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UN ECE CONVENTION ON LONG-RANGE TRANSBOUNDARY AIR POLLUTION

International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems

Report of the UK Focal Point to DoE

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EPG Reference No. 1/3/65

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EXECUTIVE SUMMARY

This report summarises the progress of the UK Integrated Monitoring Focal Centre for the period September 1994 to July 1996.

A major acidification modelling study has been undertaken, examining deposition scenarios for a range of European sites including one in the UK. Additional funding under the EU LIFE financial instrument has been secured to assist in the running of these activities. The results of these studies showed that dynamic acidification models could be successfully applied to IM sites. Confidence in the scenario assessment approach was given by the consistent results gained from the different models used. The result of the 'Best prediction' scenario, incorporating the Second S - Protocol and current NO_x and NH_y emissions, was a stabilisation in soil acidification, although significant improvements were not always shown. Further model applications to a wider range of IM sites were recommended as well as the need to improve N process descriptions in the models.

The UK Focal Centre has now sent complete data up to the end of 1994 and is preparing for the submission of data for 1995. A summary of the data sent to the Programme Centre in Helsinki is provided as well as details of the addition of the Hydrobiology sub-programme which examines the distribution of acid sensitive macro-invertebrates in stream water. These data concur with chemical observations made at both sites, confirming that the Afon Hafren (GB02) is substantially more acid impacted than the Allt a Mharcaidh (GB01).

Deposition and stream chemistry for both UK-IM sites is examined. The sources of chemical constituents in rainfall are considered and the respective catchment loadings calculated. Annual loads of nitrate-nitrogen and non-marine sulphur are estimated and the variation in time examined and set in the context of UK wide deposition. Rainfall chemistry at both sites was found to be heavily influenced by weather patterns. At the Allt a Mharcaidh terrestrial deposition episodes occur at low wind speeds, higher wind velocities bring marine deposition. These findings were independent of wind direction due to the proximity to the sea in all but the most southerly of directions. At the Afon Hafren prevailing south-westerlies bring air laden with sea-salts, high pressure systems result in easterly air streams bringing high concentrations of terrestrial/anthropogenic constituents, such as non-marine sulphur and metals. The annual loads of pollutants to the two UK sites have shown variations coinciding with weather behaviour. There is no evidence of a reduction in sulphur or nitrate-nitrogen deposition at either site. The Allt a Mharcaidh receives relatively low inputs of pollutants. The Hafren, due to its proximity to industrial and population centres and the high rainfalls, receives amongst the highest loads of non-marine sulphur and nitrate-nitrogen and this is reflected in the catchment runoff which is highly acidified. The high loads of nitrogen may lead to loss of biodiversity through the generation of nitrophillic plant species.

The stream waters of the Allt a Mharcaidh are relatively well buffered and show a marked decrease in non-marine sulphur concentration. This decline is not evident in deposition and is not yet fully explained. The Hafren is highly acid impacted, its stream waters being well buffered only at the lowest flows when deep groundwater feeds the stream. Due to the very high acid deposition at this site the catchment has become nitrogen saturated and leaks a considerable nitrate load to the stream. In a pristine catchment inputs of nitrogen are matched by vegetational and microbial uptake. The Hafren is amongst the most nitrogen saturated sites in the IM programme. This condition has implications in terms of acidification and eutrophication. The leakage of nitrate ions results in high stream water concentrations of aluminium in its most environmentally harmful form with the attendant impact on fish populations. High loads of base cations, macro and micro-nutrients are lost from the catchment and this has a serious implication for the future soil fertility of the site.

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1 Introduction

The present project is coordinated by ICP IM Programme Centre of the Finnish Environment Institute, Helsinki. The IM-programme is part of the Effects Monitoring Strategy under the UN/ECE Convention on Long-Range Transboundary Air Pollution. The network includes 57 sites (catchments/plots) in 23 ECE countries, the sites are monitored using standardised protocols described in the Programme Manual (EDC, 1993).

This report presents the progress of the UK Focal Point of the ICP-IM programme for the period August 1994 to June 1996 and follows the previous report in 1994. The responsibilities of the UK Focal Point are broadly as follows:

- To collate, summarise and interpret data from the two sites in the IM network; to transmit data summaries to the programme centre in Finland.
- To continue to develop and apply the MAGIC model at sites within Europe with particular emphasis on critical load assessment and incorporation of nitrogen dynamics.
- To represent the UK at ICP-IM Task Force meetings as appropriate.

To these ends this report outlines, (i) the data collated and submitted to the IM Programme Centre at the Finnish Environment Institute in Helsinki, (ii) describes the new sub-programmes and additional data collated, (iii) analysis and interpretation of IM data and (iv) outlines dynamic modelling activities undertaken at IH. The modelling studies were reported by the Programme Centre and are reproduced as an appendix to this report, as are abstracts from papers outlining research undertaken at the IM sites.

Minutes of the ICP-IM Fourth Task Force Meeting are provided to highlight the activities of the IM programme, collaboration with the other UN-ECE programmes, and the work schedule adopted for 1995 and 1996. This work schedule does not affect the current remit of the UK Focal Point which remains unchanged with the data reporting and assessment programme continuing.

The UK input to the UNECE ICP-IM has been supplemented through participation in two closely linked projects; (i) "coordinated application of three dynamic models (MAGIC, SAFE and SMART) on selected ICP-IM sites", funded by the Nordic Council of Ministers (1 January 1995 to 31 December 1995); and, (ii) "development of assessment and monitoring techniques at Integrated Monitoring sites in Europe", funded by the EC LIFE Programme (1 April 1996 to 31 March 1998). This new programme secures IH input to the Europe wide dynamic modelling assessment but does not incorporate model development objectives. These remain within the current DoE research programme (EPG 1/3/65).

2 The EC-LIFE financial instrument and new IM activities

2.1 GENERAL DESCRIPTION OF THE PROJECT

Development of Assessment and Monitoring Techniques at Integrated Monitoring Sites in Europe

The project involves organisations from five EU-countries (Denmark, Finland, Spain, Sweden, UK);

1) National Board of Waters and the Environment, Environment Data Centre, Helsinki, Finland (coordinating organisation, coordinator and subproject leader : Dr M Forsius).

2) National Environmental Research Institute, Department of Terrestrial Ecology, Silkeborg, Denmark (subproject leader: Dr K E Nielsen).

3) Research Center for Energy, Environment and Technology, Institute for Environmental Research (IMA/CIEMAT), Madrid, Spain (subproject leader: Dr R Guardans).

4) Swedish Environmental Protection Agency, Solna, Sweden (subproject leaders: Anders Bemtell and S Bråkenhielm).

5) Institute of Hydrology, Wallingford, UK (subproject leader: Dr A Jenkins).

The project is based on the existing network of intensively monitored reference sites of the UN/ECE International Cooperative Programme on Integrated Monitoring (ICP IM). The main aims of the project are:

1) To improve the assessment and collection of empirical data in the IM network regarding: (i) the effects of vegetation on the biogeochemical fluxes of elements, and (ii) the biological effects of air pollutants and potential changes in the global climate. Such integrated studies on a large number of sites allow the comparison of complex and multiple effects across climatic gradients, as well as geological, ecozone and political boundaries.

2) To enhance the intercalibration and data quality assurance of the above methods between the organisations and countries in the IM-network.

3) To use the data collected within the ICP IM framework for the application of existing, well-documented biogeochemical/mathematical models to IM-sites throughout the EU. The calibrated models can be used in a decision-making framework to assess and predict past and future trends in soil and water response of catchments/sites to pollutant deposition, change in land use and climate. The results of the modelling programme will assist in/facilitate both the setting of emissions targets required to meet environmental quality targets, and help in the development of catchment management policy to minimise harmful impacts on biota thereby preserving biodiversity.

4) To (i) disseminate knowledge regarding these advanced data assessment and collection techniques through the IM-network by arranging workshops and field courses; (ii) to improve the coordination of these activities between other related international monitoring, assessment and research activities, (iii) to report the results of the model based assessments and other policy related data evaluations of the present project to relevant international bodies (European Commission, EEA, UN/ECE, UNEP/GTOS), and (iv) to present the results in appropriate scientific journals and bulletins to maximise the audience to which the information is made available.

The project contains several elements of relevance to the development and implementation of EC environment policy, and the implementation of the Fifth Action Programme:

1) By establishment and development of several new innovative integrated assessment and monitoring techniques for assessing complex ecosystem effects.

2) Contribution to the development of environmentally sound and cost-effective abatement strategies for air pollution and land-use management in the EU/ECE-region.

3) By dissemination of knowledge on advanced assessment and monitoring techniques, and increased exchange/transfer of experiences on a true transnational scale.

4) By enhanced assessment and collection of data at the semi-natural reference sites of the ICP IM, as well as the assessment of different impact scenarios.

5) By assessment of the integrated effects of transboundary atmospheric pollution, changes in land use and climate change on reference sites throughout Europe.

6) The project has a clear international scope and would thus foster greater cooperation between assessment and research organisations and authorities particularly with regard to the assessment of present and potential effects of transboundary air pollution and Global Change.

Since the project is based on an existing network structure, the consortium already has experience from previous collaboration. Basic investments on sampling devices and other infrastructure has already been made at the IM-sites. For these reasons, the available funding is efficiently used for achieving the aims of the project.

2.2 RESULTS EXPECTED

Multiple hierarchical levels of monitoring are necessary for the development of rational environmental policies. In such a hierarchy, ICP IM represents the highest level having international cooperation and therefore is in an excellent position to respond to the needs of the international decision making process. Integrated monitoring ensures the collection and assessment of essential data on the integrated effects of air pollution, land-use change and climate change and thereby facilitates the preservation of sensitive semi-natural ecosystems. The present project enhances the implementation of such advanced integrated assessment and measurement techniques in the European Union and the neighbouring countries in the ECE region.

Specific results of the present project can be summarised as follows:

1) Enhanced field monitoring and assessment techniques on the IM-sites regarding deposition, transport and circulation of elements (including S, N, base cations, and heavy metals).

2) Enhanced monitoring and assessment techniques regarding (i) biological effects of air pollutants (use of plant indicator values, effects of N deposition on soil biology and understorey vegetation), and (ii) mutual relationships between vegetational changes and biogeochemical element fluxes (by comparing different lysimeter techniques for the assessment of soil chemical effects).

3) Model based assessments on the environmental consequences of different scenarios with regard to emission control and land use change on IM-sites throughout the EU and ECE regions. These assessments would include an analysis of the dynamic response to estimated critical load exceedances. The environmental effects to be analysed would include soil and water quality as well as vegetational changes. Four different linked model systems will be used.

4) Comparison of model results and an assessment of the uncertainties involved. The coordinated application of four different model systems using consistent input data and impact scenarios will allow these assessments to be made. Such information is obviously of central importance,

when the results are to be used in the international decision making process.

5) First results on model based assessment of the effects of potential changes in the global climate on selected IM-sites.

6) Dissemination of knowledge through workshops, reports and publications on analysing techniques and field methods, data quality assurance, as well as advanced data assessment techniques.

7) Intercalibration exercises and improved data quality assurance programme within ICP IM.

8) Improved coordination and information transfer between ICP IM and related monitoring, assessment and research activities in the EU and ECE region.

9) Reporting of policy related information to relevant international bodies (European Commission, EEA, UN/ECE, UNEP/GTOS, etc.).

2.3 COMMUNITY INTERESTS

The expected results of the project are of relevance for several topics regarding the development and implementation of the Community environmental policy and the implementation of the Fifth Action Programme:

1) The project will enhance the development and implementation of advanced integrated assessment and monitoring techniques in Europe through the established network of organisations and monitoring sites of the UN/ECE ICP IM.

2) The modelling program will enable the coordinated assessment of different impact scenarios. These scenarios may be tailored to suit, for example, existing frameworks for pollutant emission reduction (eg UN/ECE protocols), 'business as usual' and increased emission scenarios, or to examine the effects of land use change such as afforestation and deforestation. The results of this work will assist in policy matters with regard to emissions control and land use. The suitability or impact of emissions reduction criteria and national/European land use policy assessed in a range of catchments with different ecological response characteristics or tolerances.

3) ICP IM is one of the regional networks suggested to be included in the 'Global Terrestrial Observing Systems (GTOS/UNEP)' (IGBP Global Change Report 26). The proposed project would further increase the potential of the IM-programme to assess and predict the integrated effects of the various components of Global Change (changes in climate, pollutant deposition and land use).

4) The project would enhance the assessment and collection of data at semi-natural reference sites, as well as the assessment of different impact scenarios. This information is of relevance for several projects included in the Work Programme 94/95 of the EEA (eg MN5, SC1, SC2).

5) The project has a clear international scope and would thus foster greater cooperation between the assessment and research organisations and authorities of the EU and ECE countries participating in the IM-programme, particular with regard to the assessment and Global Change.

