SPATIALLY RESOLVED MONTHLY RIVERINE FLUXES OF OXIDISED NITROGEN (NITRATE AND NITRITE) TO THE EUROPEAN SHELF SEAS, 1960-2005

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SUMMARY

This report documents the methodology developed for statistically modelling the spatial and temporal patterns of oxidised nitrogen (nitrate plus nitrite) riverine fluxes into the coastal waters of northwestern Europe, over the period 1960-2005. The purpose of the study was to provide boundary data for a modelling study of new primary production in European waters.

For the UK and Ireland, monthly freshwater discharges to a set of grid cells around the coastline were modelled from rainfall data and calibrated from detailed analyses performed for a subset of years with contrasting climatology. The mean and long-term trends in nitrate and nitrite content of the river discharges were modelled from Harmonised Monitoring Scheme data and flux estimates for each of the years of contrasting climateology. The product of the discharge rate and nitrogen content provided estimates of the monthly flux to each grid cell.

Scandinavian inputs of nitrate and nitrite to the North Sea, Skagerrak and Kattegat were assembled from a composite of statistically modelled freshwater discharge, and recent estimates of nitrogen flux from national monitoring agencies.

Fluxes of nitrate and nitrite from the rivers flowing into the North Sea from Germany, Netherlands and Belgium during 1960-2005 were assembled from previous analyses by researchers at the University of Hamburg.

Nitrate and nitrite fluxes from French rivers flowing into the English Channel, in particular the Seine, were indirectly derived by correlation with the River Scheldt, calibrated from published estimates of annual fluxes.

The results show the total oxidised nitrogen input to European shelf seas increasing from approximately 0.6Mt pa. in the 1960's to 1.2Mt pa. in the mid-1980's. Recent estimates of the annual flux since 2000 have been approximately 1.1Mt pa. Around 60-70% of the total annual flux to the northwest European shelf enters via the North Sea. Winter input rates are approximately twice those in the summer in all areas except the Skagerrak/Kattegat.

INTRODUCTION

The Oslo and Paris Commission for the Protection of the marine Environment of the North-East Atlantic (OSPAR) sets out guidelines for the monitoring and annual reporting of nutrients and other contaminant fluxes to the sea in Riverine Inputs and Direct Discharges (RID) (OSPAR 1998). However, the spatial resolution required for this reporting is coarse (e.g. North Sea, Atlantic), and annually integrated. Such resolution is inadequate for establishing external boundary conditions for marine ecosystem modelling initiatives, which typically require a minimum of monthly temporal resolution and some degree of sub-regional spatial resolution. For this purpose it is necessary to revert to the more basic national data. The main problem then is that the accessibility, resolution and extent of these data are highly variable.

The North Sea Task Force modelling group (Anonymous 1992), addressed the problem of estimating spatially and temporally resolved nutrient fluxes to the North Sea, and were able to derive values for some of the major rivers for the year 1985. These were subsequently extended to daily resolved time series for the period 1977 to 1993 for the major continental European rivers using river flow and nutrient concentration data by Lenhart *et al*. (1996), and updated to the period 1977 to 1998 by Lenhart and Pätsch (2001). Pätsch and Radach (1997) described the application of the European Regional Seas Ecosystem Model (ERSEM; Baretta-Bekker 1995, Baretta-Bekker and Baretta 1997) to simulating long-term trends in eutrophication status of the North Sea, for which they extended the continental European river series back to 1955, and crudely estimated daily inputs to the North Sea from UK rivers flowing into the North Sea. Recently, Pätsch and Lenhart (2004) updated the daily time series for the continental rivers forward to 2002.

Heath *et al*. (2002) expanded the North Sea ERSEM to cover the entire European shelf from northern France to north of the Shetland Islands, and west of Ireland to the Skagerrak (referred to as ERSEM model “sc278”; 49°20’N, 12°00’W; 61°40’N, 11°45’E). The region was discretized to an average spatial resolution of approximately 60km with a grid of 278 cells, and the of nutrients from the land estimated for all coastal cells for each of three years of contrasting climatology (1984, 1987 and 1990). The methodology for estimating nutrient fluxes varied from region to region, depending on the availability of data. For Scotland, England and Wales, detailed flow and nutrient concentration data for individual rivers were available for each of the specified years, and these were used together with a GIS-based land use model (Appendix 2) to simulate the daily (monthly for England and Wales) fluxes to every adjoining coastal cell from the entire land catchment area, according the OSPAR principles (Appendix 1) for calculating riverine fluxes. For the Irish Republic, only long term monthly average flows and annual compositional data could be obtained, whilst for Northern Ireland, year-specific flow but no composition data were available. Out of these, it was possible to estimate monthly resolution nutrient fluxes to coastal cells only for 1990. Daily fluxes from the major rivers flowing out of Germany, Netherland and Belgium were taken from the data sets which were eventually published by Pätsch and Lenhart (2004). For Denmark, a crude scaling of fluxes from northern German rivers was applied, though this resulted in an underestimate. Norwegian monthly fluxes to the North Sea and Skagerrak cells were crudely estimated from published annual inputs assuming a constant rate of input throughout the year. No estimates could be compiled for inputs from France or Sweden.

Here, the objective was to estimate monthly integrated fluxes of oxidised inorganic nitrogen (nitrate + nitrite) to each coastal cell, for all years between 1960 and 2005 rather than simply a few specific years. Even for the regions best endowed with accessible river flow and concentration data (other than the major rivers flowing out of Germany, Netherlands and Belgium), this interval of years far exceeded the availability of data. Hence, an alternative approach was developed, which involved estimating freshwater discharge to each coastal cell from a statistical model based on monthly precipitation data. To this was applied the mean input per unit freshwater discharge volume over the years 1984, 1987 and 1990 implied by the data of Heath *et al*. (2002). This was further adjusted according to an annual river water concentration anomaly derived from a second statistical model of such monitoring data as existed for the land catchment of each coastal cell.

Model Grid for Specifying Nutrient Inputs

The spatial grid for the sc278 version of ERSEM is shown in Figure 1. The domain was divided into two depth layers at 30m. The upper layer (surface-30m depth) comprised 278 inner cells in which the state variables of the ERSEM were simulated dynamically, plus 32 boundary cells in which the concentrations of key state variables were specified as data time series.

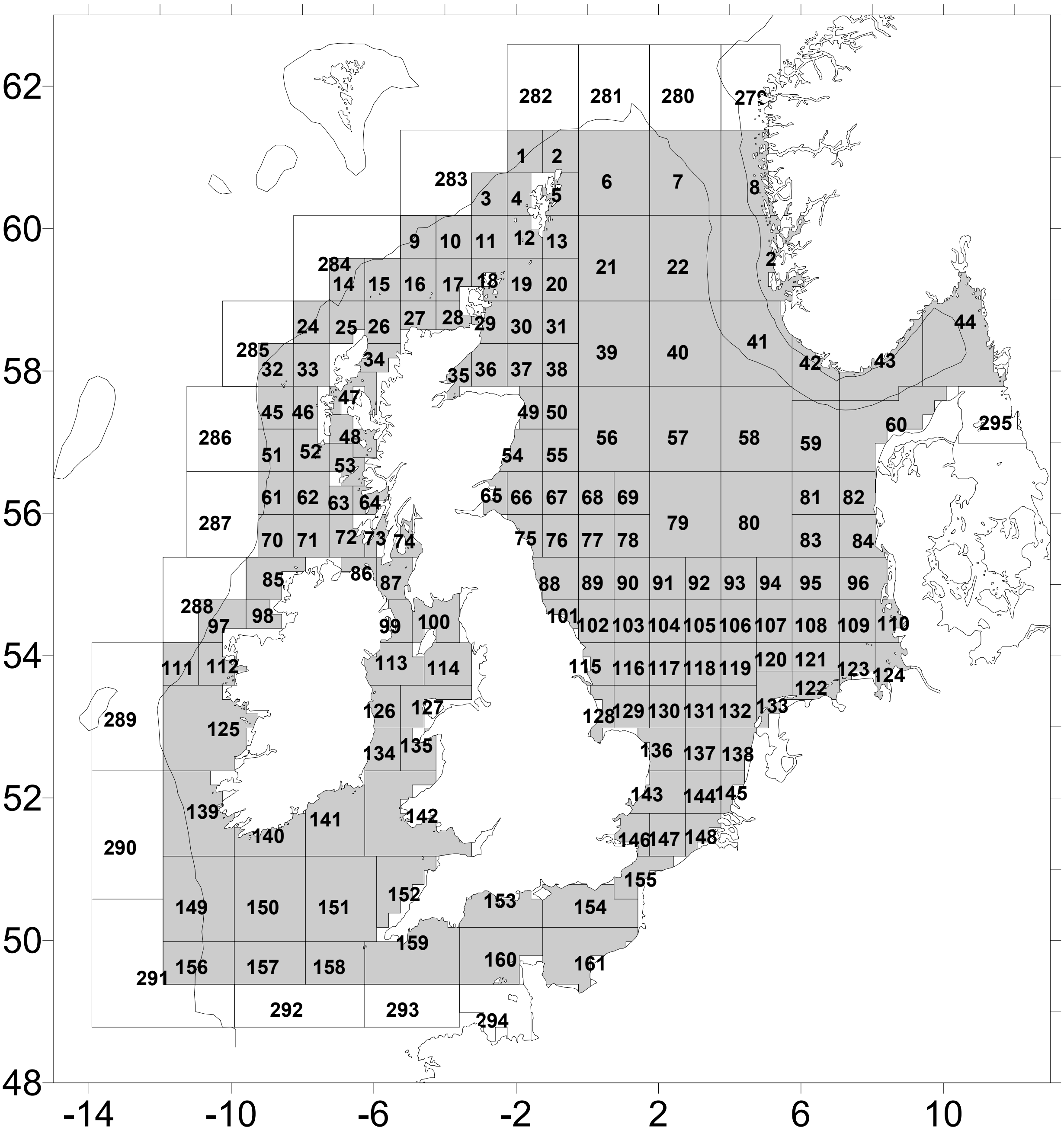

Figure 1 Map of the surface (0-30m) grid cells for the sc278 version of ERSEM. Grey shaded cells represent the inner grid for which state variables were simulated dynamically. Un-shaded cells represent the model boundary area for which forcing time series of concentration data on certain state variables was supplied.

Of the 278 inner cells of the model, 87 had contact with the coastline, and hence potentially received inputs of nutrient from land runoff and discharges to the sea. Nations contributing to each cell are shown in Figure 2 and Table 1. Note that some cells received input from one than one nation.

Cell	Scotland	England & Wales	Ireland	Germany, Netherlands & Belgium	Norway	Sweden	Denmark	France
1	1	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0
4	1	0	0	0	0	0	0	0
5	1	0	0	0	0	0	0	0
8	0	0	0	0	1	0	0	0
12	1	0	0	0	0	0	0	0
13	1	0	0	0	0	0	0	0
17	1	0	0	0	0	0	0	0
18	1	0	0	0	0	0	0	0
23	0	0	0	0	1	0	0	0
25	1	0	0	0	0	0	0	0
26	1	0	0	0	0	0	0	0
27	1	0	0	0	0	0	0	0
28	1	0	0	0	0	0	0	0
29	1	0	0	0	0	0	0	0
33	1	0	0	0	0	0	0	0
34	1	0	0	0	0	0	0	0
35	1	0	0	0	0	0	0	0
36	1	0	0	0	0	0	0	0
37	1	0	0	0	0	0	0	0
41	0	0	0	0	1	0	0	0
42	0	0	0	0	1	0	0	0
43	0	0	0	0	1	0	0	0
44	0	0	0	0	1	1	0	0
46	1	0	0	0	0	0	0	0
47	1	0	0	0	0	0	0	0
48	1	0	0	0	0	0	0	0
49	1	0	0	0	0	0	0	0
52	1	0	0	0	0	0	0	0
53	1	0	0	0	0	0	0	0
54	1	0	0	0	0	0	0	0
60	0	0	0	0	0	0	1	0
64	1	0	0	0	0	0	0	0
65	1	0	0	0	0	0	0	0
71	0	0	1	0	0	0	0	0
72	1	0	1	0	0	0	0	0
73	1	0	0	0	0	0	0	0
74	1	0	0	0	0	0	0	0
75	1	1	0	0	0	0	0	0
82	0	0	0	0	0	0	1	0
84	0	0	0	0	0	0	1	0
85	0	0	1	0	0	0	0	0

86	0	0	1	0	0	0	0	0
87	1	0	1	0	0	0	0	0
88	0	1	0	0	0	0	0	0
96	0	0	0	0	0	0	1	0
97	0	0	1	0	0	0	0	0
98	0	0	1	0	0	0	0	0
99	0	0	1	0	0	0	0	0
100	1	1	0	0	0	0	0	0
101	0	1	0	0	0	0	0	0
102	0	1	0	0	0	0	0	0
110	0	0	0	1	0	0	0	0
112	0	0	1	0	0	0	0	0
113	0	0	1	0	0	0	0	0
114	0	1	0	0	0	0	0	0
115	0	1	0	0	0	0	0	0
122	0	0	0	1	0	0	0	0
123	0	0	0	1	0	0	0	0
124	0	0	0	1	0	0	0	0
125	0	0	1	0	0	0	0	0
126	0	0	1	0	0	0	0	0
127	0	1	0	0	0	0	0	0
128	0	1	0	0	0	0	0	0
129	0	1	0	0	0	0	0	0
133	0	0	0	1	0	0	0	0
134	0	0	1	0	0	0	0	0
135	0	1	0	0	0	0	0	0
136	0	1	0	0	0	0	0	0
138	0	0	0	1	0	0	0	0
139	0	0	1	0	0	0	0	0
140	0	0	1	0	0	0	0	0
141	0	0	1	0	0	0	0	0
142	0	1	0	0	0	0	0	0
143	0	1	0	0	0	0	0	0
145	0	0	0	1	0	0	0	0
146	0	1	0	0	0	0	0	0
147	0	0	0	1	0	0	0	0
148	0	0	0	1	0	0	0	0
151	0	1	0	0	0	0	0	0
152	0	1	0	0	0	0	0	0
153	0	1	0	0	0	0	0	0
154	0	1	0	0	0	0	0	1
155	0	1	0	0	0	0	0	1
159	0	1	0	0	0	0	0	0
160	0	0	0	0	0	0	0	1
161	0	0	0	0	0	0	0	1

Table 1 Nations discharging nutrient to each cell of the model grid having contact with coastline. 0 denotes no input, 1 denotes input. Rows shaded in grey receive input from more than one nation. Six cells (1, 2, 17, 102, 147 and 151) had only short perimeter contact with a coastline and land inputs to these cells were disregarded. Cell 142 had coastline contact with both England and Wales, and Ireland, but the perimeter contact with Ireland

was small and Irish in put to cell 142 was disregarded. A further 3 cells (110, 123) had significant perimeter contact with the coastline, but do data could be located to reso lve any nutrient inputs.

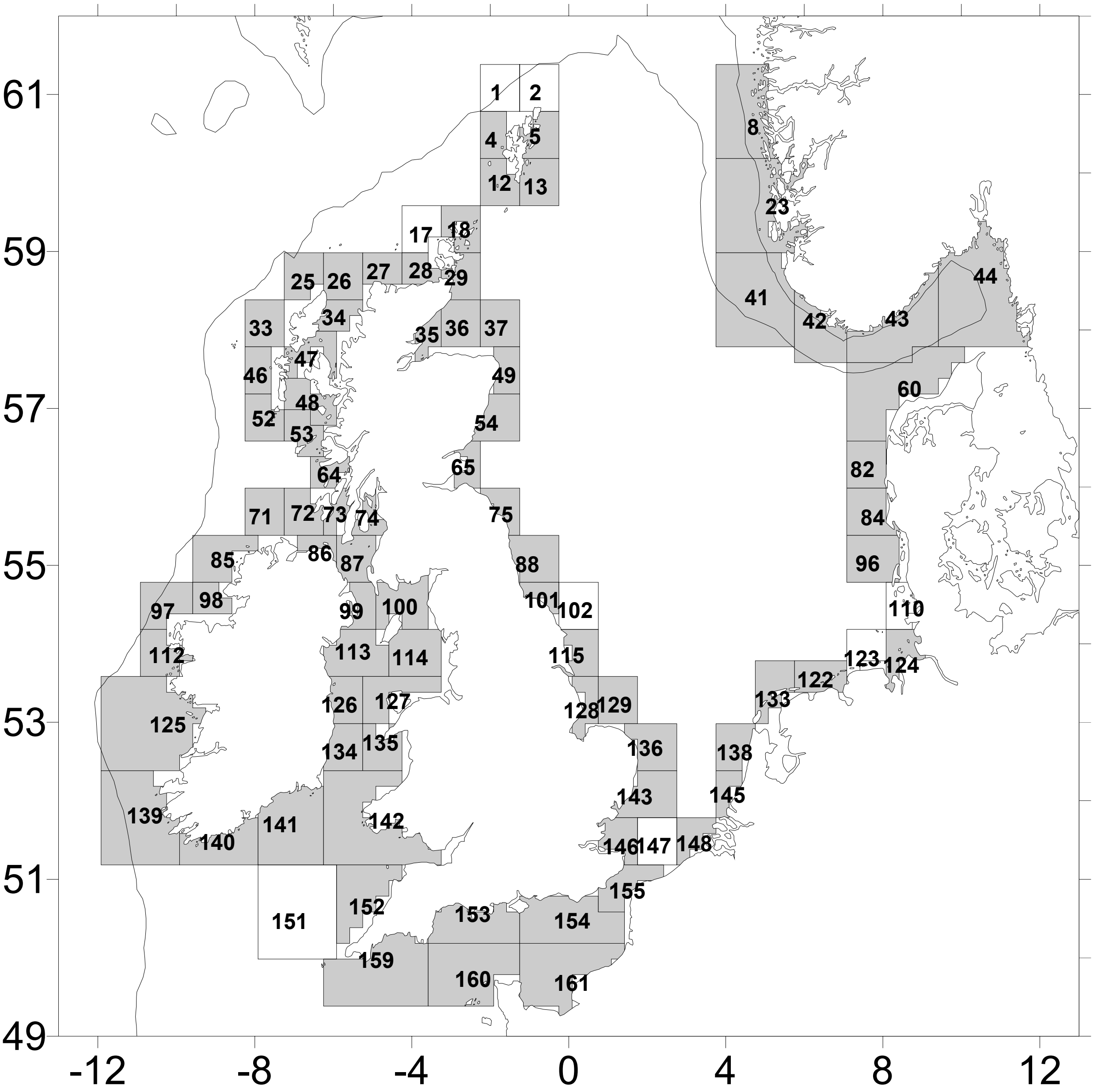

Figure 2 Map of the model grid cells having contact with coastline. Data were successfu lly compiled for each of the grey shaded cells. No data could be compiled for the un-shaded cells.

Extension of the Nutrient Load Estimates for 1984, 1987 and 1990 from Heath *et al*. (2002) to a Monthly Resolution Time Series, 1960-2005

Monthly riverine nutrient fluxes to coastal cells from Germany, Netherlands and Belgium during 1960-2002 were readily compiled by merging the data from 1955-1993 from Pätsch and Radach 1997 (http://www.ifm.uni-hamburg.de/~wwwem/dow/ERSEM/ERSEM.ZIP), and the data from 1977-2002 from Pätsch and Lenhart 2004 (ftp://ftp.ifm.zmaw.de/pub/data/riverload/). The series was extended to 2005 by substituting 1999 data for 2003, 2000 data for 2004 and 2001 data for 2005. By this means, the inputs to coastal cells 122, 124, 133, 138, 145, 148 were derived. No data on German inputs to cells 110 and 123 could be estimated by this means since none of the rivers included in the original data sets discharged to these cells.

