aqua*, **2**, 51–57.

World Health Organisation (1984). Guidelines for drinking-water quality.