6) Strong emphasis is put in the project on the dissemination of knowledge regarding advanced data collection and assessment techniques. The IM-network includes several Third Countries and other countries outside the EU, this permitting increased exchange/transfer of experiences on a true transnational scale.

2.4 INNOVATION

The project includes the development and implementation of several new techniques regarding ecosystem monitoring, assessment of empirical data and dynamic modelling, as well as the derivation of new information of relevance for formulating environmental policies. All the techniques are implemented on a transnational scale, and this process thus offers a unique pan-European data quality control, data assessment and model calibration exercise. The enhanced IM-programme may serve both as data supplier for the ongoing effort of reducing emission levels in Europe and at the same time as "early warning" network for unwanted ecosystem changes.

2.5 TASKS AND DELIVERABLES FROM UK LIFE-SUBPROJECT

Task:

1) Application of the MAGIC model to selected IM sites.

    1.1 Data Assessment and model calibration.
    1.2 Assessment of future deposition and land-use change scenarios.

2) Application of the MAGIC-Wand model to selected IM-sites.

    2.1 Data assessment and model calibration.
    2.2 Assessment of coupled S&N deposition scenarios.

3) Assessment of critical loads and emission reduction agreements.

4) Dissemination of information.

Task	Deliverable	Month/Year
1.1	Calibrated MAGIC model at UK, Finnish, Swedish sites	8/96
	Calibrated MAGIC model at Spanish, Danish site	12/96
1.2	Assessment of future S scenarios	4/97
	Report on MAGIC applications	5/97
2.1	Calibrated MAGIC-WAND model at UK, Finnish and Swedish sites	6/97
	Calibrated MAGIC-WAND model at Spanish and Danish sites	8/97
2.2	Assessment of coupled S & N scenarios	9/97

Task	Deliverable	Month/Year
	Report on MAGIC-WAND applications	10/97
3.	Assessment of critical loads and reduction agreements	10/97
	Assessment of interaction with potential climate change	10/97
	Final interpretive and assessment report	11/97
4.	Arrangement of a workshop on ecosystem modelling	-97

3 The UK IM data

Data collation and transmission to Helsinki has continued on a regular basis for the main monitoring sub-programmes for the past two years; these are meteorology (AM), deposition chemistry (DC) and stream chemistry (RW). Additional subprogrammes include air chemistry (AC). Until recently the data submitted for the IM has been purely hydrochemical, but in order to broaden the scope of the UK contribution a new sub-programme, the hydrobiology of streams (HB), has been added. This provides the first index of the impact of acidification on stream macro-invertebrates to the IM Programme Centre. The new data covers the whole period (8 years) of IM monitoring and the raw data, collected as part of the UK Acid Waters Monitoring Network, has been supplied by ENSIS.

3.1 SUMMARY OF DATA TRANSMITTED TO IM PROGRAMME CENTRE FOR 1994 AND 1995.

The main work of the Focal Point has been the maintenance and improvement of the current programme of data summary and transmission and the addition of new sub-programmes.

Meteorological data for the two UK IM sites is derived from the monitoring programmes of the Institute of Hydrology and Macaulay LandUse Research Institute at GB01 (Allt a Mharcaidh) and the Institute of Hydrology at GB02 (Afon Hafren). From GB01, relative humidity and air temperature are submitted. For GB02 relative humidity, air temperature, ground temperature and soil temperature at 20cm depth are provided. Solar radiation data is available for these sites, however, since the IM manual stipulates UV radiation, these data are not transmitted. Wind speed and direction data is also available for these sites, but is not currently a requirement of the programme. The relative significance of marine and terrestrial sources of pollutants in atmospheric deposition is know to vary through time (Davison and Hewitt, 1992; Donald *et al.*, 1990; Reynolds *et al.*, 1984), and so it has been suggested to the Programme Centre that the addition of wind speed and direction data would provide added value to the interpretation of observed trends. Data for the Allt a Mharcaidh is collected from an automatic weather station (AWS) at weekly intervals. The data down loaded from the AWS data loggers is submitted to IH every month and undergoes quality control checks prior to being added to the IH database. The data is then collated annually for submission to the Programme Centre. For the Afon Hafren, AWS data is collected by IH staff at the Plynlimon Laboratory in the Hafren Forest. The Institute operates a series of AWS sites in this area and runs a duplicate manual and AWS meteorological monitoring programme in order to quality control the AWS data. Data transmission for the AM sub-programme is now complete upto 1995 for GB01 and upto 1994 for GB02 (Table 3.1).

Table 3.1 *Summary of sub-programmes and years for which data submission is complete for the UK contribution to the UNECE-Integrated Monitoring Programme*

Sub-programme	GB01: Allt a Mharcaidh	GB02: Afon Hafren
AM: Meteorology	88-95	88-94
AC: Air chemistry	91-94	92-94
DC: Deposition chemistry	88-94	88-95
TF: Through-fall chemistry		*88-91
SF: Stem-flow chemistry		*88-91
SC: Soil chemistry	90	
SW: Soil water chemistry		90-91
GW: Groundwater chemistry	90-91	
RW: Streamwater chemistry	88-94	88-94
RB: Hydrobiology of streams	*88-94	*88-94

*New sub-programmes or additional data to be sent to IM Programme Centre.

Data submitted under the air chemistry (AC) sub-programme includes sulphur dioxide concentration at GB02 and nitrogen dioxide concentration for both GB01 and GB02 sites. This monitoring is carried-out by the AEA Technology, National Environmental Technology Centre as a part of their acid deposition monitoring activities (Campbell *et al.* 1994). The sulphur dioxide measurements are made using an "air bubbler" technique, whereby air is bubbled through an absorbing solution, in this case hydrogen peroxide, which dissolves the sulphur to produce sulphate ions (EMEP, 1977). Diffusion tubes are used in the monitoring of nitrogen dioxide. Data transmission for this sub-programme is complete to the end of 1994.

Rainfall samples are collected by IH staff each week from the Carreg Wen meteorological site which is located near to the Hafren Forest and a collector in the Afon Gwy catchment. Originally samples were analysed separately, since the concentrations were found to be very similar and as other studies demonstrated that mean ion concentrations of rainfall samples from collectors widely spread across the Gwy catchment were within 10% of each other (Reynolds, 1984) the samples are now bulked and a single analysis is made. Alkalinity and pH determinations are made at the Plynlimon Laboratory before samples are returned to the main IH laboratory in Wallingford, for full chemical analysis. The analyses determine major, minor, trace constituent concentrations, including the heavy metals, transition elements and rare earth elements (Neal *et al.* 1992). These data are submitted to the programme centre as monthly volume weighted means (EDC, 1993).

Quality control of the GB02 deposition data has highlighted the impact of recent motor sports activities in the Plynlimon catchments. Pollutant concentrations at the Afon Hafren exhibit their highest values from 1991 onwards (Figure 3.1), these high concentrations are not reflected by increasing loads of contaminants (Figure 3.3). This is because these high concentrations are associated with very low rainfalls and hence their contribution to the catchment load and monthly flow weighted means is insignificant. An examination of the rainfall data shows that in previous years a minimum weekly

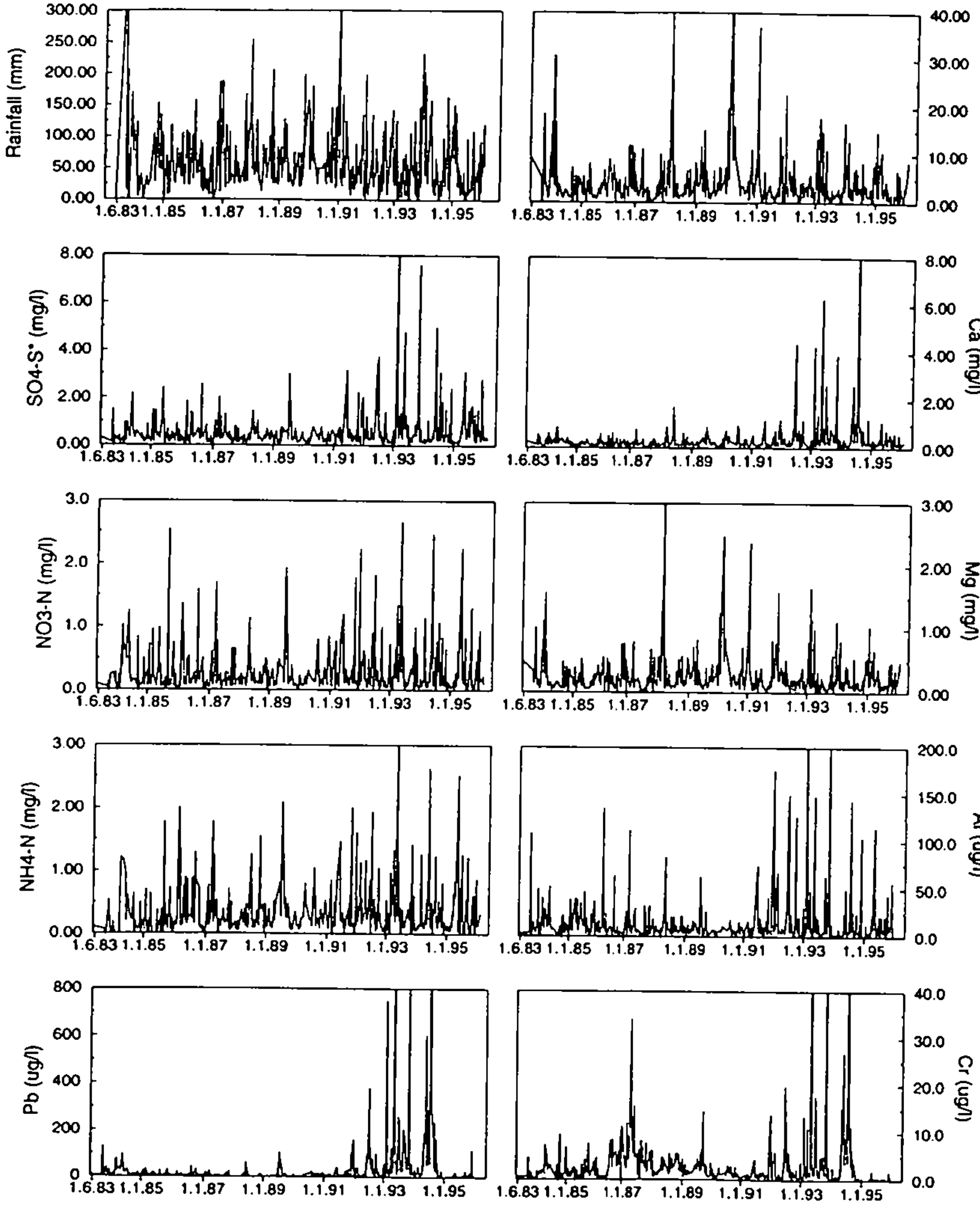

Figure 3.1 *Rainfall data and major ion concentrations in bulk deposition samples at the Afon Hafren (GB02). Variations in rainfall have a large influence on ion concentrations at Plynlimon. Low rainfalls in the mid 1980s and 1990s result in high pollutant concentrations (SO_4-S, NO_3-N, NH_4-N, Al, Cr), the spikes in the later period result from dust events. Higher rainfalls of the late 1980s and early 1990s resulted in high concentrations of marine constituents.*

rainfall of around 25mm has occurred. From 1992 the rainfall has become more erratic with frequent periods of negligible rainfall (<10mm). There has also been a considerable increase in car rallying activities in the Gwy catchment over the past four years (Hill, pers comm. 1996). It is thought that the combination of dryer conditions and motorsport activities has resulted in the generation dusts which have entered the Gwy rainfall collector. If this is the case it would explain the high Pb, Al, Cr and other peaks in metal concentrations observed; lead mining was once a major activity in this area. The pollutant anion concentration peaks during this period are less easy to explain, but may result from the dissolution of pollutant gases adsorbed to dust or soot particles which have settled on the collector funnels. The location of rainfall collectors is currently under consideration in order to avoid such local impacts in the future.

Two sources of deposition data are available for GB01. The first is a bulk rainfall collector operated by the AEA Technology, National Environmental Technology Centre at the River Mharcaidh site located downstream of the main river gauging site on the catchment outflow. The second is a network of raingauges in the Allt a Mharcaidh catchment, designed to assess local differences in deposition related to altitude and aspect (Ferrier *et al.*, 1990; MLURI, 1996). The data currently transmitted to the Programme Centre is from the AEA source, and includes major anions, base cations and rainfall. The MLURI data is more extensive and includes metals, aluminium, copper, zinc, iron and manganese. The possibility to submit this data to Helsinki is being explored. Submission of deposition chemistry data for GB01 is now complete to the end of 1994.