1960-2005 riverine inputs from all other nations required extensive new data analysis. For Scotland, England, Wales, Ireland and Norway this analysis involved statistical modelling of volume discharge and nutrient concentrations. For Sweden, Denmark and France, inputs were derived by scaling Norwegian, German or Belgian inputs according to various data.

General Methodology for Statistical Modelling of Long-Term Data Series on Riverine Fluxes to the Coastal Zone

The exact details of the methodology used to generate monthly resolution data series of riverine fluxes of oxidised nitrogen (nitrate + nitrite) from 1960 onwards, varied between regions depending on the accessability and quality of the available data from each contributing nation. The general approach is described below, followed by the details for each national data set.

General Methodology for Statistical Modelling of Freshwater Discharge to each Coastal Cell

Gauged flow data for UK rivers in the NRFA database are sparse prior to the mid-1970's. Hence, the conventional OSPAR approach for deriving monthly integrated freshwater discharge volumes from the catchment of each coastal cell, was not feasible. Instead, a General Additive Modelling (GAM) approach was used to statistically derive monthly discharge volumes from monthly precipitation data.

For the catchment basin corresponding to each coastal cell, monthly freshwater discharge data were assembled from various sources and a GAM fitted with explanatory variables being the corresponding monthly precipitation data at the monitoring site most appropriate for the catchment, and a cyclical annual function (cosine) as an analogue of the seasonal changes in evapo-transpiration and retention of water. The GAM was then used to predict the monthly time series of freshwater discharge from the 1960-2005 monthly precipitation data for the same site.

General Methodology for Estimating Oxidised Nitrogen (nitrate+nitrite) Flux from Freshwater Discharge Data

For each coastal cell, best estimates of nitrate + nitrite flux to the coastal zone were assembled from national assessment reports and other sources. These varied in resolution from annual to daily, but were typically for only a few years out of the 1960-2005 sequence. For these specific years (referred to as reference years), the mean input per unit volume of freshwater discharge was estimated, to monthly resolution where possible but often only as an annual average. This average input rate (per unit volume) was then applied to each month in the 1960-2005 series of freshwater discharges from the GAM model based on rainfall data, resulting in an initial estimate of the time series of nutrient flux, assuming no trend in the concentration of oxidised nitrogen in the river waters.

Time series of measured concentrations (mg l^{-1}) of oxidised nitrogen (nitrate + nitrite) in river waters were obtained from national monitoring authorities. These varied from sample-by-sample records for individual river monitoring sites for some nations, to regional annual mean values for others. The data were analysed with the objective of deriving annual average concentration as a proportion of the average over the reference years indicated above. Where appropriate, a GAM was fitted for each river to sample-by-sample concentration data with independent variables being year and a cyclical annual function (cosine) as an analogue of the seasonal changes in concentration in river waters. The GAM was then used to predict the concentration each year from 1960-2005 for a given month, and the predictions expressed relative to the average for the reference years. These relative concentrations were then averaged over rivers within each coastal cell catchment, giving equal weighting to each river and applied uniformly over each year, to scale the initial estimate of 1960-2005 monthly nutrient flux to reflect trends in river nutrient concentrations.

Details of Analysis for Scotland

Daily estimates of freshwater discharge (10^3 m^3 day^{-1}) and nitrate + nitrite flux to each coastal cell adjoining the coastline of Scotland (kg day^{-1}) for the years 1984, 1987 and 1990 were provided by A. Edwards (Macaulay Land Use Research Institute) (originally for Heath *et al*. 2002). These data were integrated to monthly resolution. Freshwater discharge was modelled as a function of monthly precipitation at nearby monitoring sites (Tables 2 and 8), and inter-annual variation in river nutrient concentrations modelled from HMS data for rivers in or close to the catchment of each coastal cell (Tables 2 and 10).

Three cells had only very short perimeter contact with the coastline of Scotland (1, 2 and 17). Inputs to these cells were disregarded.

In the analysis of Heath *et al*. (2002), the estimated input to cell 33 (west of the Isle of Lewis) in fact included the catchment of both cell 33 and cell 25. Hence, in the analysis presented here, the 1984, 1987 and 1990 inputs of freshwater and nutrient to cell 33 have been divided equally between cells 33 and 25.

Coastal cell	Precipitation monitoring site	r^2 observed vs fitted FW discharge	River HMS data used for annual scaling	r^2 observed vs fitted HMS data
4	Lerwick	0.539	No data	
5	Lerwick	0.538	No data	
12	Lerwick	0.537	No data	
13	Lerwick	0.542	No data	
18	Lerwick	0.539	No data	
25	Tiree	0.541	No data	
26	Stornoway	0.395	No data	
27	Stornoway	0.579	No data	
28	Lerwick	0.271	Thurso	0.493
29	Lerwick	0.549	Thurso	0.493
33	Tiree	0.541	No data	
34	Stornoway	0.532	Carron	0.125
35	Stornoway	0.677	Beauly, Connon, Ness and Shin	Beauly 0.150 Ness 0.128 Connon 0.180 Shin 0.268

36	Braemar	0.622	Findhorn, Lossie and Spey	Findhorn 0.088 Lossie 0.074 Spey 0.079
37	Braemar	0.630	Deveron	0.523
46	Tiree	0.540	No data	
47	Stornoway	0.709	Carron	0.125
48	Stornoway	0.668	Carron	0.125
49	Braemar	0.667	Don, Ythan	Don 0.581 Ythan 0.640
52	Tiree	0.530	No data	
53	Tiree	0.530	No data	
54	Braemar	0.782	Dee and South Esk	Dee 0.351 S. Esk 0.197
64	Tiree	0.48	Lochy	0.184
65	Braemar	0.749	Earn, Eden, Forth, Leith, Leven and Tay,	Earn 0.120 Eden 0.421 Forth 0.441 Leith 0.280 Leven 0.576 Tay 0.139
72	Tiree	0.480	No data	
73	Paisley	0.906	No data	
74	Paisley	0.870	Clyde, Irvine and Leven (Clyde)	Clyde 0.246 Irvine 0.420 Leven 0.180
75	Paisley	0.572	Eye and Tweed	Eye 0.470 Tweed 0.061
87	Paisley	0.759	Ayr	0.238
100	Paisley	0.831	Cree and Esk	Cree 0.320 Esk 0.345

Table 2 Coastal cells, rainfall monitoring sites, and Harmonised Monitoring Scheme (HMS) river water chemistry monitoring sites used in the statistical modelling of Scottish nitrogen fluxes.

Examples of the relationship between modelled nitrate plus nitrite flux to coastal cells, and the monthly values estimated by A. Edwards (for Heath *et al*., 2002) are shown in Figure 3.

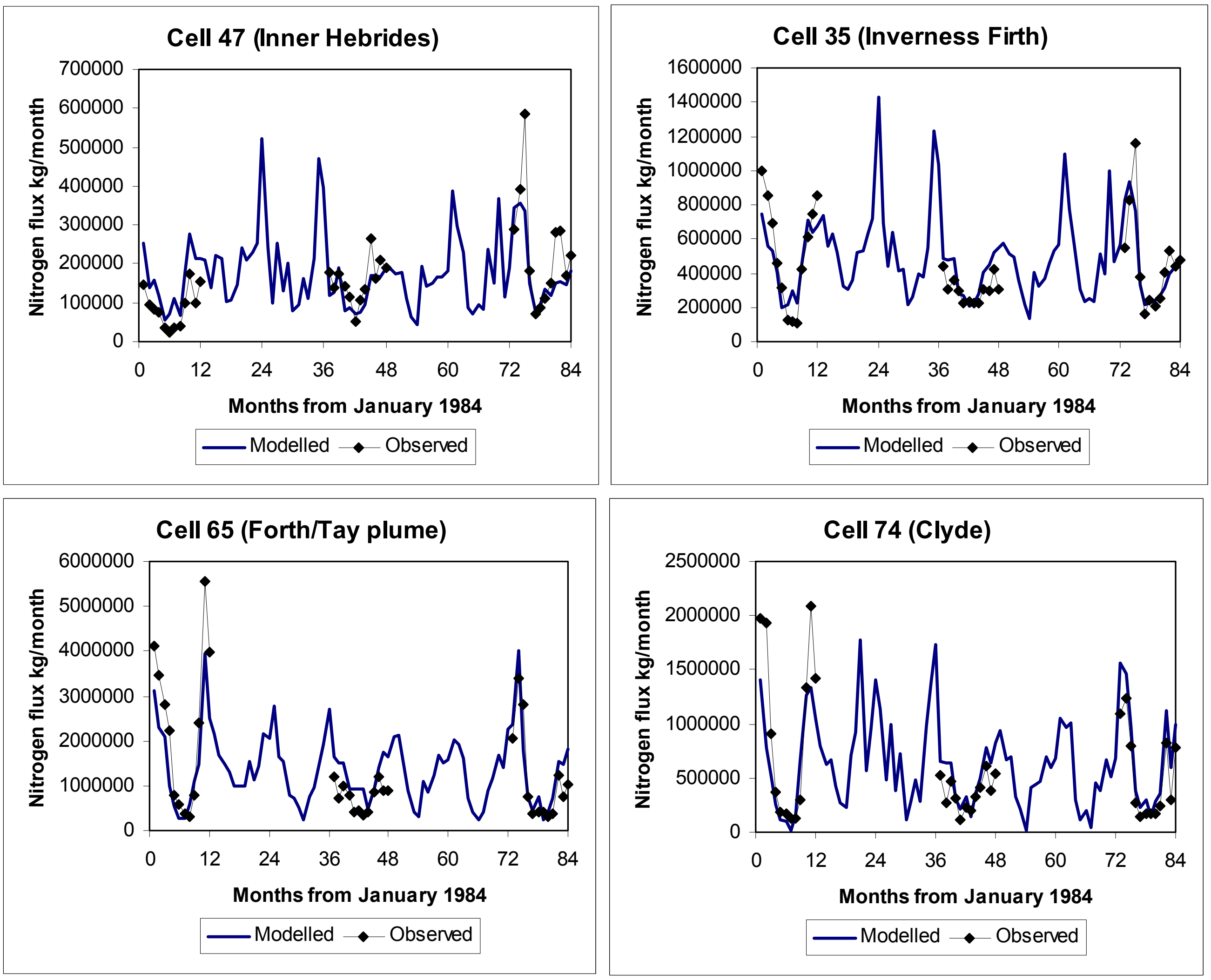

Figure 3 Modelled and 'observed' fluxes of nitrate + nitrite (kg month^{-1}) for four of the coastal cells around Scotland. 'Observed' values are as estimated by A. Edwards (MLURI) for Heath *et al*. (2002).

Details of Analysis for England and Wales

Monthly estimates of freshwater discharge (10^3 m^3 month^{-1}) and nitrate + nitrite flux to each coastal cell adjoining the coastline of England and Wales (kg month^{-1}) for the years 1984, 1987 and 1990 were provided by A. Edwards (Macaulay Land Use Research Institute) (originally for Heath *et al*. 2002). Freshwater discharge was modelled as a function of monthly precipitation at nearby monitoring sites (Tables 3 and 8). Interannual variation in river nutrient concentrations (relative to the average for 1984, 1987 and 1990) in the catchment of each coastal cell was derived from the regional mean annual nitrate + nitrite concentrations in the rivers within each of the Water Authority regions in England and Wales (Tables 3 and 10).

Two cells had only very short perimeter contact with the coastline of England and Wales (102 and 151). Inputs to these cells were disregarded.

Coastal cell	Precipitation monitoring site	r^2 observed vs fitted FW discharge	Water authority regional data used for annual scaling
75	Newtonrigg	0.724	North East

88	Durham	0.556	North East
100	Newtonrigg	0.880	North West
101	Newtonrigg	0.776	North East
114	Newtonrigg	0.869	North West
115	Bradford	0.674	Northeast and Midlands
127	Valley	0.755	Welsh and North West
128	Sheffield	0.203	Anglian
129	Cambridge	0.257	Anglian
135	Aberporth	0.852	Welsh
136	Cambridge	0.301	Anglian
142	Ross on Wye	0.816	Welsh, Midlands and South West
143	Greenwich	0.559	Anglian
146	Oxford	0.453	Thames and Southern
152	St Mawgan	0.867	South West
153	Hurn	0.720	South West
154	Southampton	0.778	Southern
155	Eastbourne	0.901	Southern
159	St Mawgan	0.873	South West

Table 3 Coastal cells, rainfall monitoring sites, and Water Authority regional river water chemistry data used in the statistical modelling of English and Welsh nitrogen fluxes.

Examples of the relationship between modelled nitrate plus nitrite flux to coastal cells, and the monthly values estimated by A. Edwards (for Heath *et al*., 2002) are shown in Figure 4.

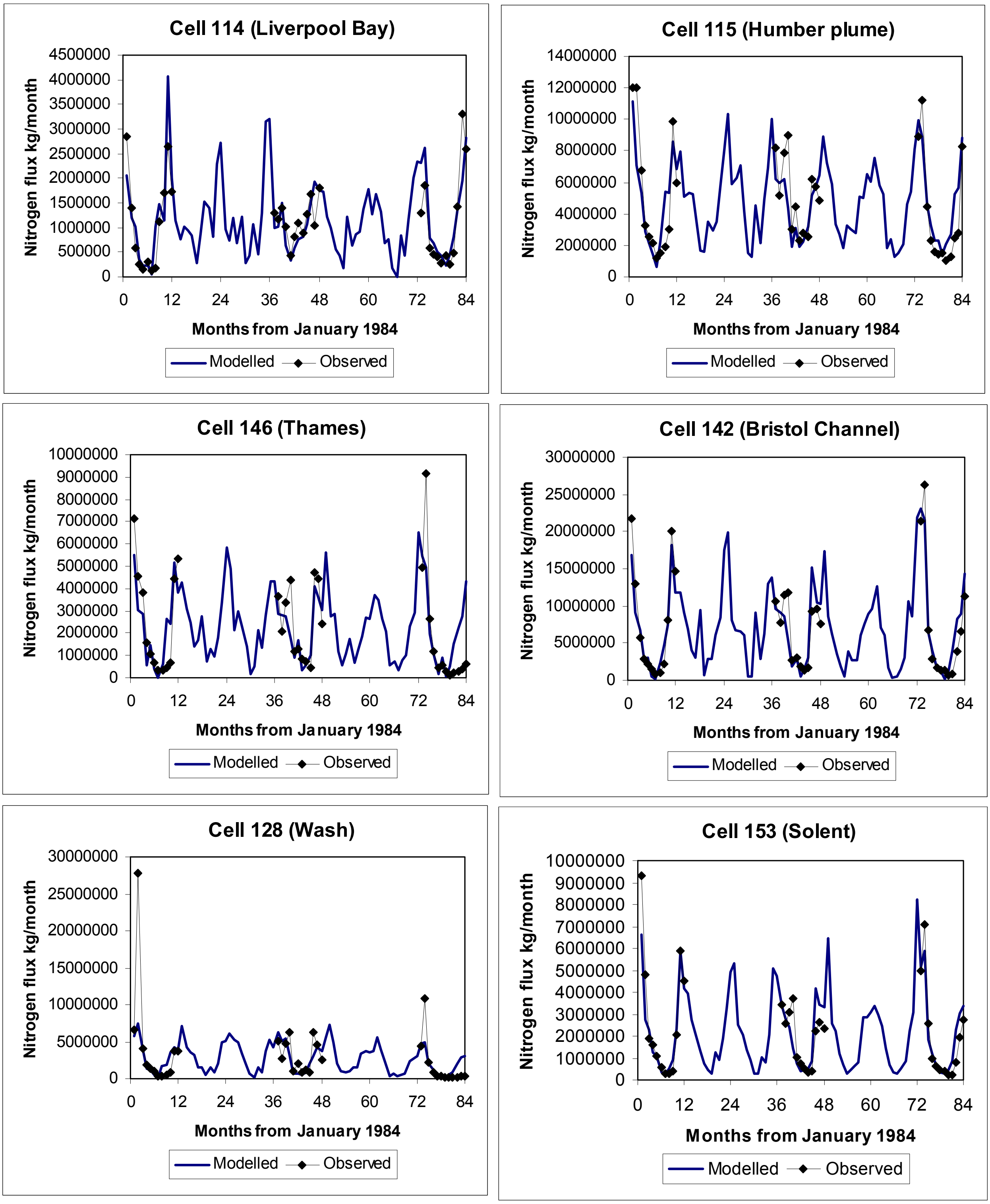

Figure 4 Modelled and 'observed' fluxes of nitrate + nitrite (kg month^{-1}) for six of the coastal cells around England and Wales. 'Observed' values are as estimated by A. Edwards (MLURI) for Heath *et al*. (2002).

Details of Analysis for Northern Ireland and the Irish Republic

Monthly estimates of freshwater discharge (10^3 m^3 $month^{-1}$) and nitrate + nitrite flux to each coastal cell adjoining the coastline of Northern Ireland and the Irish Republic (kg $month^{-1}$) for 1990 were provided by A. Edwards (Macaulay Land Use Research Institute) (originally for Heath *et al*. 2002).

1961-1990 monthly average precipitation, but no year-by-year monthly data, for the Irish Republic were available from the Irish Meteorological Service (Table 10). These data were correlated with the equivalent monthly averages for Armagh and for Cardiff and St Mawgan in southwest Britain, and for the Northern Ireland regional average precipitation derived from a model at the Hadley Centre. The results showed that precipitation data for Armagh, St Mawgan and the Northern Ireland region, probably represented reasonable surrogates for the time series of precipitation at Irish Republic sites (Table 4). Freshwater discharge was therefore modelled as a function of monthly precipitation at Armagh, St Mawgan as over the Northern Ireland region as appropriate for each catchment.

	NI-regional	Armagh	Cardiff	St Mawgan
Belmullet	0.986	0.910	0.939	0.930
Birr	0.897	0.949	0.746	0.739
Casement	0.807	0.877	0.684	0.688
Claremorris	0.990	0.939	0.924	0.921
Clones	0.970	0.977	0.846	0.836
Cork	0.865	0.755	0.897	0.907
Dublin	0.857	0.910	0.726	0.724
Kilkenny	0.949	0.900	0.894	0.895
Malin	0.973	0.896	0.922	0.903
Mullingar	0.971	0.961	0.870	0.862
Rosslare	0.940	0.856	0.958	0.970
Shannon	0.972	0.909	0.954	0.951
Valentia	0.959	0.855	0.965	0.966

Table 4 Correlation coefficients between the series of 1961-1990 monthly average precipitation (mm $month^{-1}$) at monitoring sites in the Irish Republic (rows) and various data sets for Northern Ireland and southwest Britain (colums). Shaded cells indicate the maximum value in each row.

Data on riverine nutrient concentrations in Northern Ireland and the Irish Republic were scant. No data collected by the competent monitoring authority in Northern Ireland could be located, but data from 3 rivers in the region collected by the Centre for Ecology and Hydrology, Lancaster, from 1995 – 2003 were found to be available (Table 12). Similarly, for the Irish Republic, sampling data could not be located, but graphs of variations in annual average nitrate concentration between 1981 and 2002 in the major rivers of south-eastern Ireland were found in an assessment report, and digitised (Table 12). Annual mean data for each southeastern Irish river were first scaled relative to 1990, and then averaged for each year, giving equal weighting to each river. The annual mean data for each Northern Irish river were scaled relative to 1995, and then averaged for each year (Table 5).

Based on these data, relative (to 1990) nutrient concentrations in southeastern Ireland were assumed constant from 1960-1981 and from 2002-2005, and to vary according to the reported data for the period 1981-2002. In Northern Irish rivers, the relative (to 1990) nutrient concentration was assumed to be as in southeastern Irish rivers from 1960 to 1995. From 1995 onwards, the concentration relative to 1995 was further scaled by the ratio 1995:1990 relative concentration in southeastern Irish rivers.

For coastal cells adjoining the west coat of the Irish Republic there were no riverine nutrient concentration data available. In the absence of information it was assumed that there was no trend in these catchments.

Cell 142 had a short perimeter contact with the coastline of the Irish Republic, but input across this boundary was disregarded since no major rivers discharged into the celll.

Coastal cell	Precipitation monitoring site	R^2 observed vs fitted FW discharge	River nutrient data used for annual scaling
71	Northern Ireland regional	0.822	Bush, Garvery, Faughan
72	Northern Ireland regional	0.822	Bush, Garvery, Faughan
85	Northern Ireland regional	0.822	Bush, Garvery, Faughan
86	Northern Ireland regional	0.822	Bush, Garvery, Faughan
87	Northern Ireland regional	0.822	Bush, Garvery, Faughan
97	Northern Ireland regional	0.822	No data
98	Northern Ireland regional	0.822	No data
99	Armagh	0.815	Bush, Garvery, Faughan
112	Northern Ireland regional	0.822	No data
113	Armagh	0.815	Bush, Garvery, Faughan
125	Northern Ireland regional	0.822	Barrow, Nore, Slaney, Suir
126	Armagh	0.815	Barrow, Nore, Slaney, Suir
134	St Mawgan	0.801	Barrow, Nore, Slaney, Suir
139	St Mawgan	0.801	No data
140	St Mawgan	0.801	Barrow, Nore, Slaney, Suir
141	St Mawgan	0.801	Barrow, Nore, Slaney, Suir

Table 5 Coastal cells, rainfall monitoring data, and river water chemistry data used in the statistical modelling of nitrogen fluxes from Northern Ireland and the Irish Republic.

Examples of the relationship between modelled nitrate plus nitrite flux to coastal cells, and the monthly values estimated by A. Edwards (for Heath *et al*., 2002) are shown in Figure 5.

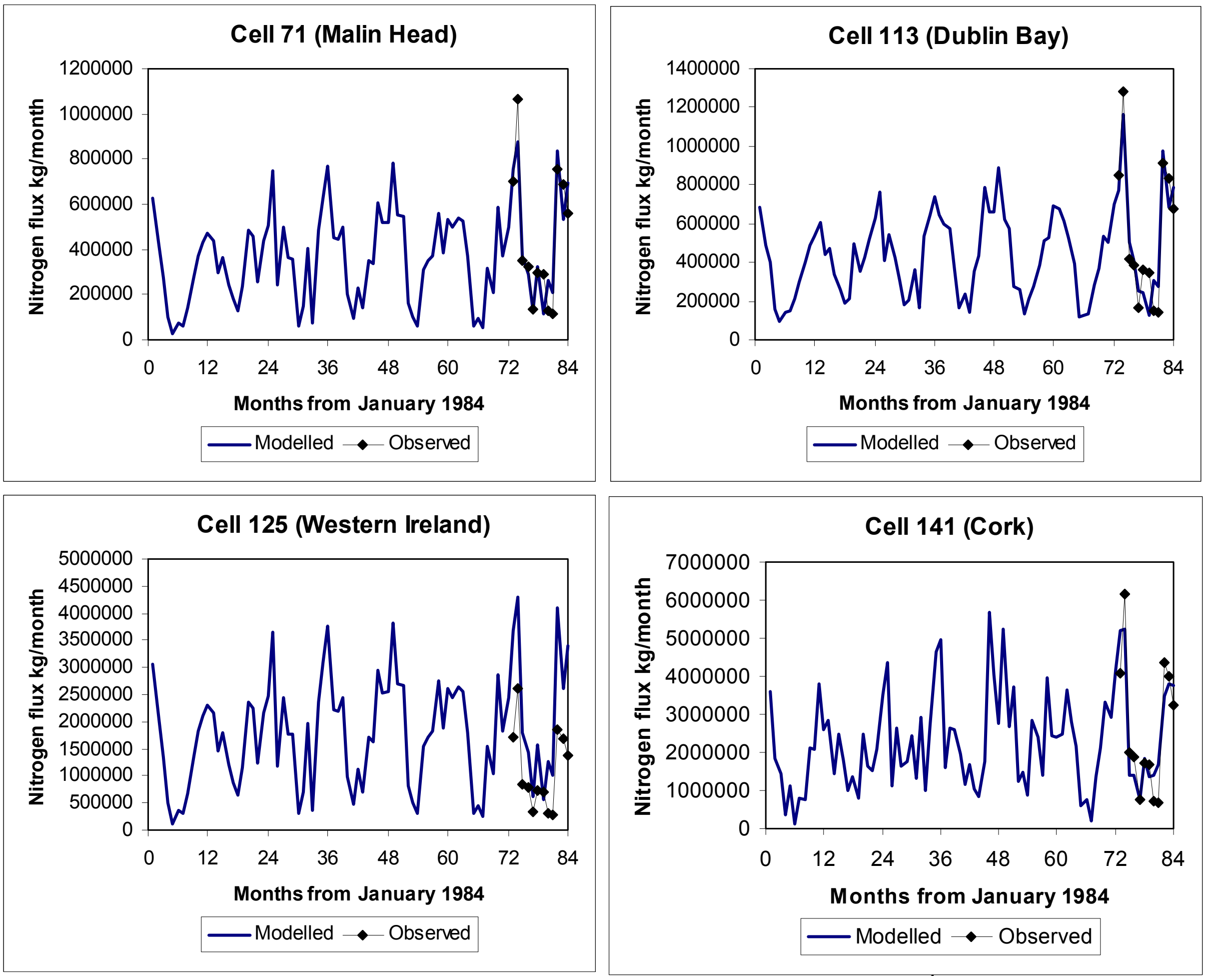

Figure 5 Modelled and 'observed' fluxes of nitrate + nitrite (kg month^{-1}) for four of the coastal cells around Northern Ireland and the Irish Republic. 'Observed' values are as estimated by A. Edwards (MLURI) for Heath *et al.* (2002).

Details of Analysis for Norway

Area-averaged monthly rainfall data for three regions in southern Norway were obtained from the Norwegian Meteorological Institute (Table 10). The runoff from these areas contributed to 6 coastal cells, forming two of the coastal regions defined by Norwegian authorities for discharge assessments (North Sea: Lindesnes-Stad, and Skagerrak: Swedish border-Lindesnes) (Table 11).

Seven major monitored rivers flow into the North Sea and Skagerrak assessment regions (North Sea: Orreelva and Suldalslagen, Skagerrak: Otra, Skienselva, Numedalslaagen, Drammenselva and Glomma (Table 11). However, the Orreelva and Suldalslagen are small and make up only a small fraction of the total freshwater discharge to the North Sea region, whilst the other 5 rivers contribute most of the discharge to the Skagerrak.

Average monthly freshwater discharge rates were available only for the rivers flowing into the Skagerrak. Data for the Otra river were used as a surrogate for the seasonal pattern of discharge from the catchment of the North Sea cells. A GAM was fitted to the average monthly river discharge data based on the average monthly rainfall in the corresponding monitoring area (Table 6). The fitted GAM was then used to predict an index of the monthly freshwater discharge to each coastal cell from 1960-2005. This index was raised to the total discharge (10^3 m^3 month^{-1}) by reference to the mean annual total runoff to each of the coastal assessment regions (Weideborg *et al.*, 2001).

Norwegian assessments of annual nitrate + nitrite flux to each coastal assessment region in 2004 (Borgvang *et al*., 2006; Table 13) were apportioned to coastal cells, and the average annual input rate (kg (10^3 $m^3)^{-1}$) derived by reference to the sum over 2004 of the total freshwater discharge volume to corresponding cells predicted from the GAM. Nitrogen concentrations in samples collected at monitoring sites along each of the major rivers were reported to show no significant trend over the period 1990-2004 (Borgvang *et al*., 2006; Table 12), so the rate of nitrate + nitrite input per unit volume of discharge was assumed to be constant over the period 1960-2005, and no year-specific scaling was applied (Table 6).

Coastal cell	Norwegian coastal region containing each cell	Precipitation monitoring area draining into coastal cell	River used to represent seasonality of FW discharge	r^2 observed vs fitted FW discharge	Proportion of inputs to Norwegian coastal region entering via each cell	Factor to raise river FW discharge to total entering coastal cell	2004 NO_x input to cell (t yr^{-1})
8	North Sea	Vestlandet	Otra	0.813	0.33	11.85	3833
23	North Sea	Vestlandet	Otra	0.813	0.34	12.21	3949
41	North Sea	Vestlandet	Otra	0.813	0.17	5.93	1916
42	North Sea	Vestlandet	Otra	0.813	0.17	5.93	1916
43	Skagerrak	Agder	Otra	0.589	0.10	1.23	1829
44	Skagerrak	Austlandet	Skienselva Numedalslaagen Drammenselva Glomma	0.766	0.90	1.23	16922

Table 6 Coastal cells and regions, rainfall monitoring regions, and river data used to estimate Norwegian riverine fluxes of oxidised nitrogen.

Details of Analysis for Sweden

Sweden contributed to coastal cell 44 of the model area, along with Norway. To estimate the monthly 1960-2005 Swedish input of nitrate and nitrite to coastal cell 44, it was assumed that the trend and seasonality were related to the Norwegian input. A linear regression relationship was therefore established, expressing the annual Swedish flux (scaled from Swedish authority estimated of total nitrogen flux to the Skagerrak and Kattegat combined; Table 13), in terms of the corresponding annual integral of the estimated Norwegian flux (Swedish annual flux = -9543.48 + 0.5965 * Norwegian annual flux (t yr^{-1}), $r^2 = 0.46$). The fitted annual Swedish flux was then expressed as a year-specific ratio Swedish:Norwegian flux, which was applied uniformly over each year of the monthly 1960-2005 time series of Norwegian fluxes.

Swedish authorities have reported annual total nitrogen fluxes to the Skagerrak and Kattegat combined from 1969-2001 (Table 13). 33% of this was estimated to be input to coastal cell 44, based on the approximate relative coastline length. Based on sample-by-sample analysis of water samples from the major Swedish rivers flowing into the Skagerrak and Kattegat (Table 12), the proportion of total nitrogen represented by nitrate and nitrite was 54%.

Details of Analysis for Germany, Netherlands and Belgium

Nine coastal cells were located adjacent to the North Sea coastlines of Germany, Netherlands and Belgium. Major rivers flow into 6 of these, and daily nutrient fluxes for 1955-1993 were available from Pätsch and Radach (1997), and for 1977-2002 from Pätsch and Lenhart (2004). These data sets were blended together to produce a monthly resolution series from 1960-2002. The rivers discharging to each coastal cell in the two data sets are shown in Table 7. The concordance between the two sets was checked for each cell by comparing the sum for all contributing rivers averaged over the common period 1977-1993. This factor, which in all cases was between 0.98 and 1.05, was applied to the 1955-1993 data set to achieve matching with the more recent series.

The data were combined by assuming values from the 1955-1993 series between January 1960 and December 1976, and from the more recent series therafter. The combined series were extended to December 2005, by substituting 1999 data for 2003, 2000 data for 2004, and 2001 data for 2005.

Coastal cell	Rivers in the 1955-1993 dataset of Pätsch and Radach 1997	Rivers in the 1977-2002 dataset of Pätsch and Lenhart 2004
110	none	none
122	Ems	Ems
123	none	none
124	Elbe, Weser, Jade	Elbe, Weser
133	Lysselo, Lysselw, Lauer	Ijssel
138	Ijmuiden	Nordzeekanaal
145	Rhine, Meuse	Nieuwewaterweg, Haringvlet
147	none	none
148	Scheldt, Yzer	Scheldt

Table 7 Coastal cells, and corresponding rivers in two data sets of nutrient fluxes from Germany, Netherlands and Belgium.

Details of Analysis for Denmark

Estimating nutrient fluxes from Denmark was problematic. There are few major waterways draining the land catchment and the inputs are diffuse. The approach used for the UK and Norway was not possible due to inaccessibility of data. Instead, fluxes were estimated by correlating such data as could be located with the time series from a nearby catchment.

Pätsch and Radach (1997) crudely estimated the annual nutrient inputs from all land-based sources to the equivalent of coastal cell 82 in the current grid setup for the years 1955 to 1993, but were unable to estimate the seasonal variations, and assumed a linear change in daily input between years.

Correlation between the crude estimate of monthly flux of nitrate + nitrite from Denmark to cell 82 (Pätsch and Radach, 1997) and the compiled monthly fluxes from Germany to coastal cell 124, which is closest to the Danish-German border, was $r^2 = 0.3$. A linear regression predicting Danish flux in terms of German flux to cell 124 was: Danish flux to cell 82 = 28194 + 0.00123* German flux to cell 124 (kg month^{-1}). This approach provided some crude basis for establishing a trend and seasonality for Danish nitrate + nitrite fluxes, but not the absolute level of input.

The Danish Environmental Protection Agency (DMU) has published annual estimates of the total flux of dissolved inorganic nitrogen from river, diffuse and point sources to coastal waters, for the years 1989 to 2001 (Table 13). For 2001, the total input has been apportioned between various sea areas (24% of total to the North Sea, and 3% to the Skagerrak. Pätsch and Radach (1997) estimated nitrate + nitrite to constituted 36% of the total inorganic nitrogen input from Denmark. To establish the absolute level of input to each of the coastal cells in the model grid, it was assumed that the Danish nutrient flux to the North Sea was distributed equally across 3 coastal cells of the model (82, 94 and 96), and the Skagerrak input to cell 60. Comparing the crude estimate of annual Danish flux to cell 82 for the years 1989-2001, derived by scaling the German flux to cell 124, with the independent values from DMU, indicated a scaling factor of 5.218 to convert the crude estimate to a realistic level for that cell. The resulting time series of annual scaled values was highly correlated with the independent estimates from the DMU ($r^2 = 0.58$, for the period 1994-2001 (0.26 for the period 1989-2001)).

In 2001, the ratio of Danish nitrogen flux to the Skagerrak relative to that for the North Sea was 0.131: 1. Assuming that this ratio remained constant over time, the scaling factor to estimate flux to the Skagerrak (cell 60) from the crude estimate to cell 82 was 2.057.

Details of Analysis for France

Four coastal cells of the model had French coastline boundaries (cells 160, 161, 154 and 155). Of these, the major input is to cell 161 which receives material from the River Seine and various other smaller rivers. However, details of freshwater and nutrient inputs to the coastal zone from France are extremely scarce. Annual data reports to OSPAR on Riverine Inputs and Direct Discharges often contain no information from France (e.g. OSPAR 2004a).

No raw data on monthly rainfall, river discharge, river nutrient concentrations or monthly inputs to the coastal zone could be located. However, various publications provided information which allowed a correlative approach to be developed, similar to that used to estimate Danish inputs. The approach concentrated on resolving the flux from the River Seine, this being the largest discharge on the region, and relating fluxes to other cells to the Seine input.

Lacroix *et al*. (2004) showed plots of daily flow rates for various continental European rivers including the Seine. There was a clear correlation between the flow of the Seine and Scheldt rivers, which have similar catchments. The aim was therefore to derive a scaling factor for estimating the nitrate + nitrite flux from the Seine, based on that from the Scheldt.

The average flow rate of the Scheldt during 1977-2002, according to the data of Pätsch and Lenhart (2004), was 137.16 $m^3\ s^{-1}$, whilst Cugier *et al*. (2005) quote the mean flow rate of the Seine to be 450 $m^3\ s^{-1}$. Hence, a scaling factor of 3.281 was applied to the monthly freshwater discharge of the Scheldt to estimate the discharge of the Seine. For comparison, Aminot *et al*. (1998) quoted the discharge of the Seine to be 348, 408 and 669 $m^3\ s^{-1}$ (mean 475 $m^3\ s^{-1}$) in the years 1992, 1993 and 1994 respectively. The corresponding estimates from rescaling the River Scheldt flow rate were 443, 486 and 557 $m^3\ s^{-1}$, (mean 495 $m^3\ s^{-1}$). The annual average input of nitrate + nitrite per unit volume of freshwater discharge from the Scheldt (kg $(10^3\ m^3)^{-1}$) was calculated for the years 1977-2002 from the data of Pätsch and Lenhart (2004). The equivalent rate for the Seine was calculated from data presented by Aminot *et al* (1997) on the annual flux of nitrate + nitrite from the River Seine (t yr^{-1}) between 1976 and 1994, and the corresponding volume discharges derived as above. These indicated that, over the period 1977-1994, the oxidised nitrogen content of the Seine discharge (kg $(10^3\ m^3)^{-1}$) was higher than that of the Scheldt by an average factor (referred to as the Seine:Scheldt concentration ratio) of 1.32 (maximum 2.20 in 1978, minimum 0.91 in 1993).

Further information on oxidised nitrogen concentrations in the River Seine were located at the Centre d'Enseignement dt de Recherche Eau Ville Environment, in a document by M Poulin (2001) (http://www.enpc.fr/cereve/HomePages/thevenot/piren-models.pdf) relating to the PIREN project on ecological modelling of the Seine (Chesterikov *et al* 1998). Annual average nitrate concentrations (mg l^{-1}) in the Seine during the years 1901-1992 were digitised from the diagram on p31. During the period of overlap with the Aminot *et al*. (1997) the concentration from the Poulin data was inversely correlated with the Seine:Scheldt concentration ratio (r = -0.65). In other words, despite the increasing nitrate concentrations in Seine river waters since 1960, concentration in the Scheldt must have been increasing more quickly, so that the Seine:Scheldt ratio declined.

Based on the correlation with Seine river nitrate concentrations, estimates of the Seine:Scheldt concentration ratio were derived for the period 1960 to 1976 and 1995-1996 by linear regression (Seine:Scheldt ratio = 2.336 – 0.064 * Seine nitrate concentration). For the years 1977-1994, the values derived directly from the data of Aminot *et al* (1997) were used. For the period 1997-2005, values were randomly assigned in a range between the minimum and maximum values during the years 1991-1996.

Finally, the annual scaling factor to estimate nitrate+nitrite flux from the River Seine to coastal cell 161 from the flux by the River Scheldt to coastal cell 148, was the product of the freshwater volume scaling factor (3.281) and the year-specific Seine:Scheldt concentration ratio. This factor was applied equally to the monthly Scheldt fluxes for each year in the 1960-2005 series.

A number of smaller rivers also flow into the Bay of the Seine (cell 161) (Orne, Vire and Dives, Touques). Cugier *et al* (2005) stated that input from these rivers combined amounts to approximately 10% of that from the Seine. Hence, the estimates of monthly flux from the Seine were raised by a factor of 1.1 to account for these additional rivers.

Few nutrient or hydrological data could be found for the rivers flowing into cells 154 and 155 or 160. However, data submitted by France to the Fifth North Sea Conference (The North Sea Secretariat 2002), included annual flow rates (million m^3 yr^{-1}) and fluxes of nitrate and nitrite (tonnes nitrogen yr^{-1}) for numerous French rivers during 1989-2000. Each of these rivers was therefore assigned to one of the 4 coastal cells adjoining the French coastline, and the total annual flux of nitrate and nitrite estimated by summing the fluxes for the individual rivers:

Cell 154: Somme, Canche and Authie
Cell 155: Aa, Slack, Wimereux and Liane
Cell 160: Saire and Divette
Cell 161: Seine, Touques, Dives, Orne, Seulles, Vire, Andelle and Eure.