Soil chemistry and groundwater chemistry for GB01 were submitted for 1990 and 1990/91. These data were derived from the Surface Water Acidification Programme (SWAP) which has now been discontinued. Soil water chemistry from the Hafren Forest was collected during 1990 and 1991 and these data have been sent to the Programme Centre.

Stream water chemistry for the Allt a Mharcaidh is sampled twice a week and stage, pH, conductivity and temperature are monitored continuously (20 minute intervals). Analysis of the samples includes major anions and cations. Flow weighted mean concentrations are calculated and submitted to the Programme Centre. Stream chemistry data for the Afon Hafren is sampled weekly and dates back to 1983. Sample analysis is identical to that for bulk deposition. The length of record and wide range of chemical constituents analysed makes this a unique data set in the UK and the subject of considerable and on-going study (for example, Robson and Neal, 1996; Neal *et al.*, 1996; Durand *et al.*, 1994; Neal *et al.*, 1990a&b; Neal *et al.*, 1989; Reynolds *et al.*, 1986). Monthly flow weighted means have been submitted to the IM Programme Centre for the period 1988-94.

Additional data on throughfall and stemflow chemistry have now been collated. Weekly samples were collected between 1984 and '92 from within the Hafren Forest (Neal *et al.*, in press). These data will be submitted as monthly volume weighted means for the period 1988 to the end of 1991.

3.2 NEW SUB-PROGRAMME; HYDROBIOLOGY OF STREAMS

This sub-programme will complement the hydrochemistry data already held at the Finnish Environment Institute by providing a biological index of stream water acidification. Different species of macro-invertebrates have differing tolerances to stream water quality (Ormerod and Wade, 1990). The data for this sub-programme were provided from the UK Acid Waters Monitoring Network, the sampling methodologies and results for both UK-IM sites are summarised in Patrick *et. al.* (1995). The sampling methodology for macro-invertebrates for the UKAWMN programme differs from that of the ICP-IM only in the frequency of sampling. The IM manual recommends twice yearly sampling in spring and autumn, the UKAWMN takes one sample a year from a riffle zone within the stream in April or May (EDC, 1993; Patrick *et. al.*, 1995). Five replicate kick samples are taken and stored in 70% alcohol (ethanol) prior to being hand sorted (Patrick *et. al.*, 1995).

The macro-invertebrate data for the two IM sites for the period April 1988 to April 1993 are summarised in Patrick *et. al.* (1995). In the Allt a Mharcaidh (GB01) there was little variation in the dominant taxa during the 5 year study period. *Beatis* spp. dominated the macro-invertebrate fauna; this species in sensitive to very acid waters and has been absent in the Hafren through-out the period of study. There was an abundance of stoneflies and a great variety of taxa, the most common of which being listed as *Brachyptera risi, Protonemura meyeri, Amphimenura sulcicollis, Leuctra inermis, Chloroperla tripunctata* and *Isoperla grammatica*. A number of acid sensitive taxa were collected; the mayfly *Rithrongena semicolorata* (a few individuals); and other taxa, initially (1988 and 1989) found in small numbers, were absent in later years, most notable of these were two caddis, *Glossosoma* sp. and *Philopotamus montanus* (Patrick *et. al.*, 1995). The presence of *Beatis* spp. suggests that acidic episodes in this stream associated with run-off events are of insufficient duration to cause long-term and cumulative damage to that population. The decline in numbers of the more acid sensitive taxa, however, suggests an insidious and continuing acidification of the catchment not adequately reflected by changes in stream chemical composition.

The results for the Afon Hafren were unlike those for Allt a Mharcaidh and confirm that the Hafren is very acidic (flow weighted mean pH = 4.8; Neal *et al.* 1996). The macroinvertebrate fauna is dominated by acid tolerant species and the species diversity is very low. The most abundant species are the detritivorous stoneflies *Leuctra inermis, Amphimenura sulcicollis* and *Siphonoperla torrentium*. The typically acid intolerant mayflies were absent through-out the study period.

3.3 DEPOSITION AND STREAM CHEMISTRY AT THE UK-IM SITES

3.3.1 Deposition chemistry: Composition

Deposition chemistry at both of the UK-IM sites is heavily influenced by the maritime climate experienced in the UK. The deposition chemistry is characterised by two specific groups of constituents; those of marine origin, Cl, Na, Mg, Ca, SO_4 and K, and those of terrestrial/anthropogenic pollutant origin, NO_3, SO_4*, NH_4 and metals such as Pb, Cr, Cd, Al, Fe. Some of these constituents have dual sources, in particular, SO_4, Ca and K, this becomes apparent having examined scatterplots of their concentrations plotted against Cl, which is predominantly of marine origin (Figure 3.2). The shallow gradient indicates samples with concentrations close to sea-salt ratios. The steeper gradient indicates that the concentrations were in excess of the sea-salt ratio values and hence indicate non-marine sources. The main source of non-marine sulphur is the combustion of fossil fuels, the sources of K and Ca are thought to be terrestrial dust (Reynolds *et al.*, 1984; Martin, 1980).

The supply of the marine or terrestrial components in deposition at both sites is dependent on weather patterns. The Mharcaidh is close to the North Sea and the North Atlantic Ocean. The Hafren is close to the Irish sea and the North Atlantic Ocean. At the Mharcaidh the general proximity to the sea in all directions means that there is no distinct pattern in terms of wind directions and the nature of deposition. Both easterly and westerly circulations bring air laden with sea-salt. These sea-salt deposition episodes are more closely related to wind speed. High wind speeds are associated with marine deposition and lighter winds with anthropogenic pollution, ie. high non-marine sulphur concentrations. In the Hafren strong westerly and south-westerly winds provide rainfall enriched in marine constituents, and light easterly winds bring air with high levels of terrestrial/anthropogenic contaminants (Reynolds *et al.*, 1984).

The concentrations of marine components are very variable, but their ratios remain close to those of sea-water. Both concentrations and loads of sea-salts deposited on the catchments show marked seasonality. Their values peak in the autumn and winter, coinciding with high rainfall volumes associated with the progression of low pressure systems from the Atlantic (Figure 3.3, 3.4). In terms of catchment loadings the time-series for Ca, SO_4 and K are complicated by the dual sources of these constituents. Sulphate loads at Plynlimon correlate with south-westerly and westerly winds (Reynolds *et al.*, 1984). The highest rainfall volumes also coincide with these wind directions resulting in high sulphur loadings from marine sources, whereas the highest sulphur concentrations in rainfall are non-marine in origin.

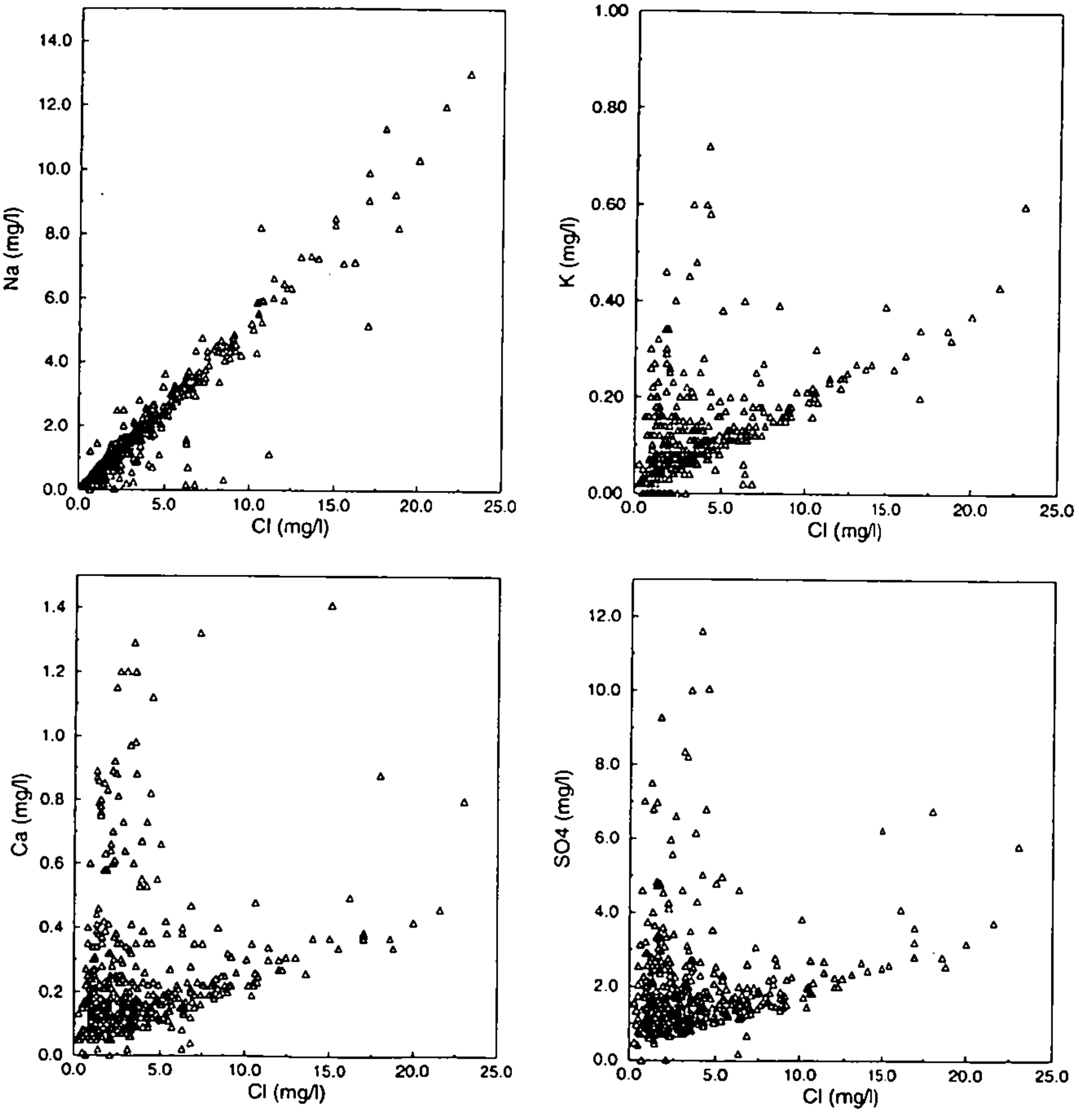

Figure 3.2 *Scatter plots of components in rainfall at GB02 with marine sources only (Na, Cl) and both marine and terrestrial/anthropogenic sources (K, Ca, SO_4)*

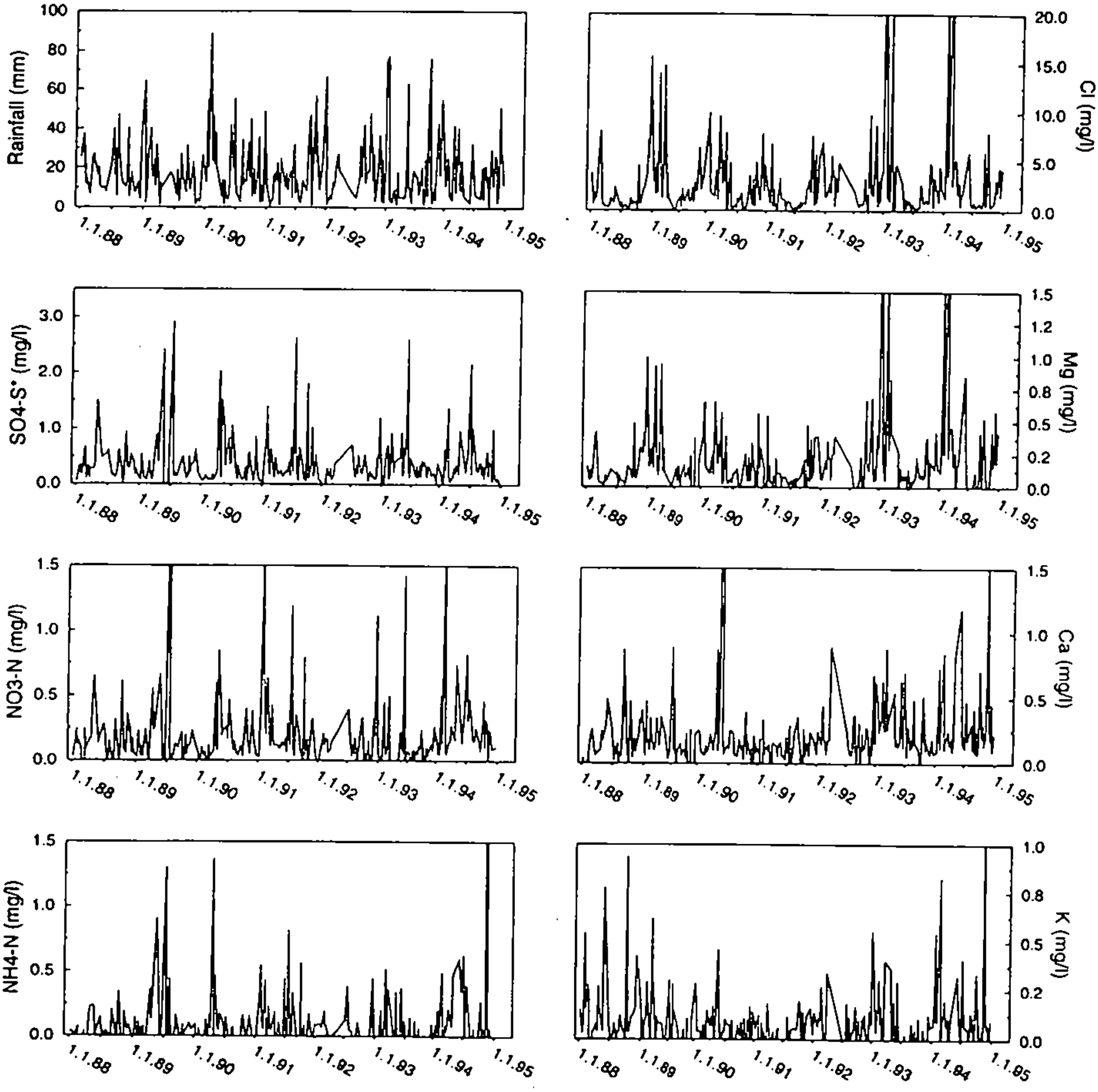

Figure 3.3 *Rainfall data and major ion concentrations in rainfall samples at the Allt a Mharcaidh (GB01). Marine constituents (Cl, Mg) peak during winter, anthropogenic pollutants (SO_4-S^*, NO_3-N, NH_4-N) peak in summer. Constituents with dual sources (Ca, K) show more complex variations.*