Averaged over the years 1990-1999, when data were available for all of the rivers, the ratios of mean fluxes to each cell relative to that for cell 161, were: cell 154: 0.0785; cell 155: 0.0388; cell 160, 0.00383. For cell 154, this ratio is similar to the ratio of catchment areas of the Somme and Seine rivers (5560 and 78650 km^2 respectively, i.e. ratio = 0.0709). These mean proportions of nitrate + nitrite flux were applied to the time series of monthly inputs to cell 161 to derive estimates of the corresponding fluxes to cells 154, 155 and 160.

Summary of Results

The results for each nation and coastal cell were combined into a single file. This involved merging 86 separate files, defining the monthly fluxes to 79 coastal cells, 7 of which had input from 2 nations.

The data are available as a comma-separated ASCII file at: \\193.63.46.53\shared\Marine_ecosystems\BioOceanog\Data_Archive\Nutrient_inputs\RID-nitrate\

Spatial Summary of Annual Fluxes

The annual flux (tonnes NOx per year), averaged over 10-year intervals (1960-1969, 1970-1979, 1980-1989, 1990-1999, 2000-2005) are shown in Figure 6. In each decade, the larges fluxes have been from the major continental rivers flowing into the southern North Sea.

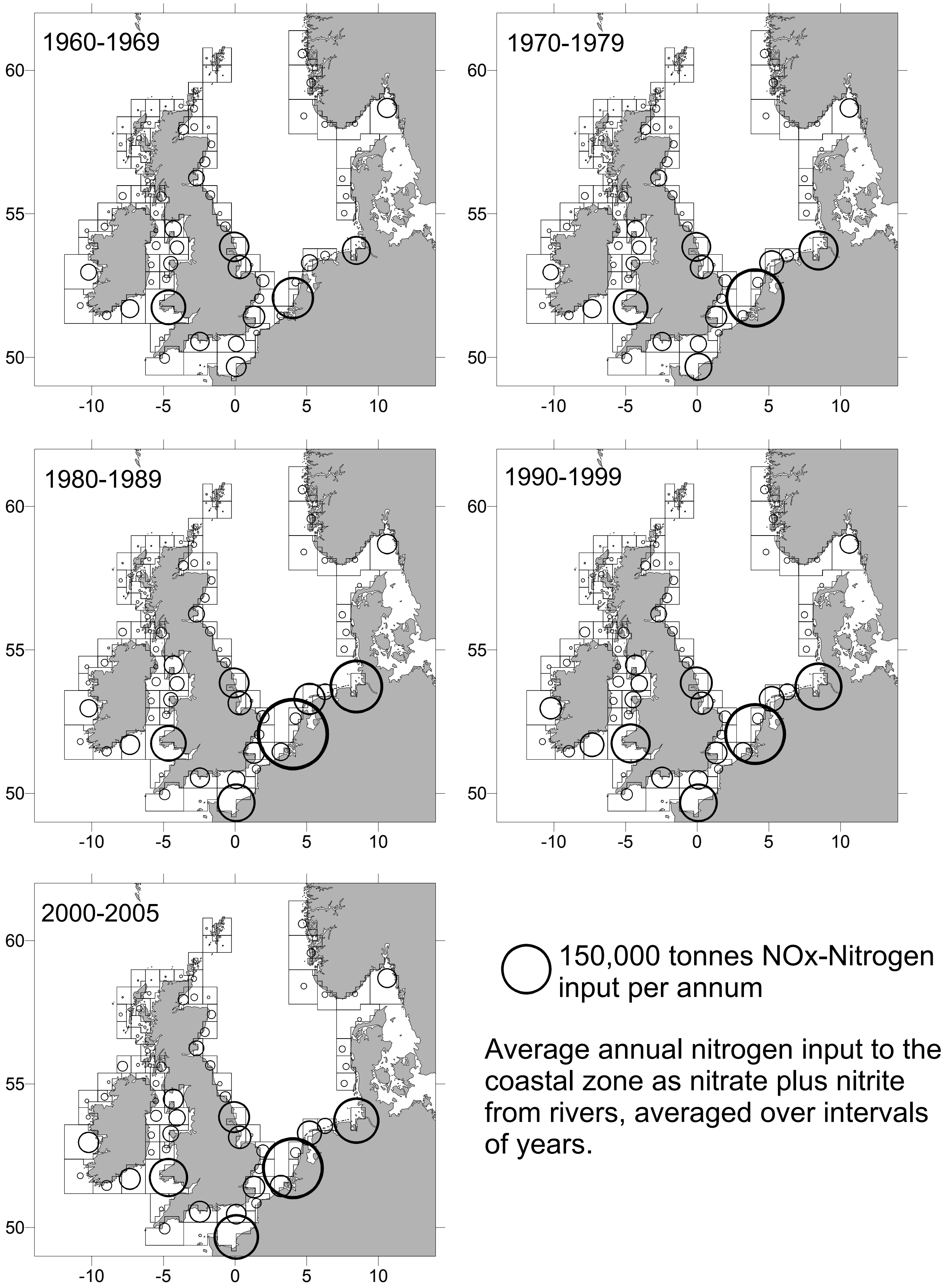

Figure 6 Average annual riverine inputs of nitrate and nitrite (tonnes nitrogen per year) over five successive intervals.

Regional Summary by Year and Month

Each of the coastal cells was assigned to one of five regions (Table 8).

Cell	Contributing nations	Region
4	Scotland	North Sea
5	Scotland	North Sea
8	Norway	North Sea
12	Scotland	North Sea
13	Scotland	North Sea
18	Scotland	North Sea
23	Norway	North Sea
25	Scotland	West of UK
26	Scotland	West of UK
27	Scotland	West of UK
28	Scotland	West of UK
29	Scotland	North Sea
33	Scotland	West of UK
34	Scotland	West of UK
35	Scotland	North Sea
36	Scotland	North Sea
37	Scotland	North Sea
41	Norway	North Sea
42	Norway	North Sea
43	Norway	Skagerrak/Kattegat
44	Norway and Sweden	Skagerrak/Kattega
46	Scotland	West of UK
47	Scotland	West of UK
48	Scotland	West of UK
49	Scotland	North Sea
52	Scotland	West of UK
53	Scotland	West of UK
54	Scotland	North Sea
60	Denmark	Skagerrak/Kattega
64	Scotland	West of UK
65	Scotland	North Sea
71	Ireland	West of UK
72	Scotland and Ireland	West of UK
73	Scotland	West of UK
74	Scotland	Clyde/Irish Sea/Celtic Sea
75	Scotland and E&W	North Sea
82	Denmark	North Sea
84	Denmark	North Sea
85	Ireland	West of UK
86	Ireland	West of UK
87	Scotland and Ireland	Clyde/Irish Sea/Celtic Sea
88	E&W	North Sea
96	Denmark	North Sea
97	Ireland	West of UK
98	Ireland	West of UK
99	Ireland	Clyde/Irish Sea/Celtic Sea
100	Scotland and E&W	Clyde/Irish Sea/Celtic Sea

101	E&W	North Sea
112	Ireland	West of UK
113	Ireland	Clyde/Irish Sea/Celtic Sea
114	E&W	Clyde/Irish Sea/Celtic Sea
115	E&W	North Sea
122	GN&B	North Sea
124	GN&B	North Sea
125	Ireland	West of UK
126	Ireland	Clyde/Irish Sea/Celtic Sea
127	E&W	Clyde/Irish Sea/Celtic Sea
128	E&W	North Sea
129	E&W	North Sea
133	GN&B	North Sea
134	Ireland	Clyde/Irish Sea/Celtic Sea
135	E&W	Clyde/Irish Sea/Celtic Sea
136	E&W	North Sea
138	GN&B	North Sea
139	Ireland	West of UK
140	Ireland	West of UK
141	Ireland	Clyde/Irish Sea/Celtic Sea
142	E&W	Clyde/Irish Sea/Celtic Sea
143	E&W	North Sea
145	GN&B	North Sea
146	E&W	North Sea
148	GN&B	North Sea
152	E&W	Clyde/Irish Sea/Celtic Sea
153	E&W	English Channel
154	E&W and France	English Channel
155	E&W and France	North Sea
159	E&W	English Channel
160	France	English Channel
161	France	English Channel

Table 8 Coastal cells for which monthly nitrate + nitrite fluxes (kg month^{-1}) were estimated, the nations contributing to each cell, and their assignment to larger regions.

The data were then aggregated by region, and the time series derived of annual flux (tonnes year^{-1}) and monthly average flux (tonnes month^{-1}) by region (Figures 7-10).

The results show the nitrogen flux to the North Sea peaking in the 1980's at about double that in the 1960's. Since 1990 there has been an underlying decrease in oxidised nitrogen input to the North Sea from riverine sources.

In the waters west of the UK (Clyde, Irish Sea, Celtic Sea and Atlantic shelf waters, the oxidised nitrogen flux reached a peak at around 2000, and has since declined. Fluxes to the English Channel have increased steadily since the 1960's, with no underlying decline in recent years. In contrast, fluxes to the Skagerrak and Kattegat have remained relatively stable over the same period.

The mean seasonal pattern on fluxes shows approximately 2-3 times the rate of input in winter compared to summer in all regions except the Skagerrak and Kattegat. Here, the seasonal pattern is approximately the inverse of that in other regions with maximum input rates in the summer, partly due to the freshwater discharge from Swedish and Norwegian rivers which show peak flows in the spring and summer due to snow melt inland.

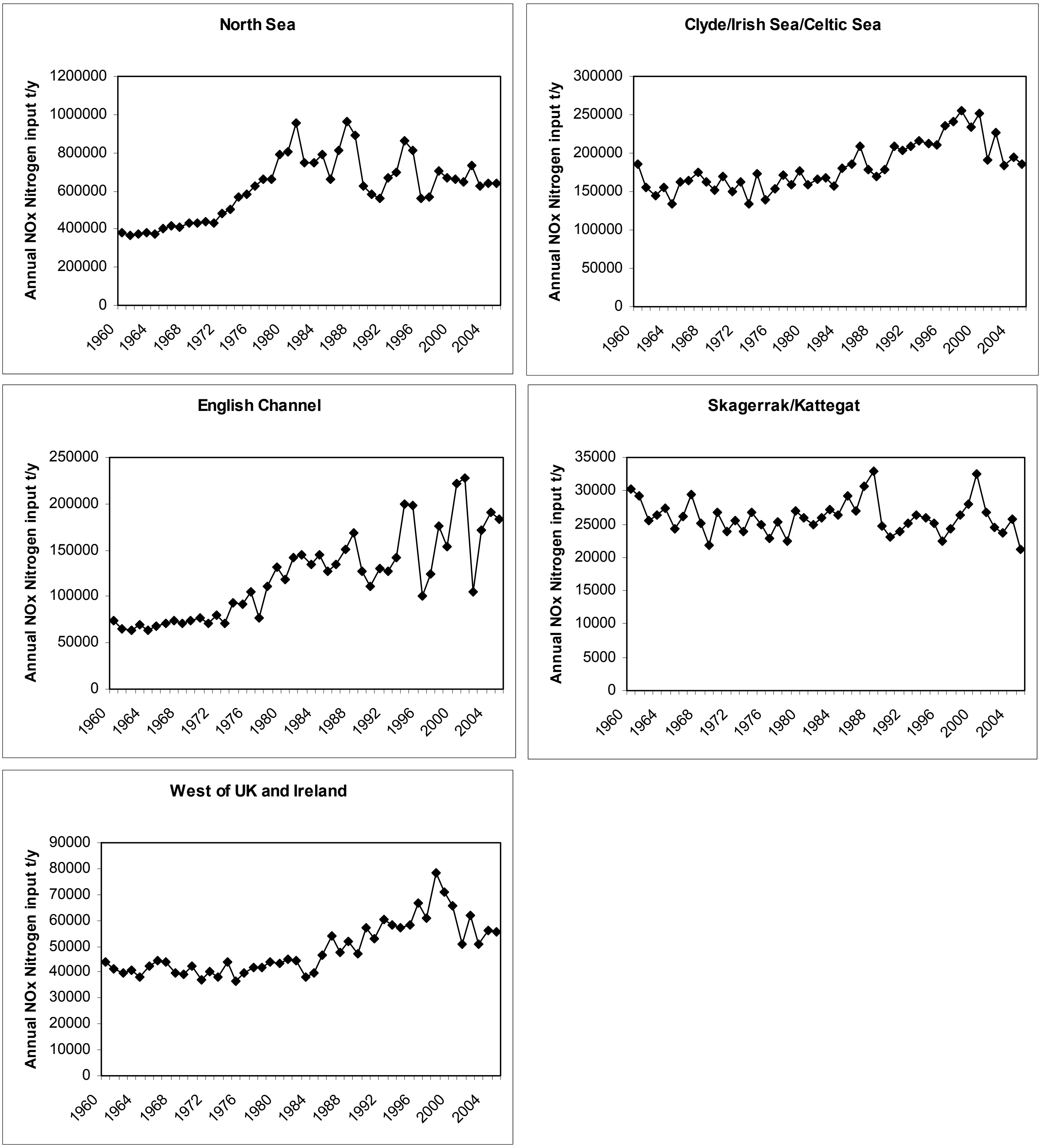

Figure 7 Annual riverine fluxes (tonnes year $^{-1}$) of nitrogen as nitrate plus nitrite to 5 regions of the northwest European shelf between 1960 and 2005.

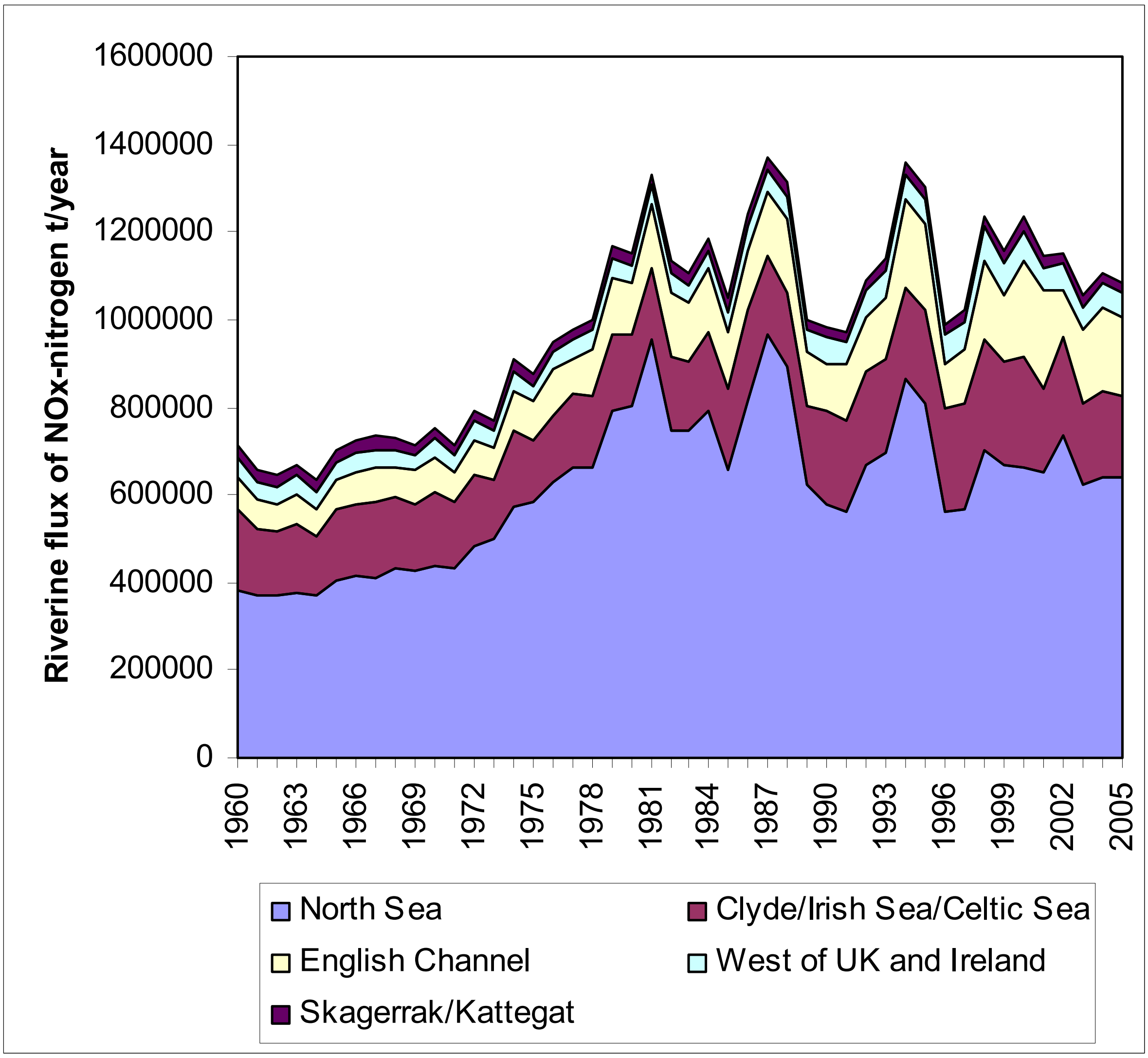

Figure 8 Annual riverine fluxes (tonnes year^{-1}) of nitrogen as nitrate plus nitrite accumulated over 5 regions of the northwest European shelf between 1960 and 2005.