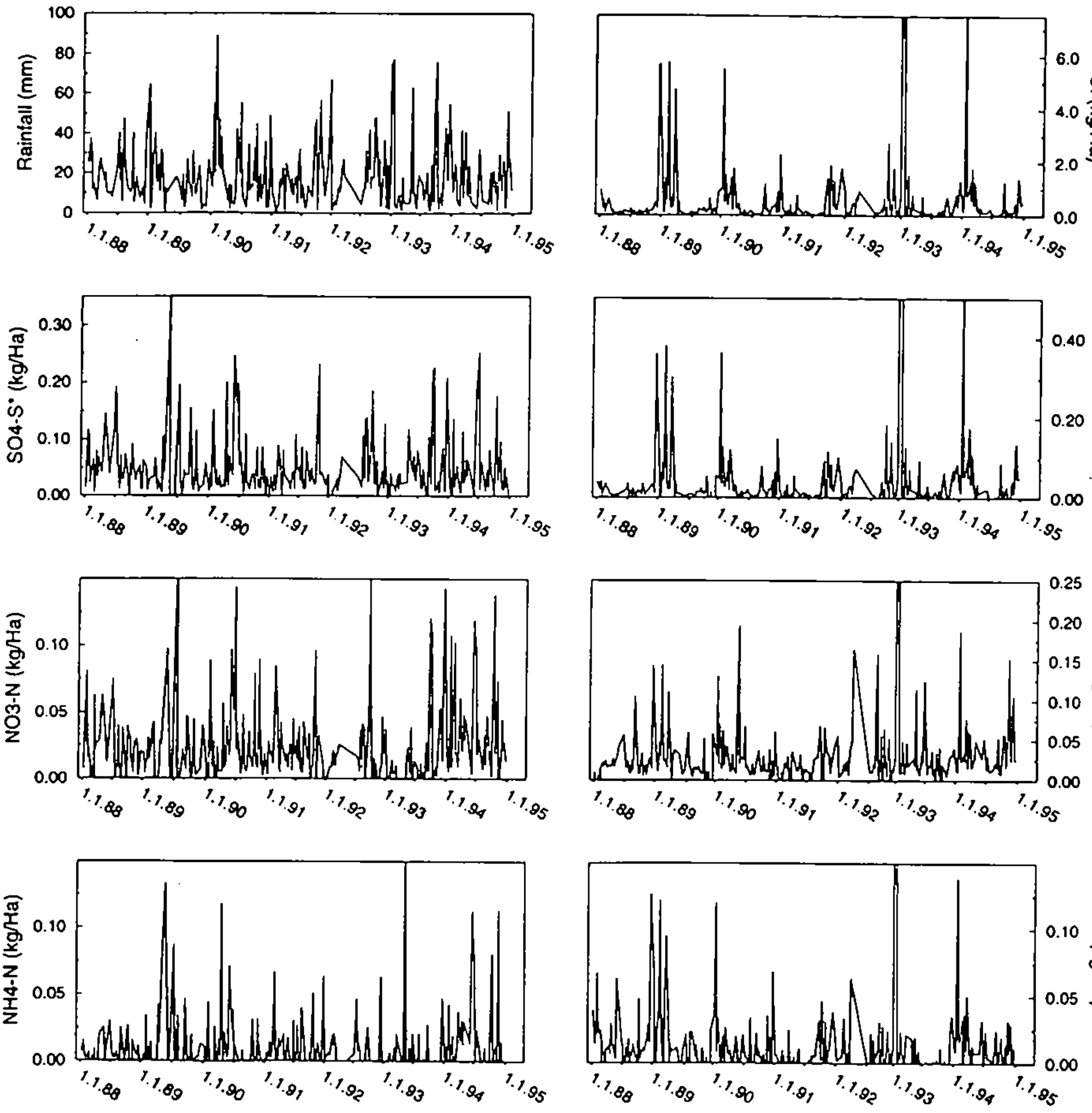

Figure 3.4 *Rainfall data and major ion loadings based-on bulk deposition samples at the Allt a Mharcaidh (GB01). Marine constituents (Cl, Mg) peak during winter, anthropogenic pollutants (SO_4-S*, NO_3-N, NH_4-N) peak in summer. Due to high winter rainfalls loadings of constituents with dual sources (Ca, K) peak in the winter.*

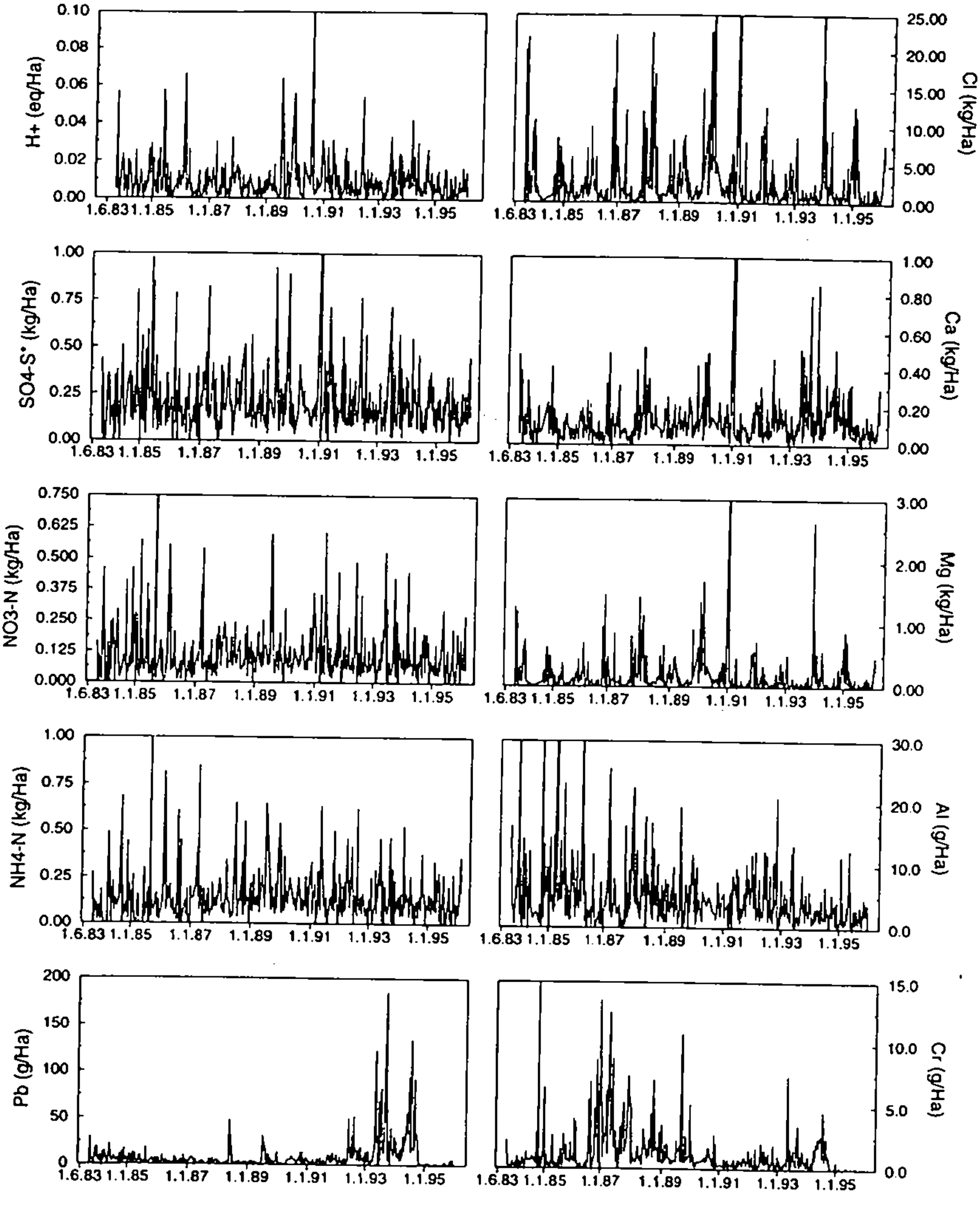

Figure 3.5 *Loadings of major and minor consitituents in rainfall at the Afon Hafren (GB02). Calculated loads demonstrate that despite the high pollutant concentrations (S, N and Al) in the 1990s (Figure 3.1), low rainfalls have meant that the actual loads of contaminants deposited were relatively small compared to previous years.*

In contrast, light easterly winds associated with high pressure systems in the spring/summer bring air that has passed over agricultural land and industrial areas resulting in high concentrations of non-marine sulphate (SO_4*), NO_3, NH_4, as well as, hydrogen ion concentration and metals. These changes in concentration associated ion sources and weather patterns are invaluable when describing the longer-term changes in concentrations and loads deposited on the catchments.

3.3.2 Deposition Chemistry: Long-term variations

At the Allt a Mharcaidh SO_4*, NO_3 and NH_4 in show no consistent change in concentration or load over the period of record (Figure 3.3, 3.4), although the annual mean values of non-marine sulphur and nitrogen dip in the period 1990 to 1993 (Table 3.2). At the Afon Hafren there is much greater variation in ion concentrations and rainfall volumes and hence loads (Figure 3.1, 3.5).

Table 3.2 *Annual rainfall weighted mean concentrations and loads of non-marine sulphate and nitrate-nitrogen from bulk deposition data at the two UK-IM sites.*

	GB01				GB02			
	SO_4* µeq/l	kgS/Ha/yr	NO_3-N µeq/l	kgN/Ha/yr	SO_4* µeq/l	kgS/Ha/yr	NO_3-N µeq/l	kgN/Ha/yr
1984					35.5	11.6	24.6	7.1
1985					28.8	9.3	22.8	6.4
1986					22.7	9.4	18.3	6.6
1987					24.6	8.9	16.4	5.2
1988					22.3	9.3	19.8	7.2
1989	31.4	2.9	27.9	2.3	25.7	9.4	19.7	6.3
1990	19.5	2.8	11.6	1.5	20.6	7.9	18.7	6.2
1991	18.6	2.2	13.2	1.3	24.1	9.6	15.3	5.3
1992	14.8	1.4	9.6	0.8	28.0	11.3	17.0	6.0
1993	18.9	2.4	9.0	1.0	33.7	12.3	20.1	6.4
1994	27.7	3.0	21.7	2.1	27.1	12.2	17.9	7.0
1995					29.1	9.7	17.3	5.0

Rainfall and weather patterns have had a major influence on ion concentrations and loads. The lower and more erratic rainfalls of the early 1980s coincided with elevated loads and concentrations of terrestrial and anthropogenic inputs. There was also a greater incidence of extreme (peaks) in load and concentration. From 1987 to 1993 baseline rainfalls remained higher and marine deposition more prevalent with higher incidence of peak concentrations, e.g. Cl, Mg. Pollutant concentrations during this period exhibited fewer peaks, presumably due to dilution by higher rainfall as well as the lack of extended periods of weather suitable for the optimal delivery of the constituents. The time series of loads of non-marine sulphate, nitrate and ammonium ions, suggest a reduction in the magnitude of their peak loads. The mean annual loads of non-marine sulphur and nitrate nitrogen, however, do not show a significant reduction has occurred over the 11 year period of record (Table 3.2). The Hafren catchment is more likely to show the affects of reduced sulphur emissions than the Allt a Mharcaidh.