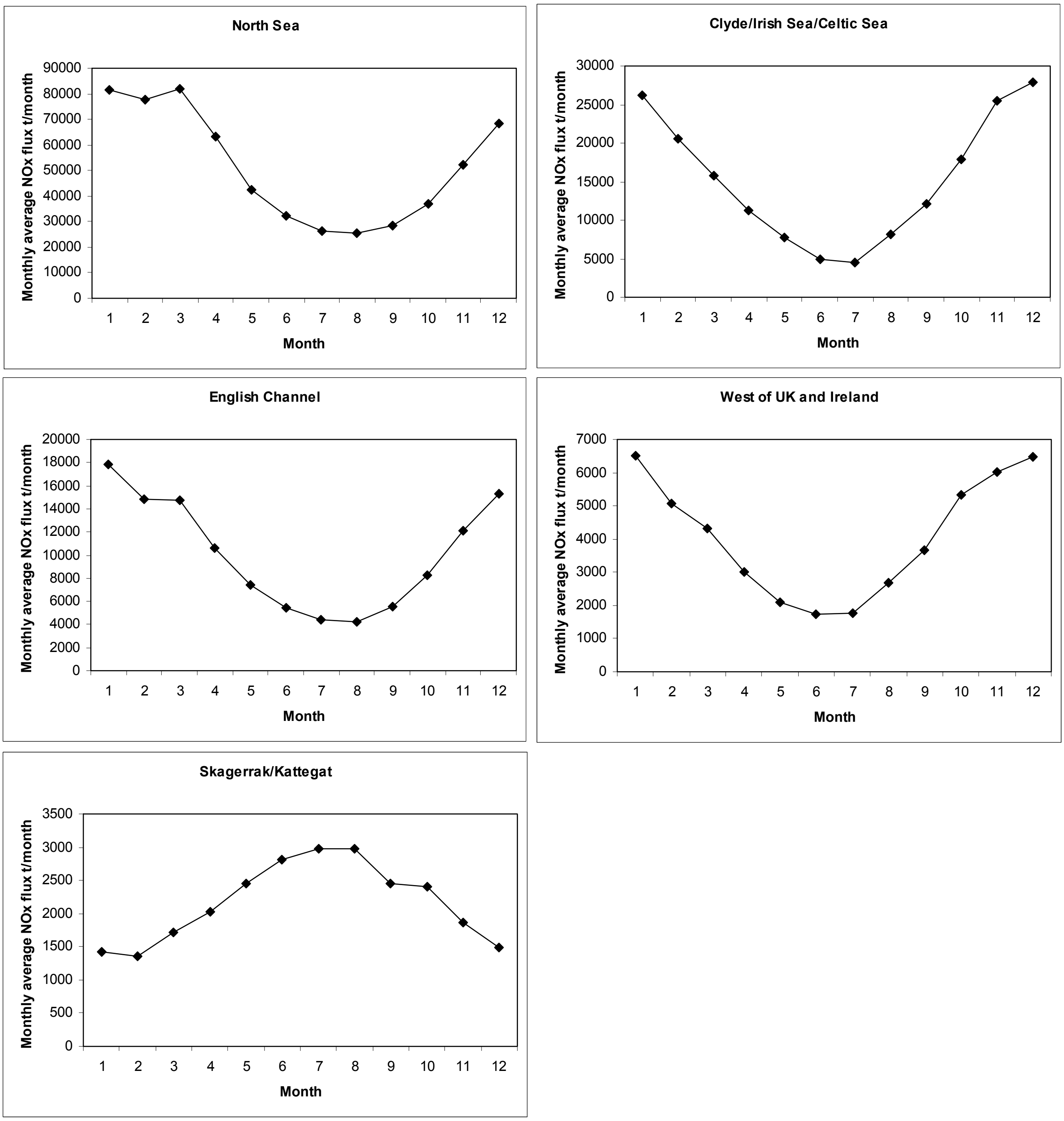

Figure 9 Monthly riveri ne fluxes (t onnes month^{-1}) of nitrogen as nitrate plus nitrite to 5 regions of the northwest European shelf averaged over the years 1960 to 2005.

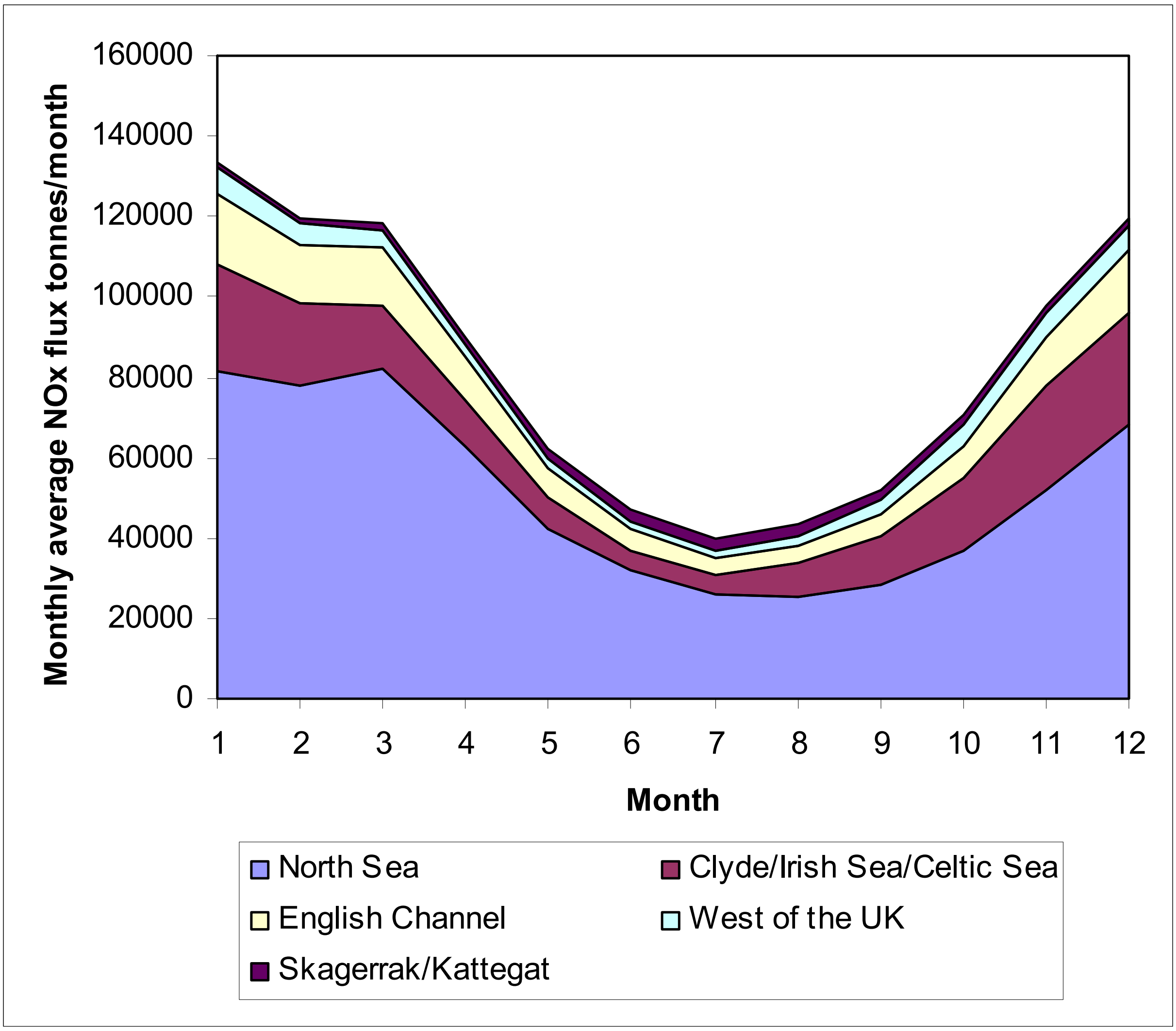

Figure 10 Monthly riverine fluxes (tonnes $month^{-1}$) of nitrogen as nitrate plus nitrite accumulated over 5 regions of the northwest European shelf, averaged over the years 1960 to 2005.

Comparison Between Modelled Oxidised Nitrogen Fluxes and Riverine Input Data Reported to OSPAR.

The models developed for Norway, Sweden, Denmark and France were all essentially calibrated against fluxes of nitrate plus nitrite derived by national monitoring authorities and reported to OSPAR, and hence should be consistent with internationally recognised data. For example, data on inputs of nitrate-nitrogen to cell 161 submitted by France to the Fifth North Sea Conference (The North Sea Secretariat 2002), which did not form part of the calibration data set of the model, were in close agreement with the model results (Figure 11).

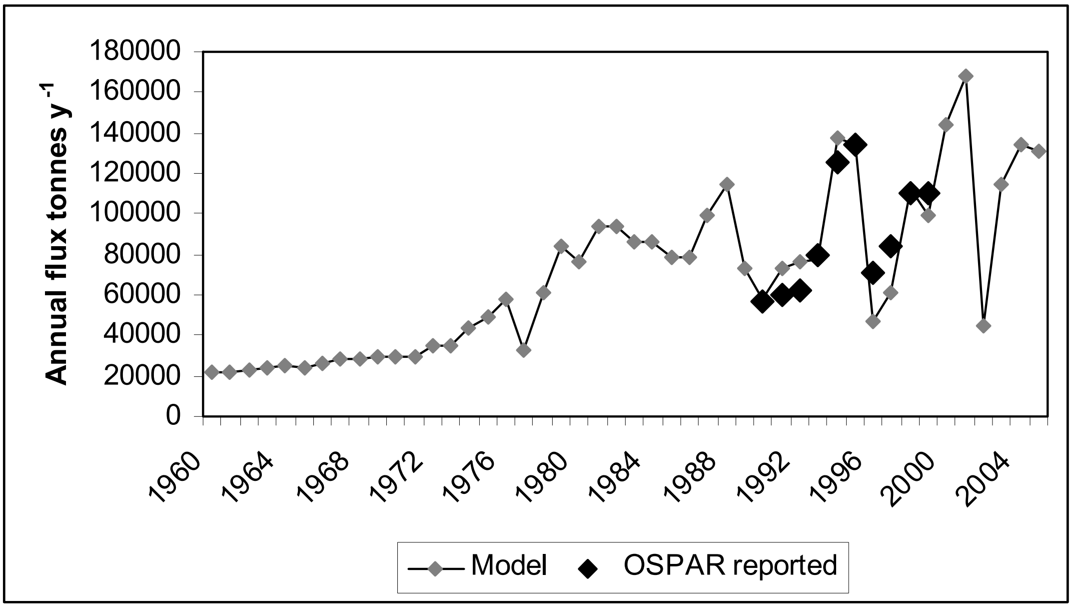

Figure 11 Model predictions of th e annual flux of nitrate+nitrite to co astal cell 16 1 (tonnes year^{-1}) compared to annual fluxes reported by France to the Fifth North Sea Conference.

However, OSPAR data submitted by the UK did not play any part in the calibration of the model. The models for Scotland, England, Wales and Northern Ireland were calibrated against the fluxes estimated for each coastal cell by Edwards (for Heath *et al*., 2002) which do not form part of the UK submission to OSPAR.

The 2006 O SPAR Assessment and Monitoring Report on riverine and direct discharges to the sea contains UK-wide estimates riverine inputs of nitrate (plus nitrite) to the sea. These were consistently approximately hal f of the UK-wide values predicted b y the sum o f models for Scotland, England and Wales and Northern Ireland presented here (Figure 12).

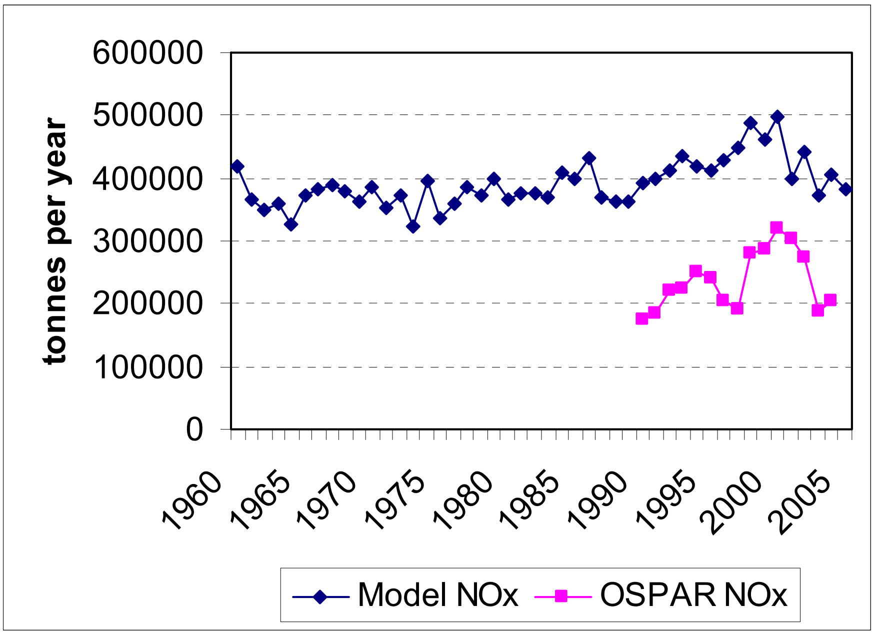

Figure 12 UK (Scotland, England, Wales and Northern Ireland) flux for ni trate plus nitrite to the sea, pr edicted fro m the model result s, and as rep orted by the national authority to OSPAR. Repored values from OSPAR 2006).

Further investigation showed that freshwater discharge rate from the UK reported to OSPAR was also substantially smaller than predicted by the model (Figure 13).

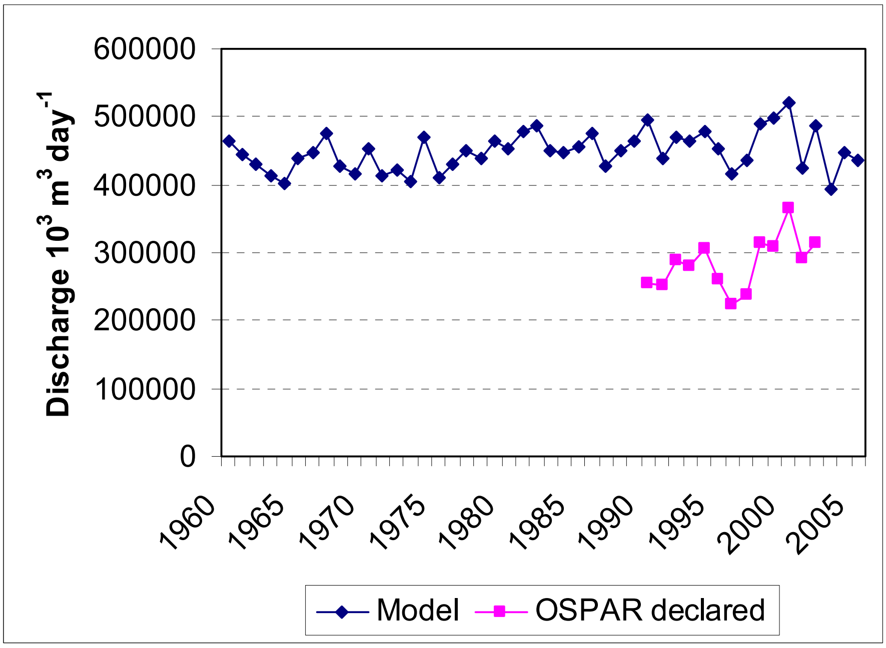

Figure 13 UK (Scotland, England, Wales and Northern Ireland) fluxes of freshwater to the sea, predicted from the model results, and as reported by the national authority to OSPAR.

Since the model was essentially calibrated against the discharge and nitrogen fluxes estimated by Edwards for Heath *et al* (2002), the values reported to OSPAR for 1990, which corresponds with one of the years analysed by Edwards, were investigated more closely.

UK riverine data for submission to OSPAR are assembled according to a set of river catchment assessment areas which are a sub-sets of 6 OSPAR sea areas (Figure 14). For 1990, the annual volume flux data to river assessment areas reported to OSPAR, grouped to match the coastal cells modelled in this report, are shown in Figures 15 and 16, together with the values estimated by Edwards for Heath *et al*. (2002).

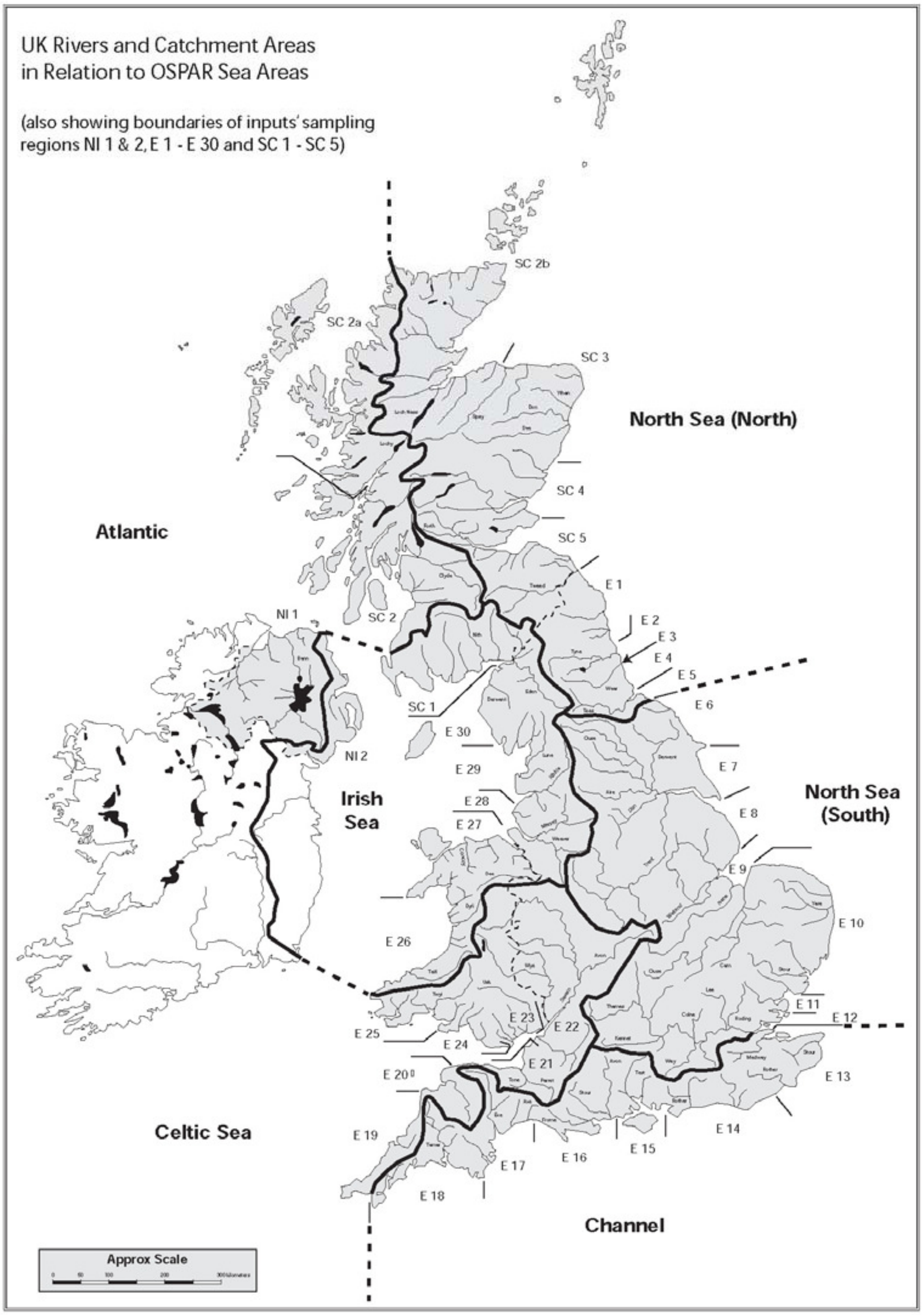

Figure 14 River catchment assessment areas (SC1-SC5, E1-E30 and NI1-NI2) used in th e compilation of discharge and nutrient inputs reported to OSPAR.

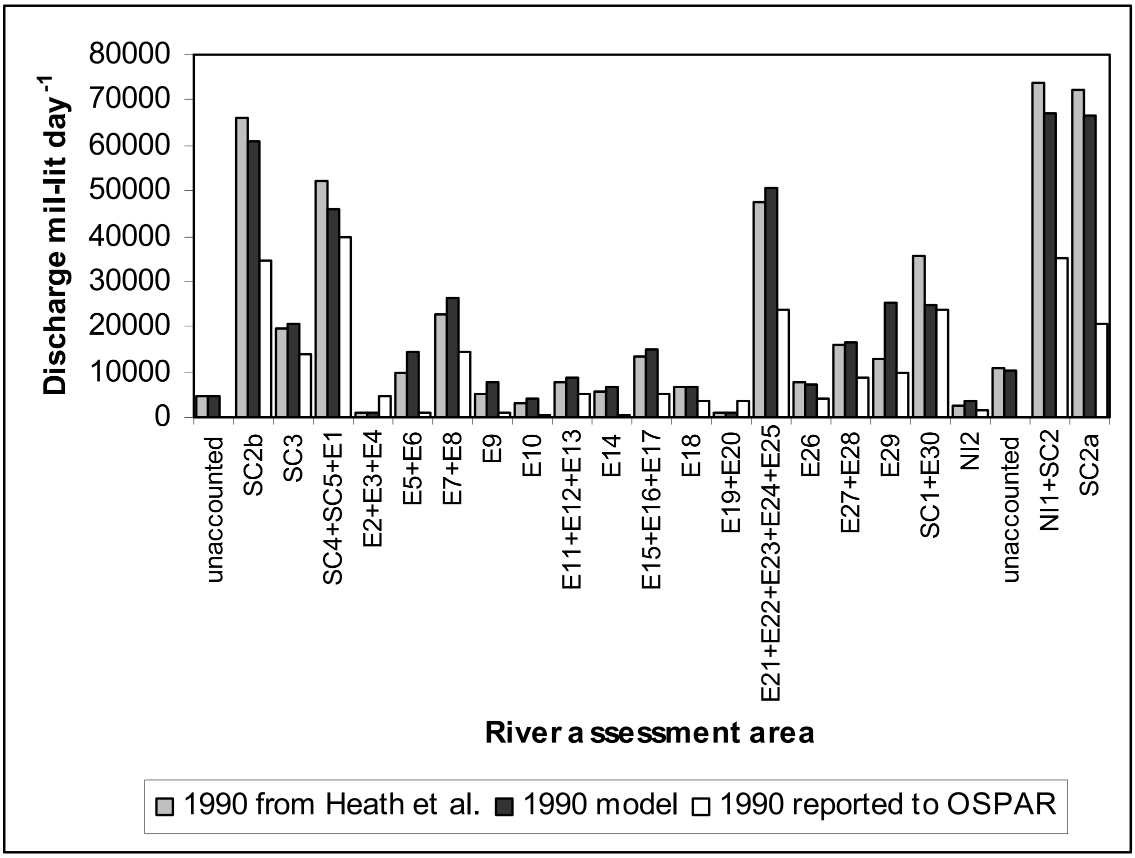

Figure 15 Freshwater discharge (annual average daily rate) from the UK for groupings of the river assessment areas shown in Figure 13, as estimated by Edwards for Heath *et al*. (2002) (pale grey), by the mod el described here (dar k grey) and as reported b y the UK to OSPAR (white).

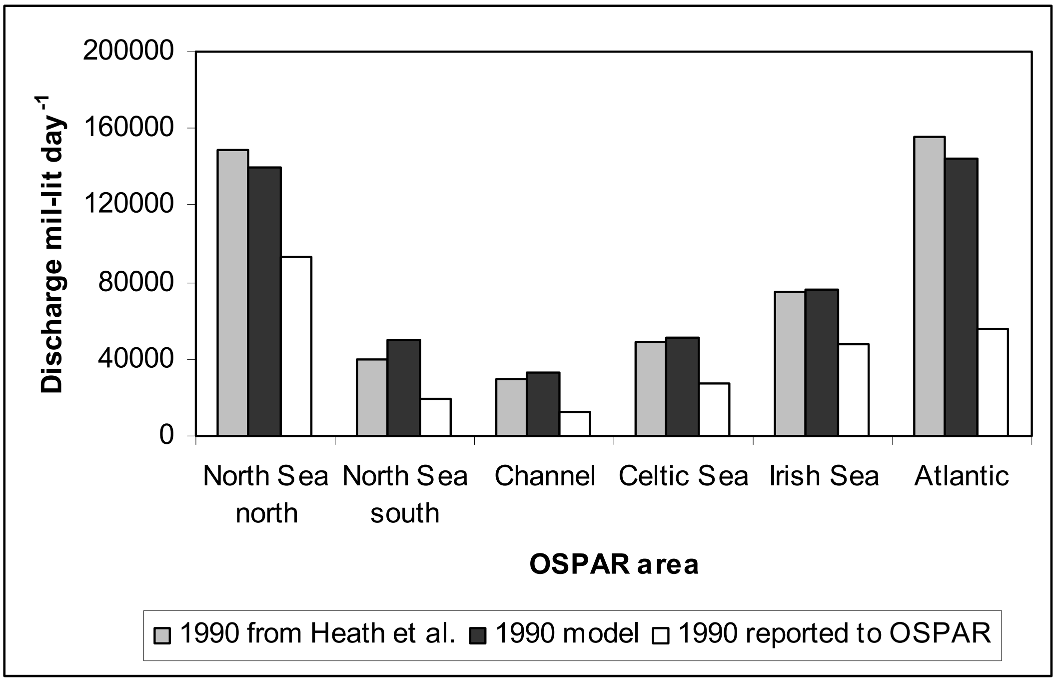

Figure 16 Data from Figure 15 aggregated by OSPAR sea area.

It was clear that the model performed well relative to the data from Edwards, against which it had been calibrated, but for every river assessment area except 1 (E2+E3+E4), the freshwater discharge was substantially higher than the values reported to OSPAR. However, the runoff (approximately rainfall less evaporation and transpiration) implied by the discharge data from Edwards were in close agreement with runoff estimates for the catchment of each of the major rivers flowing into the assessment areas listed in the NRFA database (Table 9, Figure 17). Assuming the runoff to each river assessment area to have been correctly estimated by Edwards, the flow data reported to OSPAR therefore imply catchments which are substantially smaller than is actually the case.

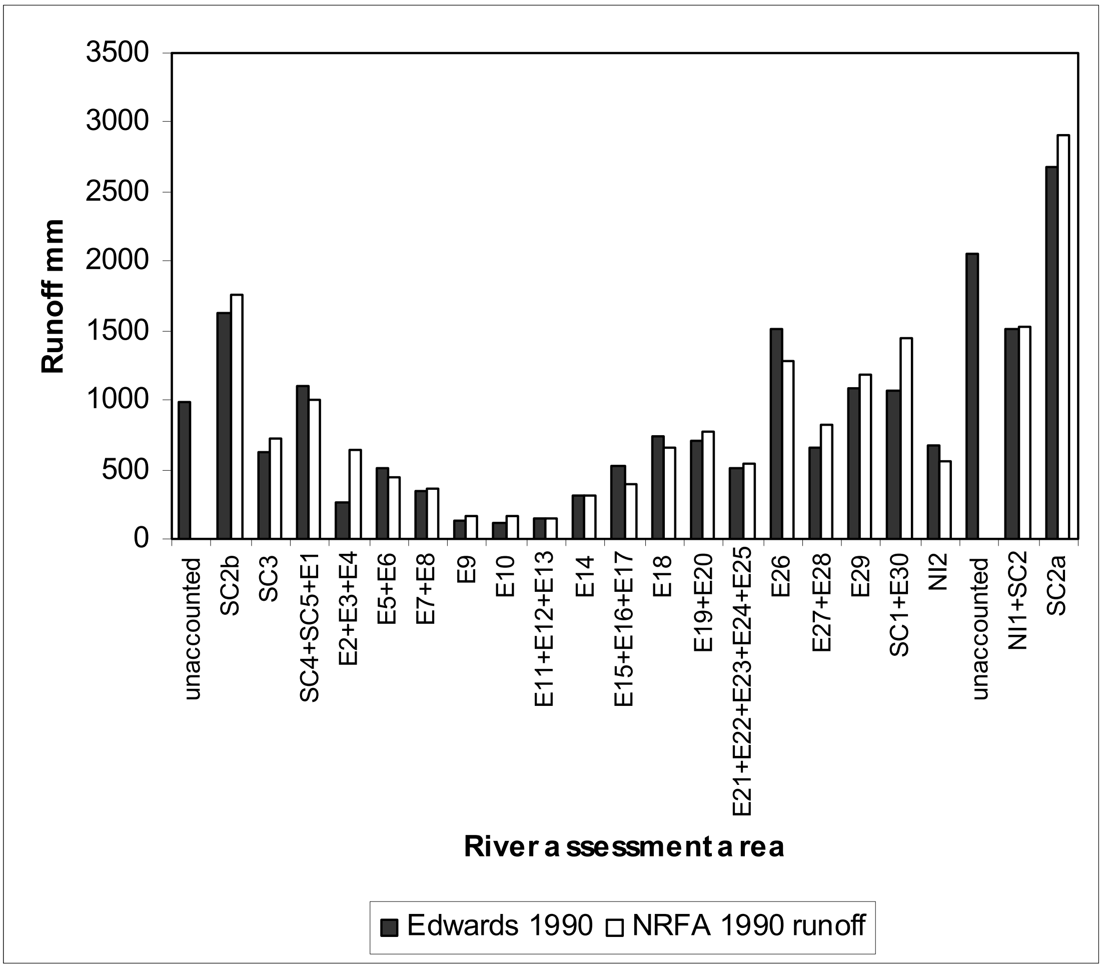

Figure 17 Runoff (mm) from the catchment of each river assessment area in 1990, as estimated by Edwards for Heath *et al* (2002), and from the NRFA database for the catchments of the major rivers flowing into each area.

River	Gauging site	Coastal cell	River assessment area	1990 runoff	1990 runoff as % of LTA
Halladale	Halladale	28	SC2b	988	129
Connon	Moy Bridge	35	SC2b	2541	167
Dee	Park	49	SC3	719	92
Tay	Ballathie	65	SC4	1479	134
Almond	Craigiehall	65	SC5	679	141
Carron	Headswood	65	SC5	1188	144
Coquet	Morwick	75	E1	337	70
Tweed	Norham	75	SC5	615	111
Tyne	Bywell	88	E2	641	100
Dove	Kirby Mills	101	E5	439	75

Ouse	Skelton	128	E7a	454	98
Trent	Colwick	128	E7a	280	78
Glen	Kates Br and King St Br	128	E9	44	39
Babingley	Castle Rising	128	E9	161	46
Bure	Ingworth	136	E10	164	77
Thames	Kingston	146	E12	140	66
Uck	Isfield	154	E14	317	80
Stour	Throup	153	E16	368	96
Itchen	Highbridge+Allbrook	153	E15	428	92
Fal	Tregony	159	E18	654	90
Taw	Umberleigh	152	E20	653	95
Camel	Denby	152	E19	886	101
Severn	Bewdley	142	E23	402	89
Teme	Tenbury	142	E23	344	86
Rhymney	Llanederyn	142	E23	860	90
Dyfi	Dyfi Bridge	135	E26	1499	99
Ystwyth	Pont Llolwyn	135	E26	1062	97
Elwy	Pont-y-Gwyddel	127	E27	709	104
Dee	Manley Hall	127	E27	947	99
Ribble	Salmesbury	114	E29	882	96
Kent	Sedgwick	114	E29	1484	113
Weaver	Ashbrook	127	E28	273	94
Derwent	Camerton	100	E30	1329	109
Cree	Newton Stewart	100	SC1	1564	119
Laggan	Newforge	99	NI2	578	109
Clanrye	Mounthill Bridge	99	NI2	526	91
Bush	Seneirl Bridge	86	NI1	898	137
Levem	Linbranne	74	SC2	2174	130
Ewe	Poolewe	34	SC2a	2841	138
Carron	New Kelso	47	SC2a	3376	136
Inver	Little Assynt	34	SC2a	2502	131

Table 9 Catchment runoff data for 1990, for major rivers flowing into each river assessment area, obtained from the NRFA database (http://www.nwl.ac.uk/ih/nrfa/webdata/index.html).

In fact, UK submissions to OSPAR acknowledge that riverine discharges from the un-gauged parts of each catchment are not accounted for in the submitted data, whereas un-gauged discharges were carefully accounted for by Edwards in the data provided for Heath *et al*. (2002) (see Appendix 2). So, we should expect there to be a difference between the two sets of data. The UK submission to OSPAR in 2006 (OSPAR 2006a) states that “riverine inputs cover some 80% of the land mass “ and, “the total inputs reported have not been proportioned up to give a 100 % estimated value”. In fact, the results presented here imply that UK-wide the flow data reported to OSPAR represent runoff from only 53 % of the total land area. This proportion varies between 38% for the Atlantic catchment, and 71% for the northern North Sea catchment (Northern North Sea 71%, Southern North Sea 45% , Channel 43%, Celtic Sea 55%, Irish Sea 63%, Atlantic 38%) (Figure 18).

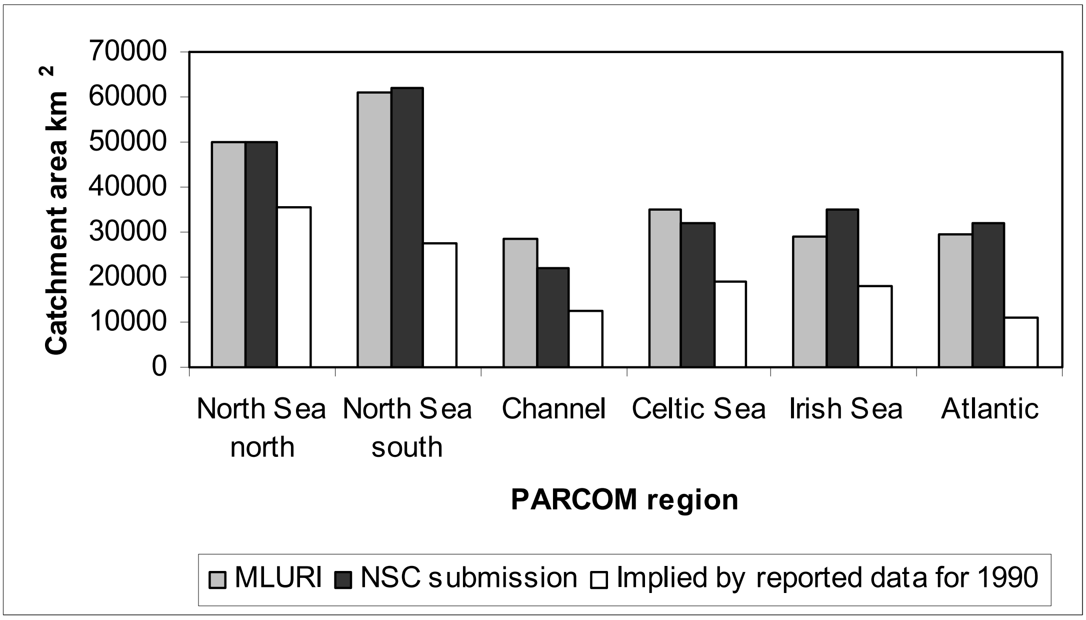

Figure 18 Catchment areas (km2) for each of the OSPAR (PARCOM) sea regions receiving freshwater discharges from the UK, as estimated by Edwards for Heath *et al*. (2002), as stated in the UK submission to the Fifth North Sea Conference (The North Sea Secretariat 2002), and as implied by the flow data submitted by the UK to OSPAR for 1990.

The annual average mass of nitrate+nitrite nitrogen per unit volume of discharge in 1990 estimated by Edwards for each OSPAR sea area was similar to that implied by the flow and nitrogen flux data reported to OSPAR by the UK (Figure 19). Hence, the discrepancy between the UK annual input of oxidised nitrogen as estimated by Edwards and as reported to OSPAR arises mostly from the underestimation of flow rates.

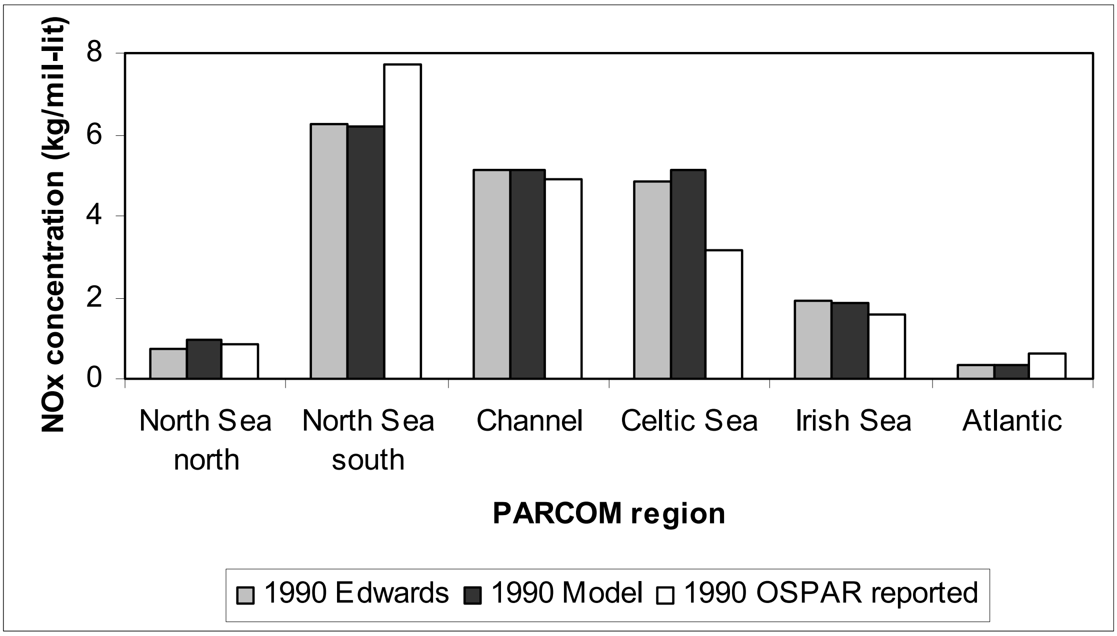

Figure 19 Mass of nitrate+nitrite nitrogen per unit volume of discharge (annual average) in 1990, as estimated by Edwards for Heath *et al* (2002), as estimated by the model, and as implied by the UK flow and nitrate inputs reported to OSPAR.

Having acknowledged the lack of accounting for discharge from the un-gauged part of the catchment, the 2006 UK submissions to OSPAR states that "as direct inputs account for all significant inputs downstream of the monitoring stations, it is considered that, overall, the 90% coverage target has been met". However, direct inputs of nitrate-nitrogen reported for 1990 amounted to 23,200 tonnes UK-wide, which brings the UK estimate of input up to only 58% of the riverine flux estimated by Edwards. Clearly, nutrients exported with freshwater discharged from the un-gauged portions of the catchments are not a trivial component of the total input to the sea and cannot be ignored. We conclude that their omission accounts for the discrepancy between the model results described here and the UK data available from OSPAR.

Shortcoming and Benefits of the Modelling Approach

The major shortcoming of the approach described here are that different methods had to be applied for different regions depending on the availability of raw data. There is little uniformity across the nations involved regarding public access to flow and concentration data.

The statistical approach to estimating freshwater discharge to the sea from rainfall data has a clear logical basis, but cannot be expected to represent inter annual variations in evaporation and transpiration losses of water from the catchments which will lead to variation in the relationship between rainfall and runoff. Similarly, the representation of variations in the concentration of nitrate+nitrite in discharged waters is crude, assuming a stable seasonality and year-to-year changes which are parameterised from highly aggregated data. But, given the state of data and the resources available for the task, the approach taken here appears to have been successful. Certainly, there is a good fit between the model and the available calibration data (e.g. Figures 3, 4 and 5) and where available, validation data (Figure 11).

The assembly of comprehensive, spatially resolved time series data sets describing the flux of nutrients from the land to the sea is desperately needed for progress with ecosystem modelling studies designed to provide assessments of the eutrophication status of shelf waters. OSPAR and other modelling groups have regularly struggled with the assembly of such data (Pätsch and Radach 1997, OSPAR 2006b). Statistical reconstruction techniques such as described here probably represent a practical solution to this problem since mechanistic estimations such as prescribed by OSPAR HARP-NUT Guidelines are unlikely to be feasible for years prior to 1990 when available data are sparse.