Table 3.3 *Rainfall weighted mean concentrations and loads of non-marine sulphate and nitrate-nitrogen at the Allt a Mharcaidh and Afon Hafren for the 5 years from January 1989 to January 1994.*

Concentrations (μeq/l)	**Allt a Mharcaidh**	**Afon Hafren**	**[1]UK range**
SO_4^*	20.9	26.6	<20 to >100
NO_3-N	14.4	18.2	<10 to >40
Fluxes (kg/Ha/yr)			
SO_4-S^*	2.8	10.2	<3 to >12
NO_3-N	1.6	6.1	<2 to >5

[1] From Vincent *et al.*, (1995)

The Hafren has a greater proximity to industrial and population centres in the UK, whereas the Mharcaidh is remote from such sources and relatively pristine, and in terms of the loads of pollutants received by the Hafren, it might be considered as a control site, the loads of S and N received being 3-4 times lower. The loads of sulphur and nitrogen received by the Hafren are also high compared to the rest of the UK (Table 3.3), as a result of the high rainfalls received. Vincent *et al.*, (1995) have shown a net reduction in wet deposited non-marine sulphur of 15% from 1986 to 1994, evidence of this reduction is, as yet, not apparent at the Afon Hafren site.

3.3.3 Deposition Chemistry: Nitrogen impacts

The total nitrogen deposition to the Hafren, including throughfall and dry/occult deposition has been estimated to be in the order of 33 kg/Ha/yr (Reynolds *et al.*, in press). The effects of high nitrogen deposition fall into two categories: 1. eutrophication and nitrogen enrichment and 2. acidification. Gundersen (1995) gives a full summary of the impacts of increased nitrogen deposition on forest ecosystems, but some of the key points are listed below. Damage to tree leaves and needles, greater wood production, increased water demand, nutrient deficiency, increased cell size and risk of wind-blow, changes in understorey to nitrophilic species, algal growth on leaves and needles reducing photosynthetic light, increased frost sensitivity and parasite susceptibility. Nutrient deficiency can result from enhanced tree growth rate driven by higher nitrogen availability and causing an absolute depletion or relative dilution of other nutrients not enhanced by deposition. Other deficiencies result from the loss of leachable cations such as Mg from the soil, which may have a further knock-on effect reducing the capacity of vegetation to retain nitrogen inputs. Mobilised Al if in high enough concentrations may result in root damage. The threshold input for nitrogen leaching is around 10 kg/Ha/yr, the Hafren receives three times this quantity and this is reflected in the stream chemistry.

3.3.4 Stream Chemistry

The differences in pollutant loads to the two IM catchments are clearly reflected in the respective stream chemistry (and biology; as has already been shown). The stream waters of the Afon Hafren are highly acidic in contrast to the Allt a Mharcaidh where they are well-buffered.

Stream chemistry data for the Allt a Mharcaidh are less comprehensive than those for Afon Hafren in that a smaller range of determinands are analysed. Figure 3.6 shows time series for the solutes in Allt a Mharcaidh run-off that are within the normal detection field for the analysis method used. A large number of the variables are at or near the detection limit of the method of analysis (K, Mg, PO_4, total oxidised nitrogen (TON), F, Fe, Mn, Cu, Zn, Ba, Br and Sr). The stream chemistry at this site is described in detail in Jenkins *et al.* (1993, 1994). The chemistry shows regular seasonal variations. During periods of low flow well buffered groundwater and deep soil water feeds the stream. These waters are rich in Si, the main product of the weathering of the siliceous bedrocks. DOC (absorbance at 250nm), aluminium and Cl concentrations are low at baseflow. The behaviour of sodium is complicated by the different sources of this anion which is present in deposition and also derived from bedrock weathering. Rainfall and snow-melt result in major periods of high flow at the beginning of each year. The storm-flow waters are derived from the surface and near surface zones and are poor in weathering products (Si) and have low pH and alkalinity values. The waters that flush rapidly through the organic upper soil layers have high DOC and aluminium concentrations. The aluminium is largely in the form of organic complexes.

In marked contrast, the stream waters of the Afon Hafren are not well buffered, they exhibit their highest pH values at only the lowest flows. Table 3.4 gives statistics for the pH distributions at both sites from 1986 to 1995. In the Mharcaidh the upper 75% of samples fall in a pH range of 0.71 units, in the Hafren the upper 75% of values lie in a range of 1.75 units.

Table 3.4 *Statistical measures for the pH distributions of stream waters at the two UK-IM sites between 1986 and 1995. In the Hafren pH is skewed towards low (acidic) values, unlike the Allt a Mharcaidh which is well buffered, pH being skewed towards higher values.*

Site	min.	5%ile	25%ile	median	75%ile	95%ile	max.	skewness	N
GB01	5.09 [1](1.00)	5.8 (0.63)	6.28 (0.38)	6.48 (0.27)	6.64 (0.18)	6.84 (0.08)	6.99 (0.00)	-1.14	459
GB02	4.12 (1.00)	4.55 (0.83)	4.87 (0.70)	5.23 (0.56)	5.83 (0.32)	6.42 (0.08)	6.62 (0.00)	0.35	495

[1] The figure in parentheses is the proportion of the range at which the quoted pH value lies. For a skewness of 0 this value would be 0.5 at the median. For GB01 the upper 50% of values lie in the upper 27% of the pH range.

The chemistry of the Afon Hafren shows similarities to the Allt a Mharcaidh with marked seasonality in marine components such as Mg, Na and Cl, which peak in the winter months as a result of high rainfall loads (Figure 3.7). Seasonal variations in concentration also occur in constituents affected by hydrological processes, for example, Al. At low flows the waters are fed from deep soil and groundwater sources, these waters are relatively well buffered due to their slow travel time through the catchment; ion exchange processes in the mineral phases of the soil and contact with the bed rock replacing hydrogen ions with base cations. At higher flows a greater proportion of the stream flow is derived from waters draining the soil surface and organic rich upper soil layers. These layers are depleted of base cations but contain aluminium, leached by the acidic waters, from the less soluble minerals phases present in the soil. Examination of the Al species has shown that around 65% of the aluminium is present in its most environmentally harmful trivalent form at stormflow (Neal *et al.*, 1992). The mean concentration of Al is ten times that in the Mharcaidh (Table 3.5). The mean stormflow Al concentrations are around 2.5 times those at baseflow, 174 and 417 μg/l.

Table 3.5 *Flow weighted mean stream chemistry of the Afon Hafren and Allt a Mharcaidh between 1989 and 1994.*

		Afon Hafren			**Allt a Mharcaidh**		
		Mean	Min	Max	**Mean**	Min	Max
Na	mg/l	**3.9**	2.3	6.7	**2.9**	1.7	5.5
K	mg/l	**0.2**	0.1	1.0	**0.3**	0.1	0.7
Ca	mg/l	**0.7**	0.3	2.4	**0.9**	0.4	1.8
Mg	mg/l	**0.7**	0.2	1.5	**0.3**	0.2	0.8
SO_4	mg/l	**4.3**	2.2	12.3	**2.2**	1.6	4.3
Si	mg/l	**1.2**	0.5	4.6	**2.4**	0.8	3.7
DOC	mg/l	**2.2**	0.0	7.3	**2.3**	0.1	7.2
NO_3-N	mg/l	**0.32**	0.0	1.4	**0.03**	0.0	1.2
Total Al	μg/l	**318.5**	16.1	1081	**33.1**	0.0	144.0
Cl	mg/l	**7.1**	3.9	12.2	**3.6**	1.7	10.5
pH		**4.8**	4.1	6.8	**6.4**	5.1	7.0
Alk	ueq/l	**-20.5**	-63.4	69.4	**51.5**	4	110
Cond	uS	**45.9**	25.0	89.0	**22.8**	13.0	45.0
SO_4*	mg/l	**4**	1.8	11.9	**2.0**	1.1	4.1

The seasonal variation in NO_3-N concentration results largely from nutrient uptake cycles in the catchments' vegetation; concentrations begin to fall each spring as plant growth commences, and rise once more at the beginning of Autumn. The acidic nature of the stream waters of the Hafren are reflected in the high concentration of NO_3-N and a variety of other species (Table 3.5); there are much higher concentrations of NO_3-N, SO_4* and Al than in the Mharcaidh. The differences between the two UK-IM sites are a result of the high deposition of acidic anions, as well as, the additional impact of being afforestation in the Hafren. Forest cover results in enhanced capture of salts from the atmosphere compared to grassland areas (Reynolds *et al.*, 1989). Forest cover also has other implications, particularly with regard to NO_3-N concentrations. As a forest grows and the canopy closes light to the understorey vegetation is cut-off, effectively removing this as a sink of nitrogen, at maturity the nutrient requirements of the forest stand itself are reduced (Stevens *et al.*, 1994, Gundersen, 1995). The presence of the forest stand has a further, hydrological, implication in that evapotranspiration from forested areas is greater than grasslands (Kirkby *et al.*, 1991) resulting a reduction in the potential to dilute chemical species entering the stream. These effects add together and increase the likelihood of nitrogen saturation and leaching from afforested catchments.