Acknowledgements

Thanks to Johannes Pätsch at Ifm Hamburg for making available the data on nutrient inputs to German, Dutch and Belgian coastal waters. The work was part funded by a contract from the EU-JRC Ispra Exploratory Research Project "Comparing spatial, long-term and seasonal changes in potential new production with fish biomass in the temperate seas of the North East Atlantic Continental Shelf".

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http://www.sft.no/publikasjoner/overvaking/1793/ta1793.pdf

TABLE 10 - Sources of precipitation data (mm per month)

Nation	Source	Description	Sites
Scotland	UK Meteorological Office http://www.metoffice.gov.uk/climate/uk/stationdata/index.html	Monthly int egrated precipitation at selected sit es (mm/mo nth), 1960-2005.	Braemar Lerwick Leuchars Paisley Stornoway Tiree
England and Wales	UK Meteorological Office http://www.metoffice.gov.uk/climate/uk/stationdata/index.html	Monthly int egrated precipitation at selected sit es (mm/mo nth), 1960-2005.	Aberporth Armagh Bradford Cambridge Cardiff Durham Eastbourne Greenwich Hurn Newtonrigg Oxford Ringway RossonWye Shawbury Sheffield Southampton StMawgan SuttonBonnington Valley Yoevileton
Northern Ireland	UK Meteorological Office http://www.metoffice.gov.uk/climate/uk/stationdata/index.html	Monthly int egrated precipitation at selected sit es (mm/mo nth), 1960-2005.	Armagh Northern Ireland

	http://www.metoffice.gov.uk/climate/uk/2003/february.html http://www.metoffice.gov.uk/climate/uk/seriesstatistics/nirain.txt	Monthly integrated precipitation (mm/month) averaged over the region taking account of topographic, coastal and urban effects, 1960-2005.	regional average monthly rainfall
Irish Republic	The Irish Meteorological Service http://www.met.ie/climate/rainfall.asp	1961-1990 monthly average rainfall (mm/month).	Belmullet Birr Casement Claremorris Clones Cork Dublin Kilkenny Malin Mullingar Rosslare Shannon Valentia
Norway	Norwegian Meteorological Institute http://met.no/met/ver_100/nedbor_100/geografisk/normalar.html http://met.no/met/ver_100/nedbor_100/geografisk/index.html	1961-1990 regional monthly average rainfall (mm/month). Monthly rainfall from 1900-2006 as a percentage of the 1961-1990 average for each region.	Austlandet Agder Vestlandet Austlandet Agder Vestlandet

TABLE 11 - Sources of river volume discharge data (volume per unit time)

Nation	Source	Description	Sites
Scotland	Provided by A. Edwards (Macaulay Land Use Research Institute) for Heath *et al*. 2002	Daily volume discharge to each coastal cell from the entire land catchment for 1984, 1987 and 1990.	29 coastal cells
	National River Flow Archive http://www.nwl.ac.uk/ih/nrfa/webdata/index.html	Daily flow rates and catchment runoff for selected rivers in 1990.	12 river monitoring sites
England and Wales	Provided by A. Edwards (Macaulay Land Use Research Institute) for Heath *et al*. 2002	Monthly volume discharge to each coastal cell from the entire land catchment for 1984, 1987 and 1990.	19 coastal cells
	National River Flow Archive http://www.nwl.ac.uk/ih/nrfa/webdata/index.html	Daily flow rates and catchment runoff for selected rivers in 1990.	26 river monitoring sites
Northern Ireland	Provided by A. Edwards (Macaulay Land Use Research Institute) for Heath *et al*. 2002	Monthly volume discharge to each coastal cell from the entire land catchment for 1990.	8 coastal cells
	National River Flow Archive	Daily flow rates and	3 river monitoring

	http://www.nwl.ac.uk/ih/nrfa/webdata/index.html	catchment runoff for selected rivers in 1990.	sites
Irish Republic	Provided by A. Edwards (Macaulay Land Use Research Institute) for Heath *et al.* 2002	Monthly volume discharge to each coastal cell from the entire land catchment for 1990.	8 coastal cells
Norway	Norwegian Pollution Control Authority http://www.sft.no/publikasjoner/vann/2147/ta2147.pdf Borgvand, S.A. (2006). Riverine inputs and direct discharges to Norwegian coastal waters – 2004. (TA-2147/2006). Study undertaken by the Norwegian Institute for Water Research – NIVA	1974-2003 average monthly river flow.	Otra Skienselva Numedalslaagen Drammenselva Glomma
		Long-term average flow for Norwegian rivers.	Otra Skienselva Numedalslaagen Drammenselva Glomma Orreelva Suldalslagen
	Norwegian Water Technology Centre Report 00-052 http://www.sft.no/publikasjoner/overvaking/1793/ta1793.pdf Weideborg *et al* (2001). OSPAR Commission. Annual report on direct and riverine inputs to Norwegian coastal waters during the year 1999. A. Principles, results and discussion. Aquateam Report 00-052. 41pp.	Average annual freshwater discharge to Norwegian coastal regions.	Skagerrak: Swedish border to Lindesnes; North Sea: Lindesnes to Stad
Denmark	Danmarks Miljoundersogelser (National Environmental research Institute Denmark), Vandlob og kilder 2000. Faglig rapport fra DMU, nr 378. 118pp. http://www2.dmu.dk/1_viden/2_publikationer/3_fagrapporter/rapporter/FR378.pdf	1971-2000 monthly average volume discharge to coastal regions around Denmark.	North Sea Skagerrak Kattegat

Germany, Netherlands and Belgium	University of Hamburg ftp://ftp.ifm.zmaw.de/pub/data/riverload/ Pätsch and Lenhart 2004	Daily volume discharge from individual rivers,, 1977-2002.	Elbe Weser Ems Ijssel Nordzeekanaal Nieuwewaterweg Haringvlet Scheldt
France	Lacroix *et al*. 2004 Aminot *et al*. 1998 Cugier *et al*. 2005 http://en.wikipedia.org/wiki/Somme_River#Flow-rate_data_.28external_links.29 The Progress Report on the Fifth North Sea Conference. Compilation of submitted inputs to the progress report of the Fifth North Sea Conference. Further reductions of nutrient inputs to the North Sea. Part II: Inputs of nutrients using HARP-NUT Guidelines. The North Sea Secretariat, 2002. http://odin.dep.no/filarkiv/160835/Nutrient-Compl.doc	1991-2002 daily flow rates. Annual volume discharge, 1992, 1993, 1994. Long-term mean flow rate. Hydrometric data and some flow data. Annual volume discharge data, 1989-2000.	River Seine River Seine River Seine River Somme River Aa Rivers Canche, Authie, Somme, Wimereux, Liane, Aa, Slack, Saire, Divette, Touques, Dives, Orne, Seulles, Vire, Seine, Andelle and Eure

TABLE 12 - Sources of river nutrient concentration data (mg nitrogen per litre)

Nation	Source	Description	Sites
Scotland	Scottish Environmental Protection Agency http://www.sepa.org.uk/data/hm/hm.asp	Sample-by-sample data on nitrate and nitrite (mg l^{-1})from 1975 onwards (start date varies between rivers), at the most downstream sampling site on each river.	Ayr Beauly Carron Clyde Connon Cree Dee Deveron Don Earn Eden Esk Eye Findhorn Forth Irvine Leith Leven Leven(Clyde) Lochy Lossie N-Esk Ness S-Esk Shin Spey Tay Teith Thurso

			Tweed Tyne Ythan
England and Wales	Department of Environment Fisheries and Rural Affairs http://www.defra.gov.uk/environment/statistics/inlwater/iwnutrient.htm#iwtb09b	1980-2004 annual average of all site means in each water authority region, each being given equal weight, irrespective of the number of samples taken.	North West North East Midlands Anglian Thames Southern North West Welsh
Northern Ireland	Environmental Change Network database, Centre for Ecology and Hydrology , Lancaster http://www.ecn.ac.uk/Database/get_sandm.asp?st=R	Quarterly and/or annual average nutrient concentrations in individual rivers, 1994-2003.	Bush Garvery Faughan
Irish Republic	Environmental protection Agency, Ireland http://www.epa.ie/NewsCentre/ReportsPublications/Water/FileUpload,6708,en.pdf Toner, P. *et al.* (2005). Water Quality in Ireland 2001-2003, page 32	1980-2002 annual average nitrate mgl^{-1}	Barrow Nore Slaney Suir
Norway	Norwegian Pollution Control Authority http://www.sft.no/publikasjoner/vann/2147/ta2147.pdf Borgvand, S.A. (2006). Riverine inputs and direct discharges to Norwegian coastal waters – 2004. (TA-2147/2006). Study undertaken by the Norwegian Institute for Water Research - NIVA	Annual average concentration of nitrate and total nitrogen in Norwegian rivers.	Otra Skienselva Numedalslaagen Drammenselva Glomma
Sweden	Department of Environmental Assessment http://info1.ma.slu.se/ma/www_ma.acgi$Project?ID=StationsMap&P=FLODMYNN&M=default	1967-2005, sample-by-sample, total nitrogen, nitrate and nitrite at monitoring sites on rivers flowing into the Skagerrak and Kattegat.	Munkendal Alelyckan Asbro Halmstad
France	Centre d'Enseignement dt de Recherche Eau Ville Environment http://www.enpc.fr/cereve/HomePages/thevenot/piren-	Annual average nitrate concentrations, 1900-1992.	River Seine

	models.pdf		

TABLE 13 - Sources of river nutrient flux data (mass of nitrogen per unit time)

Nation	Source	Description	Sites
Scotland	Provided by A. Edwards (Macaulay Land Use Research Institute) for Heath *et al*. 2002	Daily mass of nitrate and nitrite discharged to each coastal cell from the entire land catchment for 1984, 1987 and 1990.	29 coastal cells
England and Wales	Provided by A. Edwards (Macaulay Land Use Research Institute) for Heath *et al*. 2002	Monthly mass of nitrate and nitrite discharged to each coastal cell from the entire land catchment for 1984, 1987 and 1990.	19 coastal cells
Northern Ireland	Provided by A. Edwards (Macaulay Land Use Research Institute) for Heath *et al*. 2002	Monthly mass of nitrate and nitrite discharged to each coastal cell from the entire land catchment for 1990.	8 coastal cells
Irish Republic	Provided by A. Edwards (Macaulay Land Use Research Institute) for Heath *et al*. 2002	Monthly mass of nitrate and nitrite discharged to each coastal cell from the entire land catchment for 1990.	8 coastal cells
Norway	Norwegian Pollution Control Authority http://www.sft.no/publikasjoner/vann/2147/ta2147.pdf Borgvand, S.A. (2006). Riverine inputs and direct discharges to Norwegian coastal waters – 2004. (TA-2147/2006). Study undertaken by the Norwegian Institute for Water Research - NIVA	2004 annual input of nitrate from Norwegian rivers to coastal assessment regions. Observed and flow normalised annual nitrogen inputs to the coastal zone from individual Norwegian rivers, 1991-2004.	Skagerrak region North Sea region Otra Skienselva Numedalslaagen Drammenselva Glomma
Sweden	Swedish Environmental Protection Agency http://www.internat.naturvardsverket.se/index.php3?main=/documents/pollutants/overgod/eutro/flode.html	1969-2001 annual nitrogen input to the Skagerrak and Kattegat.	Southern Sweden
Denmark	Ærtebjerg, *et al*. 2003 http://www2.dmu.dk/1_Viden/2_Miljoetilstand/3_vand/4_eutrophication/inputs.asp	2001 nitrog en mass in put from Denmark to coastal regions.	North Sea Skagerrak
Germany, Netherlands and	University of Hamburg http://www.ifm.uni-	Daily mass of nutrients input to the coastal zone from individual rivers, 1955-1993.	Elbe, Weser Jade

Belgium	hamburg.de/~wwwem/dow/ERSEM/ERSEM.ZIP Pätsch and Radach 1997 ftp://ftp.ifm.zmaw.de/pub/data/riverload/ Pätsch and Lenhart 2004	Daily mass of nutrients input to the coastal zone from individual rivers, 1977-2002.	Ems Lysselo Lysselw Lauer Ijmuiden Rhine Meuse Scheldt Yzer Elbe Weser Ems Ijssel Nordzeekanaal Nieuwewaterweg Haringvlet Scheldt
France	Aminot *et al*. 1997 Cugier *et al*. 2005 The Progress Report on the Fifth North Sea Conference. Compilation of submitted inputs to the progress report of the Fifth North Sea Conference. Further reductions of nutrient inputs to the North Sea. Part II: Inputs of nutrients using HARP-NUT Guidelines. The North Sea Secretariat, 2002.	1976-1994 annual mass of nitrate and nitrite input to the Bay of the Seine. Average annual mass of nitrogen input to the Bay of the Seine. Annual mass of nitrate and nitrite discharges by various rivers, 1989-2000.	River Seine Rivers Seine, Orne, Vire and Douve Rivers Canche, Authie, Somme, Wimereux, Liane, Aa, Slack, Saire, Divette,

	http://odin.dep.no/filarkiv/160835/Nutrient-Compl.doc		Touques, Dives, Orne, Seulles, Vire, Seine, Andelle and Eure

APPENDIX 1

OSPAR procedure for estimating riverine nutrient fluxes

Riverine inputs are the mass of material carried to the sea by watercourses (natural river or man-made watercourse) per unit of time. Riverine inputs are estimated from monitoring data at some location close to the point of drainage into the sea, and hence reflect the accumulation of all inputs to the catchment from, for example, natural land erosion, rainfall, agriculture, or effluent discharge. The catchment area upstream of the monitoring point is referred to as the Monitored Area. There may remain an un-monitored part of the land catchment area which drains into the monitored watercourse downstream of the monitoring point. In addition there may be an un-monitored part of the land area which drains in to minor un-monitored watercourses which discharge to the sea, or which forms a diffuse input to the sea in small streams or freshwater seepage.

Direct discharges are the mass of material discharged to the sea from point sources (sewage effluents, industrial effluents, aquaculture or other) per unit of time at a point on a coast or to an estuary downstream of the point at which the riverine estimate of input is made.

The load of a specific determinand transported by a river is the product of the mean flow-weighted concentration and the total flow, expressed by the following formula (OSPAR 1998):

$$\frac{Q_r \sum_{i=1}^{n} (C_i Q_i)}{\sum_{i=1}^{n} (Q_i)}$$

Where: C_i is the concentration measured in sample i;
Q_i is the corresponding flow for sample i;
Q_r is the mean flow rate for each sampling period; and
n is the number of samples taken in the sampling period.

In cases where insufficient data are available to use the above formula, it is recommended that the load should be estimated by taking the average of the product of flow and concentration for a series of measurements, as expressed by the following formula:

$$\frac{\sum_{i=1}^{n} (C_i Q_i)}{n}$$

For minor load bearing rivers, for which 12 data sets per annum will not be obtained, the best available estimates of flow and flow-weighted concentration should be used to estimate contaminant loads. Tributaries which discharge directly into the saline estuaries of major river systems may fall into this category. In the absence of estimates of flow and flow-weighted concentration, estimates of contaminant loads based on per capita or per hectare calculations may be used.

Quantification of losses of nitrogen and phosphorus from unmonitored areas can be achieved by the application of OSPAR HARP-NUT draft Guideline 6 (OSPAR 2004b) in respect of diffuse losses of nitrogen and phosphorus, or the extrapolation of diffuse losses monitored in a neighbouring area with similar physical conditions (soil, climate, topography) and land-use conditions; and the summation of all monitored or estimated discharges from point sources in a complimentary catchment, using a retention coefficient where appropriate (cf. OSPAR HARP NUT Guideline 9; OSPAR 2004c).

APPENDIX 2

Description of the estimation of nitrate + nitrite fluxes from Scotland, England and Wales to coastal cells for the years 1984, 1987 and 1990, from Heath *et al*. (2002) (Carried out by A Edwards, Macaulay land Use Research Institute, Aberdeen).

UK data on riverine concentrations of nutrients and contaminants are collected as part of the Harmonised Monitoring Scheme (HMS), which is separate from the monitoring of river flows (National River Flow Archive, NRFA), though in many cases the monitoring locations coincide. Administratively, the data for Scotland are collected and archived separately from those for England and Wales.

Delineation of drainage area boundaries for each ERSEM coastal box

Apportioning the land area draining into each coastal cell was achieved by using a combination of visual interpretation of OS maps and a Digital Elevation Model. The final designations for Scotland, England and Wales as a whole, which for the purpose of this report are identified as basins are shown in Figure A2.1. Note that for some cells (e.g. cell 100), where the drainage basin straddles both Scotland and England, the basin has been divided into two parts along the national boundary.

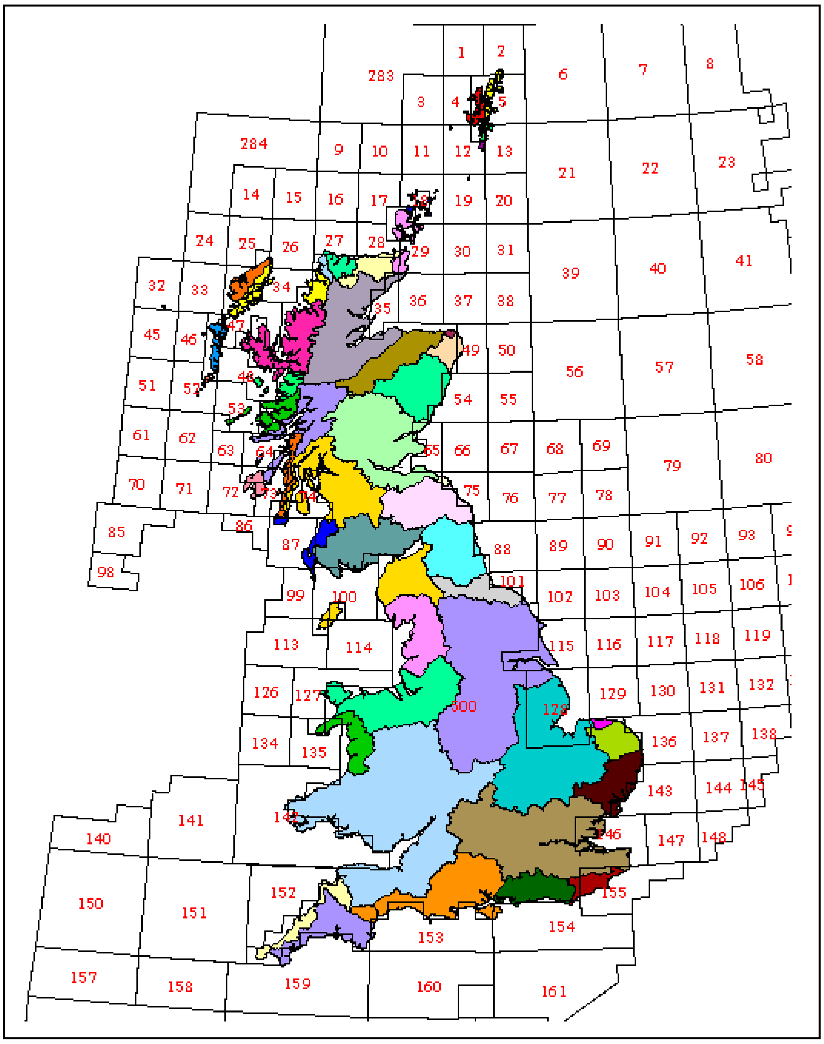

Figure A2.1 Land area of the UK (excluding Northern Ireland) divided into the drainage basins corresponding to each of the coastal cells of the ERSEM model.