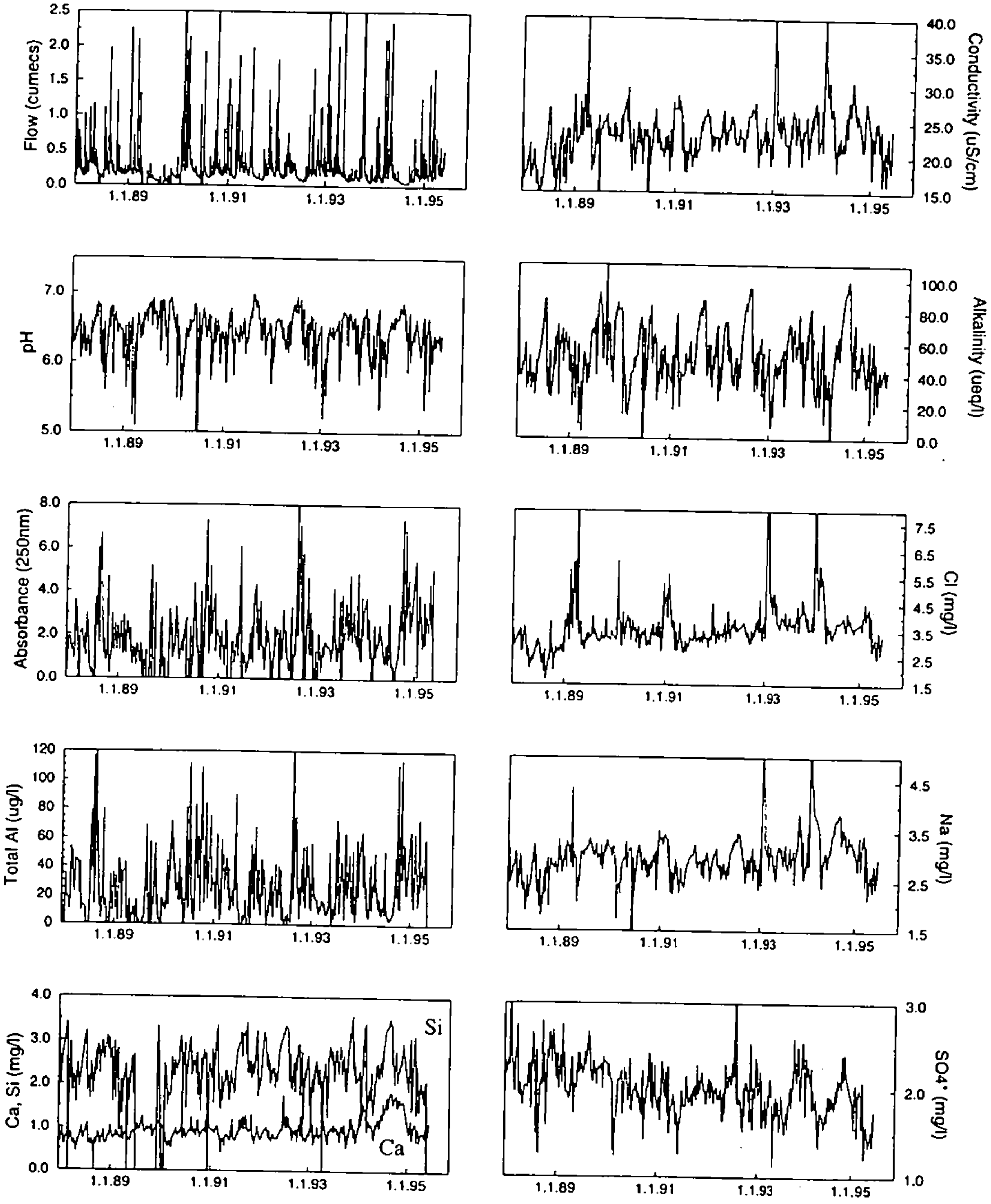

Figure 3.6 *Stream chemistry and flow data for the Allt a Mharcaidh*

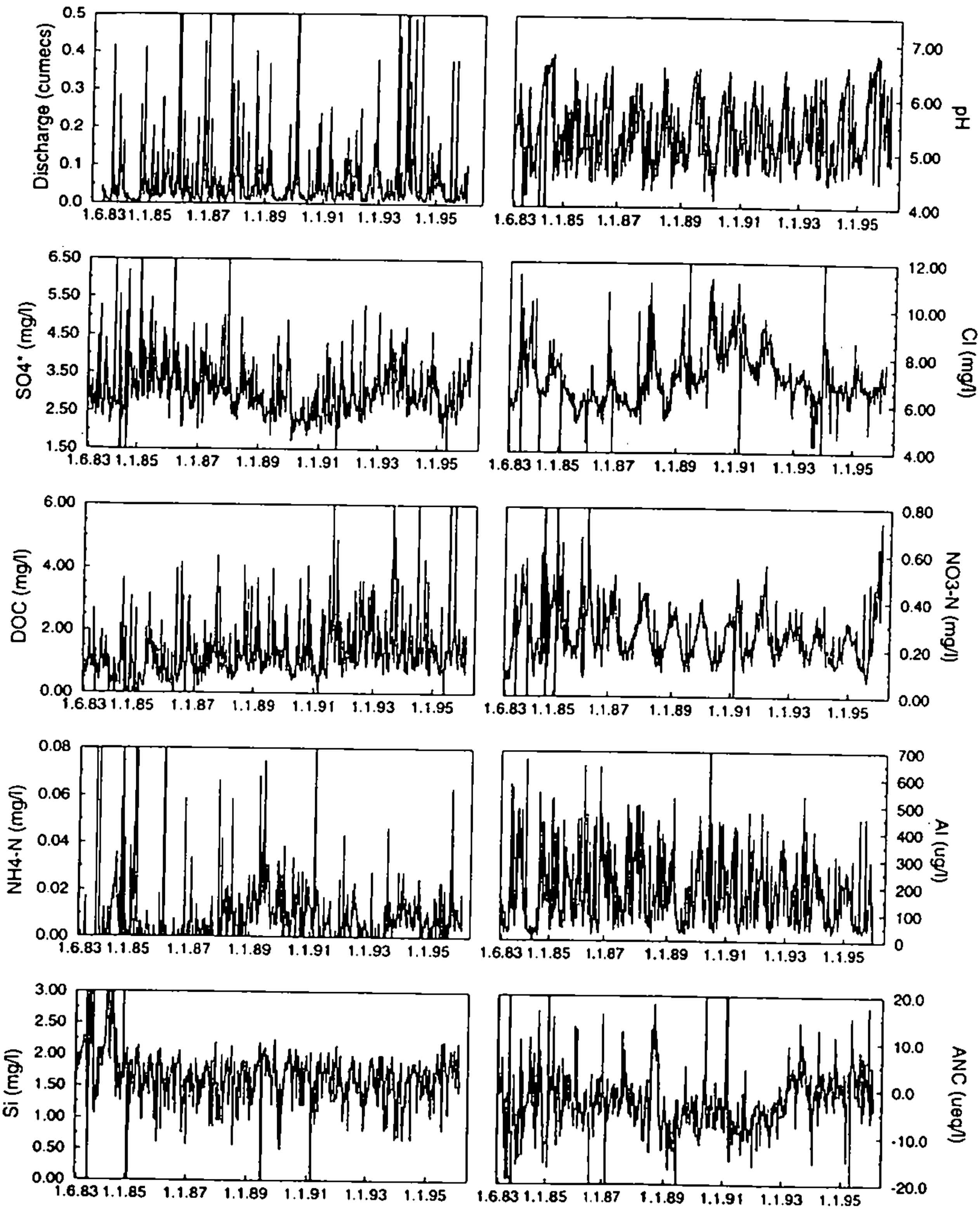

Figure 3.7 *Flow and stream chemistry data for the Afon Hafren. Cyclic behaviour is apparent in SO_4* and Cl, demonstrating the influence of long-term atmospheric patterns and drought effects, as well as, different sources of atmospheric components on stream chemistry. Trends are evident in the concentrations of DOC and NO_3-N.*

Nitrogen saturation is said to have occurred when 'inorganic N is in excess of total combined plant and microbial nutritional demand' (Aber *et al.* 1989). Of the 50 sites in the IM programme, the Hafren is the second highest nitrogen leaching catchment with an annual export of around 7 kg/Ha, the majority of sites leaching less than 1 kg/Ha (FEA, 1995). Coincident with the output of nitrate-N is the leaching of base cations and the mobilisation of Al (Gundersen, 1995). Another result of excessive acid deposition is the loss of macro-nutrients. Reynolds *et al.* (in press) estimate net losses of Na, K, Ca and Mg of 2.4, 0.7, 8.0 and 5.5 kg/ha/yr, respectively, the losses of Ca and Mg being particularly high and in the long term threaten site fertility (Gundersen, 1995).

3.3.5 Stream Cemistry: Long-term variations

Long-term trends in stream chemistry are evident at both of the UK-IM sites. At the Allt a Mharcaidh significant trends were found for Cl and non-marine sulphate (SO_4*). The interpretation of these trends, however, requires some caution. It would be convenient to propose that the fall in non-marine sulphate concentration was the result of reduced anthropogenic emissions. Such a reduction is certainly not evident in the deposition data (Figure 3.4, Table 3.2). The change may simply be part of a more complex cycle of behaviour driven by some climatic effect. There is some evidence for a reduction in stream temperature in the Mharcaidh which may result from changes in weather circulation patterns. The fact that Cl is rising and SO_4* is falling, without a significant change in flow might suggest a greater incidence of rainfall/snowfall events from air-masses that have passed over the oceans collecting sea-salts, and not contaminated air from terrestrial contaminant sources. This is the most likely explanation.

Ten years worth of deposition and stream chemistry for the Hafren has been analysed for trend using regression, Seasonal Kendall and LOWESS (robust LOcally WEighted regression and Smoothing Scatterplots) techniques (Robson and Neal, 1996). In the latter approach the time series is decomposed into a long-term curvilinear trend, seasonal component and residuals, in effect a short-term noise component (Cleveland, 1979; Hirsch *et al*,. 1991; Robson and Neal, 1996). The LOWESS approach to trend analysis certainly deserves greater use and has certain advantages over the conventional trend analysis techniques. It's main advantage is that it overcomes the problems associated with short periods of data and the identification of artificial trends; where a downward trend might be identified, but on visual examination found to be part of some longer-term cyclic behaviour. The technique offers a robust analysis which is more consistent with the kind of interpretation that visual examination would give.

The only significant trend in stream water quality found was the increase in DOC, probably related to increased organic matter breakdown. There are long term variations in constituents associated with marine (Cl) and terrestrial deposition sources, as well as, those resulting from acidification (ie, Al). These changes appear to coincide with changes in long term weather circulation patterns and drought periods. The high Cl concentrations occurring around 1990 coincide with the break in the 1989 drought, this is reflected in the high Cl loads in deposition, and demonstrates the washout of marine salts accumulated in the forest canopy as well as the upper soil layers. Clearly there was rainfall in 1989, but these were insufficient to induce significant runoff in the Hafren stream, thus components deposited in rainfall during this period must have accumulated in the catchment. At the same time SO_4* concentrations reached a minimum, peaking in the mid 1980's and around 1993, when rainfall and Cl concentrations are lower. Al shows a decline in peak concentrations, this slight reduction might result from the fall in NO_3-N winter maxima over the period 1986 to 1995. There have been a number of small felling operations in the Hafren in 1986 and 1995. Felling causes the release of NO_3-N, and this might explain peaks of concentration in those years, but not the general decline in concentration or the reduction in amplitude of the seasonal variations upto 1995. As the decline is also not evident in the deposition loads, the decline in nitrate must result from a combined vegetational/climatic affect which is the subject on-going study. NH_4-N exhibits similar behaviour to Cl and rainfall, however, the two main peaks in concentration occur in 1984 and 1989 at times of extended base flow and low Al concentration, suggesting that these are reduced groundwaters. Si concentrations, derived from bedrock weathering, remain at a near constant baseflow value of around 1.75mg/l, undergoing dilution at higher flows by rainfall.

The Hafren is clearly very chemically dynamic demonstrating large changes in concentrations over short, medium and long timescales. The catchment is also badly acidified, the Allt a Mharcaidh represents a relatively unimpacted site and the data available for these sites give a unique insight into the hydrochemistry and biology of upland catchments in the UK.

4. Acknowledgements

The UK IM Focal Centre would like to thank the following organisations and individuals for their contribution of data, field sampling and chemical analyses. Without their assistance the UK contribution to the ICP IM Programme would not be possible. Jo and Mollie Porter, sampling and data retrieval at Allt a Mharcaidh. Sue Hill; sampling and analysis at IH Plynlimon. Chris Smith and analytical staff at IH Wallingford. Keith Vincent at AEA Technology National Environmental Technology Centre for the provision of deposition and air quality data. Don Monteith of ENSIS, London for supplying macro-invertebrate data. Thanks also to Martin Forsius of the Finnish Environment Agency for permission to reproduce the modelling work in Appendix I.

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APPENDIX I. Modelling

During 1995 a major effort was placed on a dynamic model comparison exercise. This involved the calibration of MAGIC, SAFE and SMART to 5 sites in the ICP-IM using standardised parameter values and driving variables. A report on this exercise is included in the 5th Annual Report 1996 of the ICP-IM and this is reproduced on the following pages.

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2.1 Introduction

Both steady-state and dynamic models have been developed to predict the acidification of soils, lakes, streams and groundwater (e.g. Cosby *et al*, 1985; de Vries *et al*, 1989; Sverdrup *et al*, 1995). While the former are used to estimate the steady state of a system for a given load by neglecting time-dependent processes and finite pools, dynamic models are used to predict the gradual chemical response of a receptor to changing depositions by including the various buffer and adsorption/desorption mechanisms. The time development of acidification is important for determining the timing of necessary measures for emission control, and for assessing the dynamic response of possible critical load exceedance.

At the meeting of the UN/ECE Working Group on Effects in July 1994, dynamic modelling was considered to be a key activity for the WGE programme development. It was proposed that the activities on dynamic modelling should be carried out on two different scales of coverage: (i) the ICP IM will be responsible for dynamic modelling on selected sites, in cooperation with national data centers and invited modelling experts; and (ii) the Coordination Center for Effects (CCE) will take the responsibility for the model applications on a regional basis. These two projects are complementary; the catchment scale applications provide a reality check of the regional behaviour of the models.

A pilot study testing the suitability of the ICP IM database for dynamic modelling, using the SMART model, was carried out during 1994 (Bleeker *et al*, 1994 and 1995). This study showed that successful model calibrations can be carried out using data from ICP IM sites, and several recommendations for improvements for the continuation of modelling exercises were given.

A new project for the coordinated application of three dynamic models (MAGIC, SAFE, SMART) on selected ICP IM sites was therefore started in 1995. The project has been funded by the Nordic Council of Ministers. The main aims of the project were:

(i) The three models are calibrated to the observed conditions at present-day, using consistent input data, model parameters and historical deposition scenarios for the selected ICP IM sites;

(ii) The calibrated models are used to predict the long-term acidification of soils and runoff water, given different scenarios of future deposition of S and N. These scenarios are based on agreed measures for emission reductions;

(iii) The dynamic response of possible critical load exceedances are assessed;

(iv) Model results are compared and uncertainties assessed;

(v) The site-specific model applications are used as a reality check for the regional-scale modelling exercise of the CCE.

The present paper summarises some main results of the project. A more detailed description is given in Forsius *et al* (1996).

2.2 Implementation of the project

The models were applied by the same groups which have participated in the actual model development. The different tasks were carried out as follows:

Project management; data gathering; assessment and reporting	Finnish Environment Institute (Forsius, Kleemola, Johansson, Syri)
Derivation of deposition and nutrient uptake scenarios	Finnish Environment Institute (Johansson) Lund University, Sweden (Sverdrup, Alveteg, Walse)
MAGIC applications	Institute of Hydrology, UK (Jenkins) Norwegian Institute for Water Research (Lükewille)
SAFE applications	Lund University, Sweden (Sverdrup, Alveteg, Walse)
SMART applications	RIVM/CCE, The Netherlands (Posch)

2.3 Model descriptions: MAGIC, SAFE and SMART

The three models are all process-oriented dynamic models that attempt to describe the long-term impact of atmospheric deposition, net uptake by vegetation, weathering and cation exchange on the chemical composition of soil and the outflowing water. Solution chemistry is governed by charge and mass balance principles, using lumped process descriptions.

MAGIC is generally used as a one-box model (Cosby *et al*, 1985). It calculates a separate Gaines-Thomas equilibrium for the exchange of each of the cations Ca, Mg, K and Na. Sulphate adsorption is described by a Langmuir isotherm. The model keeps track of mass budgets and chemical equilibria of all major ions including organic acids.

SAFE (Sverdrup *et al*, 1995) is a multilayer model which calculates weathering rates from measurements of soil texture, minerology and moisture. The model uses a mass transfer equation for the ion exchange of base cations, which converges upon an equilibrium described by a Gapon equation.

SMART (de Vries *et al*, 1989, Posch *et al*, 1993) uses Gaines-Thomas equilibrium equations for the various exchange reactions. N-immobilisation is modelled as a function of the C:N-ratio. A simple lake module, describing retention of sulphate, nitrate and ammonia, has recently been added.

All models have been used in numerous studies on both catchment and regional scale (e.g. Jenkins *et al*, 1990, Kämäri *et al*, 1994, Sverdrup *et al*, 1995).

2.4 Site descriptions

After screening of the available data, five ICP IM sites were selected for model application: Afon Hafren (GB02), Birkenes (NO01), Forellenbach (DE01), Gårdsjön (SE04) and Hietajärvi (FI03) (see Figure 1.1 in Section 1). The size range of the catchments is 3.7-464 ha. The sites receive varying deposition loads and have different catchment characteristics. Therefore these sites represent a wide range of possible future responses to atmospheric loadings. Some major features of the sites are listed in Tables 2.1 and 2.2.

Table 2.1 Catchment and soil characteristics of the modelled catchments.

Area code	Area name	Coordinates	Catchment area (ha)	Lake area (%)	Forest area (%)	Forest age (years) av.	Dominant vegetation
DE01	Forellenbach	N48°56'E13°25'	68.8	0	95	90	Spruce
FI03	Hietajärvi	N63°10'E30°43'	464	24	51	50-100	Scots pine
GB02	Afon Hafren	N52°29'W03°41'	358	0	50	< 50	Sitka-Norway spruce
NO01	Birkenes	N58°23'E08°15'	41.6	0	90	80	Norway spruce
SE04	Gårdsjön F1	N58°03'E12°01'	3.7	0	100	80	Norway spruce

Area code	Area name	Dominant soiltype	Mean soil thickness (m)	Bulk density (g/cm3)	CEC	Base saturation (%)
DE01	Forellenbach	Dystric cambisols	1	0.981	65.4	4.6
FI03	Hietajärvi	Fibric histosols	0.85	1.291	3.8	47.3
GB02	Afon Hafren	Peaty podzols	0.88	1.256	32.2	11.6
NO01	Birkenes	Thin humus	0.22	0.773	48.1	29.1
SE04	Gårdsjön F1	Orthic podzol	0.63	0.869	68.3	15.8

Table 2.2 Annual precipitation and runoff (mm), and annual average deposition and runoff fluxes for the period 1991-94 for the modelled catchme

Annual deposition:

Area	precipit. (mm)	SO4S meq/(m2*a)	NO3N	NH4N	H	Ca	Mg	Na	K
DE01	1229.8	50.8	41.7	43.1	39.2	20.4	4.8	11.8	4.5
FI03	625.3	21.4	11.5	9.2	19.6	3.1	1.1	3.0	0.9
GB02	2579.2	87.8	35.6	44.4	34.9	33.3	53.4	242.2	6.8
NO01	1283.6	75.9	52.8	48.0	57.8	9.0	20.0	86.9	3.5
SE04	1073.0	59.1	40.6	38.4	44.6	10.0	18.7	76.8	4.6

Annual runoff:

Area	runoff (mm)	SO4S meq/(m2*a)	NO3N	NH4N	H	Ca	Mg	Na	K
DE01	870.2	74.4	39.6	5.7	2.3	125.4	39.5	81.4	11.4
FI03	391.3	15.5	0.7	0.4	0.3	25.4	10.6	19.1	4.2
GB02	2064.6	188.3	45.4		33.2	88.4	134.6	415.7	11.3
NO01	837.3	97.5	11.2		28.0	42.6	25.8	127.9	3.3
SE04	517.9	144.6	0.8	0.7	41.7	35.5	83.5	258.0	7.6

2.5 Methods

The models require deposition and nutrient uptake by forest growth as external input. The method used for generation of this input originates from the work of the SAFE modelling group (Alveteg *et al*, 1996). The derivation method of historical development and future scenarios for deposition and uptake is explained in more detail in the Annual Synoptic Report 4 (1995) with updates in Johansson *et al* (1996).

2.5.1 Deposition scenarios

The deposition of each compound was divided into different components using bulk and throughfall deposition measurements: originating from sea or anthropogenic sources, and these both in dry and wet fractions. Historical and future development and forest filtering effect were then allocated to proper components.

The total dry component for sulphur, chloride and sodium was assumed to be the difference between throughfall and bulk deposition, as they are mobile ions in the tree canopy. For base cations other than sodium, the minimum of sodium or chloride filtering was used. For nitrogen compounds the total dry component was bulk deposition times minimum filtering factor of sulphur, sodium or chloride.

The wet marine components were estimated with seasalt correction factors from the sodium or chloride wet deposition. The dry marine component for sulphur was calculated using the same ratio to its wet marine component as between its total dry and total wet component. For other compounds, except for nitrogen which is completely of non-marine origin, the dry marine component was estimated with seasalt correction factors using the sodium or chloride dry deposition. The obtained wet marine value for any compound cannot be larger than its measured total wet deposition.

The wet anthropogenic components were calculated by subtracting the wet marine component from total wet deposition. The same applies to the dry anthropogenic component. The remaining unallocated deposition was finally assigned to canopy exchange, serving as an indication of internal circulation in the forest. The wet anthropogenic component for both nitrogen compounds was the measured bulk deposition.

The wet marine component was assumed to remain constant in time. Other wet and dry anthropogenic components were dependent on deposition histories, calibrated to the present measurements of one year. Sulphur deposition history for 1880-1991 was extracted from Mylona (1993) for each EMEP grid cell separately. The earlier scaling was extended back to 1800 using an average for Europe estimated by Sverdrup *et al* (1995). Average nitrogen histories for the whole of Europe were estimated on basis of work by Sverdrup *et al* (1995) and Asman and Drukker (1988). The non-marine dry deposition component of base cations was assumed to be partly connected to anthropogenic activities reflected by measurement data during a period of considerable emission reductions (Hedin *et al*, 1994), and was assumed to follow the historical sulphur deposition curve.

All dry deposition components are affected by forest filtering, which was assumed to depend linearly on the tree needle volume represented by the needle mass in internal calculation. The present filtering factor was calibrated to current canopy volume and dry deposition estimates.

The deposition to open land was assumed to equal the sum of wet components plus 20 % of the dry deposition. The open land deposition does not have a big effect in the mainly forested IM sites.

In the scenarios, base cation and chloride depositions were kept at present levels. For acidifying deposition three future scenarios for the model application were employed (Table 2.3). The deposition was calculated with the EMEP transfer matrices and official UN-ECE emissions for the target years 2000, 2005 and 2010. The alternatives for sulphur deposition were current reduction plans (according to second sulphur protocol, SP2) and maximum feasible reductions (MFR)(Cofala and Schöpp, 1995). For nitrogen, NO_x and NH_y depositions were frozen at the present level. For NO_x, a reduction scenario of flat 30 % reduction from present deposition was used to demonstrate the possible effects of such a measure.

Table 2.3 The three scenarios employed in the acidification model runs, roughly representing the possible range of future acidifying deposition.

scenario	SO_2	NO_x	NH_y
A) best prediction	Second sulphur protocol	present level	present level
B) lower limit	Maximum feasible reductions	-30% from present level	present level
C) upper limit	present level	present level	present level

2.5.2 Nutrient uptake scenarios

The uptake by forest growth was based on biomass density and element content together with the annual increment of each tree compartment: stem over bark, branches and needles. The growth estimate is most suitable for a temporally homogenous forest with one major tree species, or a well-known tree species distribution each of known age, after clearcut or forest fire.

Potential annual growth and standing volume were calculated from a logistic growth curve, representing the whole forest and initially based on conditions from southern Germany. The branch growth was assumed to be one fifth of stem over bark growth (Mälkönen, 1975). The needle growth is described with a growth curve similar to that of stem over bark. All growth curve parameters were calibrated to current volume and growth.

Forest growth was assumed to be nitrogen limited. The growth of all above-ground compartments must be reduced if the nitrogen via atmosphere and mineralization is not enough to satisfy the estimated potential growth.

2.5.3 Model calibrations: MAGIC, SAFE and SMART

Application of the models at the catchment scale requires averaging of physical and chemical properties of the soils into one or several homogenous layers characteristic for the entire catchment.

The models were calibrated to reproduce present-day (1990-94) soil and streamwater chemistry. The weathering rate of base cations is a key model parameter in all models. In SAFE these are obtained from information on soil texture and minerology, and in the other models by calibration.

The deposition and uptake patterns were used to drive the models and produce the chemical changes in soil and streamwater over time. The models were all using a common data set for each site, but calibrated independently of one another. Yearly time-steps were used in all model runs.

2.6 Results and discussion

2.6.1 Deposition and uptake scenarios

In figure 2.1 the average sulphur and nitrogen depositions onto the whole IM plot are shown for scenario A. The forest filtering effect can be seen at most sites, especially at clearcut and for future development assuming present level emissions.

Figure 2.2 shows the net uptake by forest, which is required as model input and obtained by extracting mineralized material flux from total forest uptake values. In Afon Hafren, there was no forest at the plot before planting in 1940's. For Forellenbach, forest growth representative for the whole plot was difficult to describe with the current method. Growth estimate could not handle growth for subplot areas, where various management practices were reported, but their effect was considered for an aggregated forest.

The ion balance in modelled deposition was calculated in the period under study (1800 - 2050). The calculated pH was often slightly above four for present conditions and even the historical pH has been rather low. This may indicate an imbalance between estimated historical deposition compound values, since the calibrated models tended in some cases to overestimate acidification effects in comparison to measurements. The magnitude of historical deposition is sensitive to the measured deposition values, to which it is calibrated, calling for use of measurement data from several years. Further uncertainty is brought in by the relationship of the forest needle volume to the filtering effect, which may not be linear in all phases of the forest cycle. A more thorough comparison against measured pH values will be carried out.

The nitrogen deposition histories are estimated averages for the whole of Europe. The difference between actual and derived history is likely to be largest at sites where the short-range transport of pollutants is significant, as for ammonia.

Growth estimates could be refined by using locally estimated growth curves for the region and tree species concerned. A more complete description would, however, call for data not available for all sites in the IM program. The growth curve calibration to present volume and growth only may lead to faulty predictions in the early and late phases of the rotation period. To depict in more detail the growth of all tree compartments, various biomass functions (Marklund, 1988) could be applied in the derivation method itself. However, the data available from IM sites restricts this approach.

In some cases the potential growth curve could only be fitted to the present volume and growth by allowing a rather high final standing volume. The future growth and uptake may thus be overestimated, and a potential maximum forest volume will be applied to avoid unrealistic scenarios.

This derivation method was the first attempt to supply site-specific deposition and uptake scenarios for acidification model application at IM sites. A more straightforward approach would have been to estimate a modelled open land deposition with a constant filtering factor and historical scaling and a simple growth curve, not restricted by nutrient nitrogen available, to estimate uptake. Instead, steps were taken into an already more complex description of hypothesized deposition breakdown and of a nitrogen-limited tree growth with a dynamic filtering capacity of dry deposition, based on earlier work on SAFE model applications.

The advantage of the current approach is the rather modest requirement of input data. The results, in turn, retain considerable uncertainty due to e.g. too few calibration values, although it may be small when compared to potential uncertainties involved in the whole modelling exercise. The algorithms in the method can still be refined, especially the forest growth depiction, even with the current data available. Presently the scheme even as it is illustrates one promising way of compiling scenarios at a level sufficient for dynamic acidification models.

2.6.2 MAGIC, SAFE and SMART results

The simulated values for soil base saturation for the scenarios A-C are shown in Figures 2.3-2.5. Base saturation is a key measure for soil acidification, and therefore this variable was chosen to illustrate the behaviour of the models at the different sites. The complete results are shown in the detailed project report (Forsius *et al*, 1996).