Some of the physical attributes of the Scottish basins have been summarised in Table A2.1. Land cover statistics (LCS, 1988) were ascribed to each basin broadly defining the proportions of agricultural (arable and improved grassland) and non-agricultural (including moorland, urban, forestry and rough grass) land. Twelve basins areas are solely located on the mainland a further 8 consist of combined mainland/island while 10 consist of only islands, these account for 63 %, 28 % and 9 % of the total land area respectively (Table A2.1).

Table A2.1 Estimated Scottish land areas draining into individual coastal cells and the proportion of agricultural land (arable and improved grazing).

ERSEM cell ID associated with land drainage basin	Area (km^2)	Percentage Agricultural
4	655.8	13.6
5	587.2	14.7
12	74.3	33.9
13	142.4	18.7
18	269.2	61.9
19	7.9	20.8
25	300	4.7
26	366.6	0.8
27	953.9	1.4
28	1882.5	12.3
29	1247.6	47.6
32	8.6	0.0
33	802.1	4.7
34	2033.4	3.3
35	10739.2	12.0
36	4548.9	29.8
37	115.6	85.0
46	758.6	17.5
47	4894.0	3.4
48	904.4	1.6
49	1301.7	86.5
52	91.6	12.9
53	1636.1	3.6
54	5411.3	39.5
64	4810.6	2.4
65	11860.3	38.6
72	621.1	16.4
73	1082.3	13.0
74	8166.8	32.0
75	4503.4	47.3
87	1308.0	41.9
100	6753.0	33.4
Total	**78838.2**	**25.7**

Estimation of daily discharge for each coastal cell

Daily and monthly flows (m^3s^{-1}) were compiled for rivers represented in the National Flow Archives (NRFA - Yearbooks, 1984, 1987 and 1990) and each river catchment ascribed to the appropriate coastal cell. Where more than one gauged catchment area was associate d with an individual cell t hen the combined total daily flow was calculated. The total ga uged flow for each coast al cell was t hen converted to runoff (mm) using the total ga uged land a rea (Figure A2.2 and A2.3). The d istribution of gauged flow data was more comprehensive in the south and east than the north-west where some extrapolation between basins w as necessa ry. The measured dail y runoff value was then applied across the remaining non-gauged area of the drainage basin for each cell and converted to litres of flow.

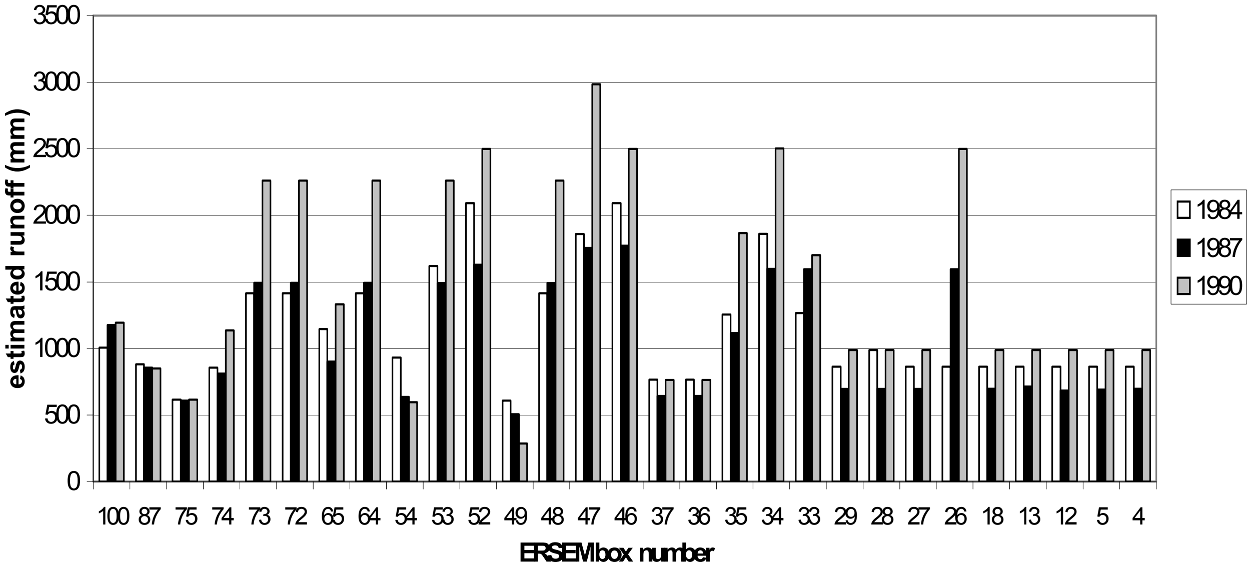

Figure A2.2 Comparison of annual runoff from Scotland to each ERSEM coastal cell for the thre e climate y ears (1984, 1987, 199 0). Note th at cells 75 and 100 also receive input from England and Wales.

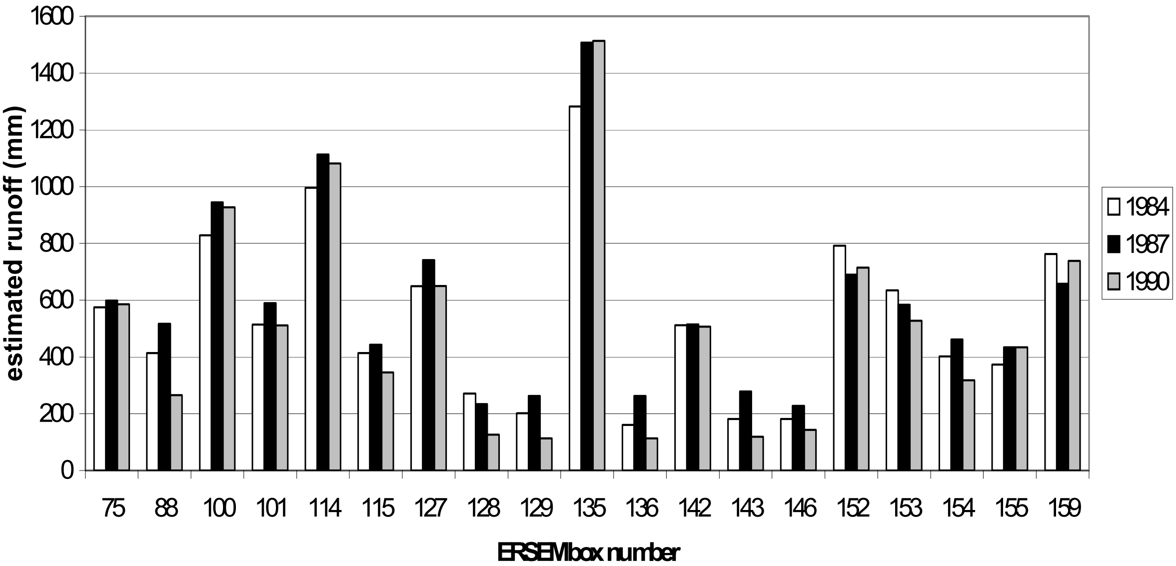

Figure A2. 3 Annual runoff (mm) from England and Wales to each of the ERSEM cells adjo ining the coastline. Note that boxes 7 5 and 100 also receive runoff from Scotland.

Estimation of daily elemental fluxes from each ERSEM cell

The only nationally available river compositional data set is the Harmonised Monitoring Scheme (HMS), which consists of approximately monthly samples per year for some 58 catchments in Scotland and an equivalent number in England and Wales. In general the HMS sites are located at the lowest non-tidal points *Note not all HMS sites and NRFA are common.* In the majority of cases flow at the time of sampling or a daily average flow is included for each water sample. Not all elements are of equal reliability (see Ferrier *et al*., 2001 for a recent review of the data)

Calculation of flow weighted concentrations (FWC)

All available data for the individual years 1984, 1987 and 1990 were collated, and flow weighted average annual concentrations of suspended solids, nitrate+nitrite, ammonium, orthophosphate, silicate and dissolved organic carbon (not available for all sites) calculated for each river catchment in the HMS (sum of instantaneous loads/total flow). *Note – the choice was made to treat the years separately because they were selected to be 'extreme' cases and it was considered that this may affect the subsequent relationships with land cover. One important limitation is that spot samples tend to be biased to lower flow conditions, but this is compensated to some degree by using daily flows and a flow weighted mean concentration.*

Relationships between land cover and FWC

Land cover attributes were ascribed to each HMS river catchment area. For Scotland, the proportions of 'Agricultural', 'Non-agricultural' and 'Forestry/rough grass' for all HMS catchments are shown in Figure A2.4. The HMS catchments as a whole account for approximately 50% of the total Scottish land area (Figure A2.5, A2.6) although importantly they do cover a wide range of land use conditions (ranging from 0 – 95% agriculture). The relationships between FWC and proportion of agricultural land (Edwards *et al*., 2000) were found to be statistically significant (Figure A2.7). Using these regression equations and the proportion of agricultural land in the catchment of each coastal cell (Table A2.1), individual average FWC were produced. These FWC were used in combination with daily river flows to produce a daily elemental flux for each cell.

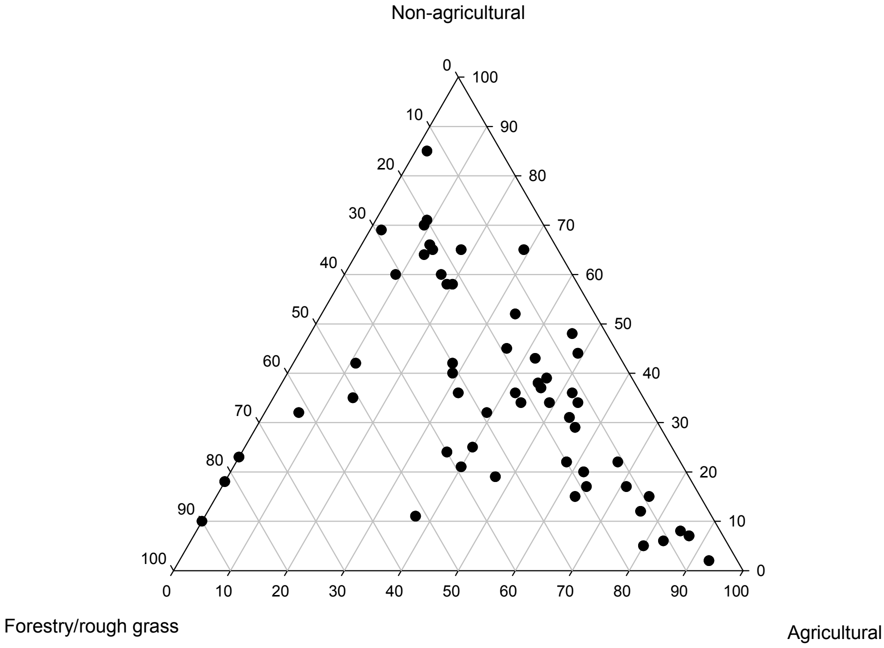

Figure A2.4 Comparison of main land cover attributes for the Scottish Harmonised Monitoring Scheme (HMS) sites. The catchments shown in Figure 2.4 (each represented by circular symbol in the triangular diagram) were characterised by the percentage contributions of agricultural, non-agricultural, and forestry/rough grass land usage

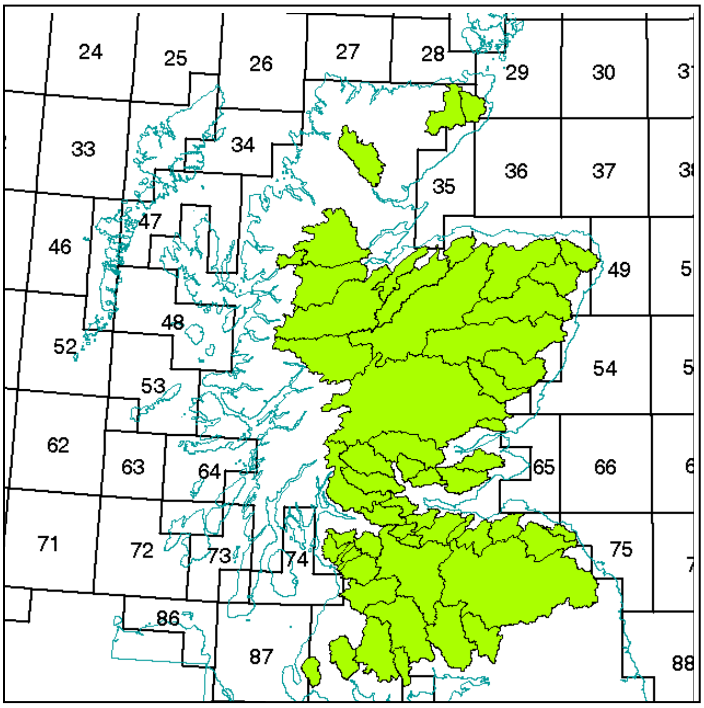

Figure A2. 5 Extent of Scottish Harmonised Monitoring Scheme catchments (in green) in relation to the land area of Scotland.

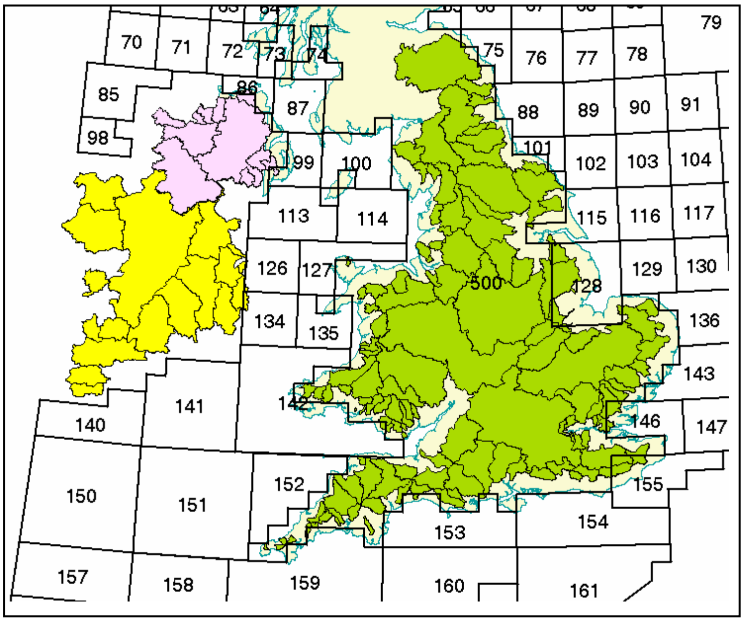

Figure A2. 6 Extent of Harmonised Monitoring Scheme catchments for England, Wales (in green) and Ireland, in relation to the total land area.

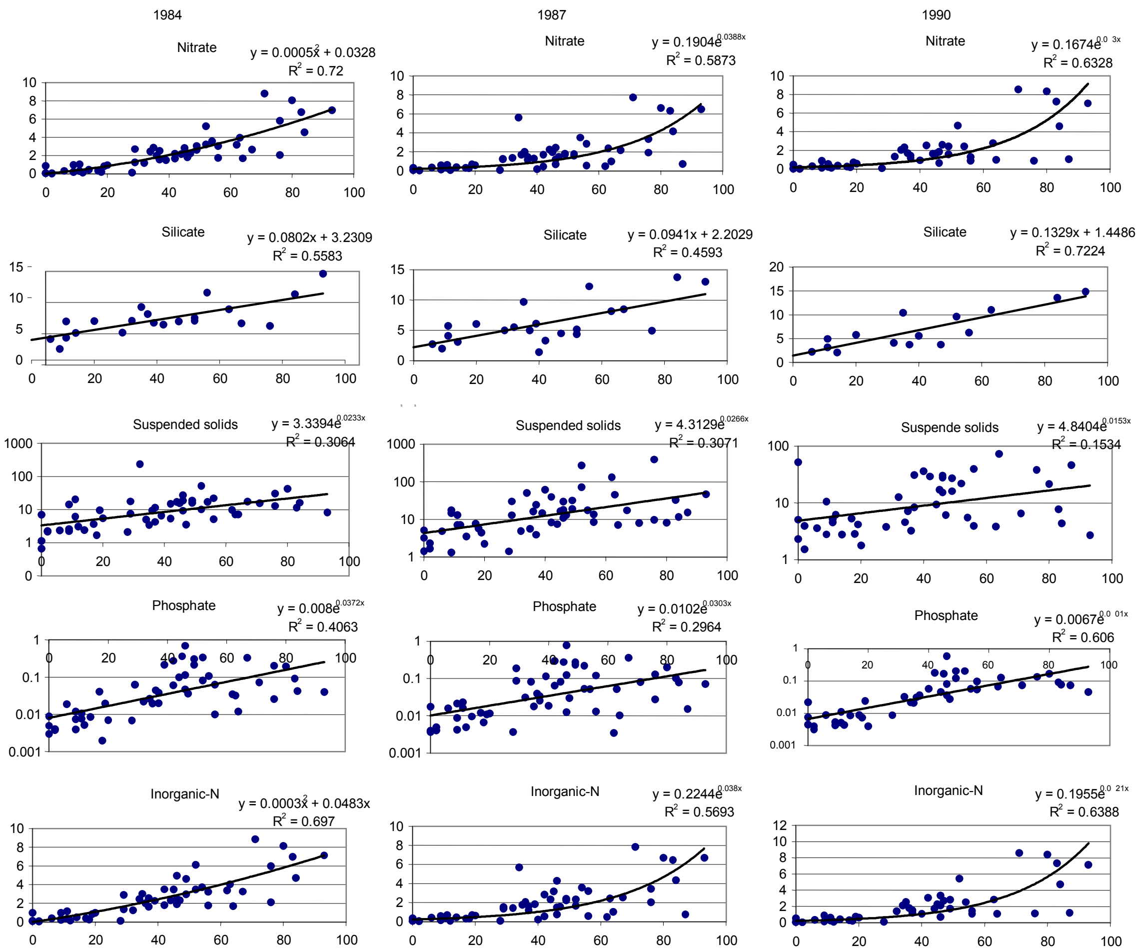

Figure A2.7 Relationships between flow weighted concentrations (mg m^{-3}) of nitrate, silicate, suspended solids, phosphate and inorganic nitrogen (y-axes), and the proportion of agricultural land (x-axes) for the Scottish Harmonised Monitoring

Scheme catchments. Left column, 1984; centre column, 1987; right column, 1990. Coefficients of the fitted relationships and r^2 values are shown for each graph.

Description of the estimation of nitrate + nitrite inputs from Northern Ireland and the Irish Republic to coastal cells for 1984, 1987 and 1990, from Heath *et al*. (2002) (Carried out by A Edwards, Macaulay land Use Research Institute, Aberdeen).

The drainage areas for each coastal cell adjoining the Irish coastline were estimated from ordinance survey maps. For the Irish Republic, long-term annual flows for the largest rivers and compositional data were obtained from the Irish Environmental Protection Agency. Flow data, but no detailed compositional data, for Northern Ireland rivers were obtained from NRFA annual reports.

In the absence of nutrient concentration data for Northern Ireland rivers, these were assumed to be the same as for Irish Republic rivers flowing into nearby ERSEM boxes.

Of the three climate years under investigation, data for calculating monthly nutrient fluxes were available only for 1990. Hence a crude extrapolation was required to estimate the fluxes for 1984 and 1987. Fluxes for 1984 were estimating by applying the month-specific ratio of 1984:1990 runoff to coastal ERSEM boxes adjoining the western seaboard of England, Wales and Scotland. The equivalent procedure was employed to estimate 1987 fluxes.