In most cases the calibrated models yield consistent results for historical base saturation in 1900. At all sites the model results indicate at least a slight decrease in base saturation until present day. It should, however, be recognised that SAFE is a multilayer model and in the figures aggregated results for the whole soil profile are shown for this model.

At each site the predicted response varies depending on the future deposition scenario. The response to the different scenarios was also consistent. As expected, scenario B, where 'Maximum Feasible Reductions' for S emissions and -30% for NOx emissions have been assumed, always resulted in the most significant improvement. For this scenario either a stabilisation of the current situation or a significant improvement was generally shown. The only clear exceptions were MAGIC and SMART simulations for GB02 where continued soil acidification was indicated also for the B-scenario.

The A-scenario (Second S-protocol for S and present level for N emissions = 'Best prediction') resulted in a slower response than the B-scenario. In many cases this emission reduction for S was enough to stop continued soil acidification, although significant improvement was not always shown. For GB02 the

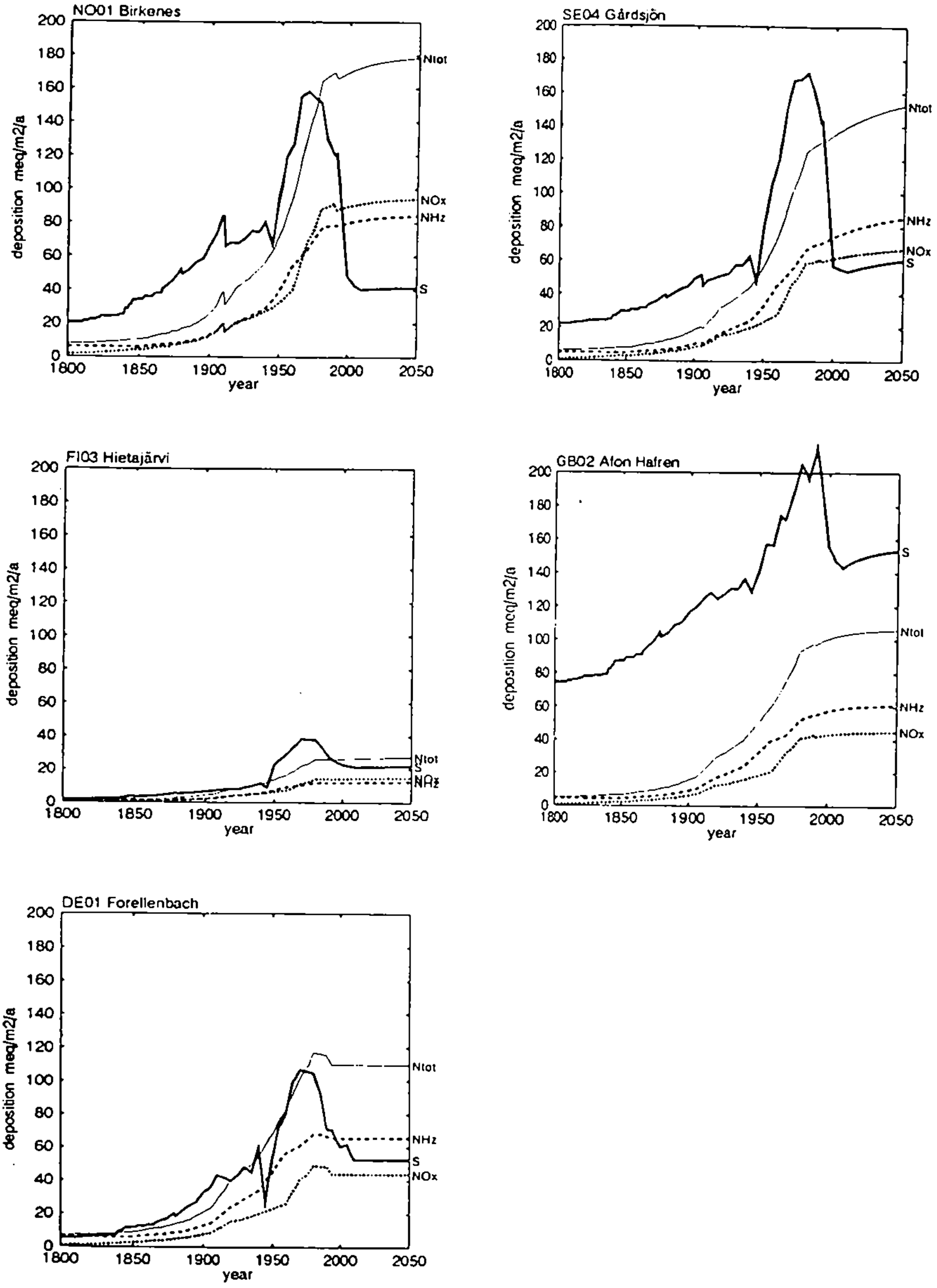

Figure 2.1. Simulated forest and open land depositions of sulphur and nitrogen compounds for scenario A for the five IM sites.

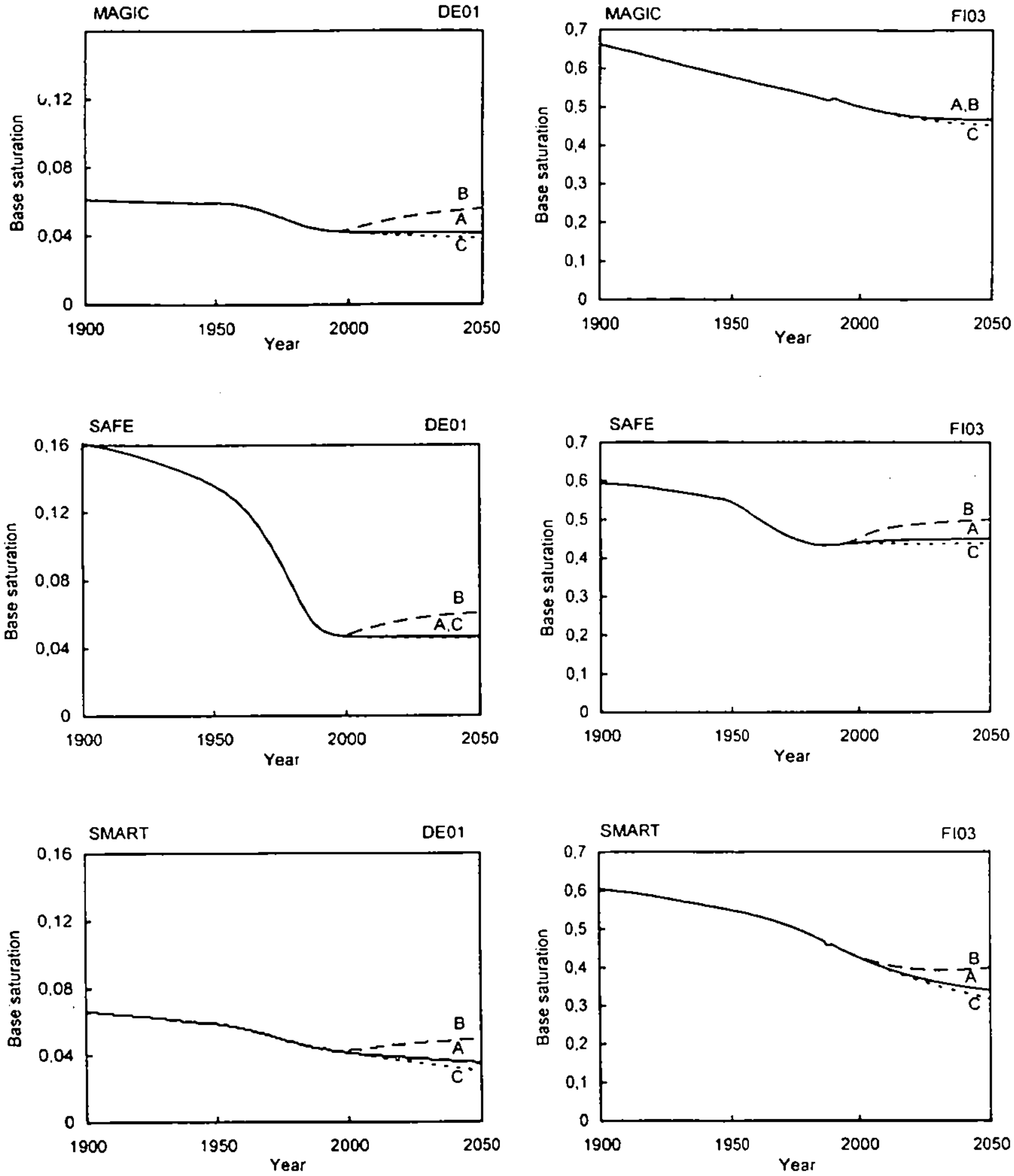

Figure 2.3. Simulated soil base saturation (fraction) for DE01 Forellenbach and FI03 Hietajärvi using three dynamic models and scenarios A-C (see Table 2.1).

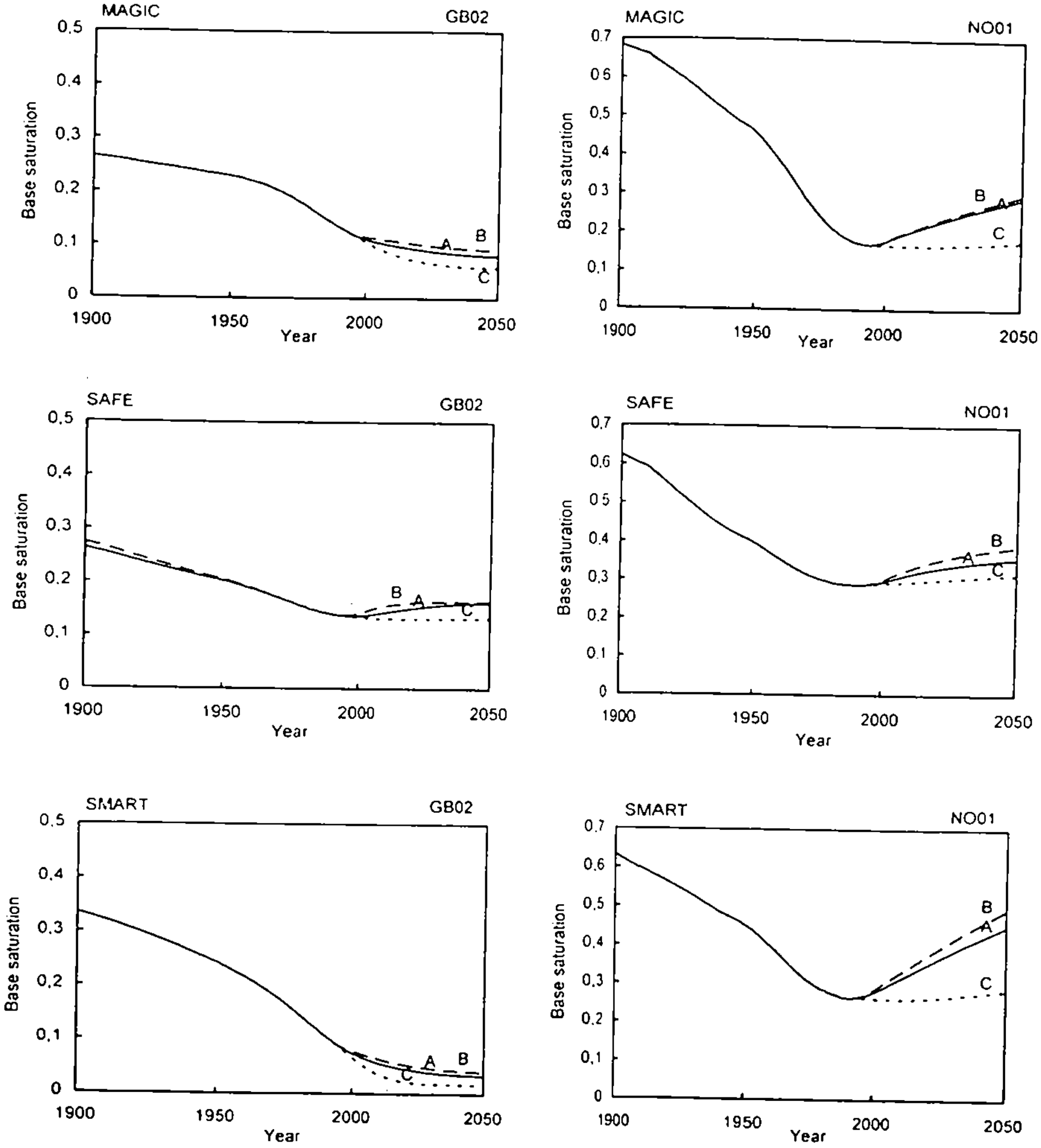

Figure 2.4. Simulated soil base saturation (fraction) for GB02 Afon Hafren and NO01 Birkenes using three dynamic models and scenarios A-C (see Table 2.1).

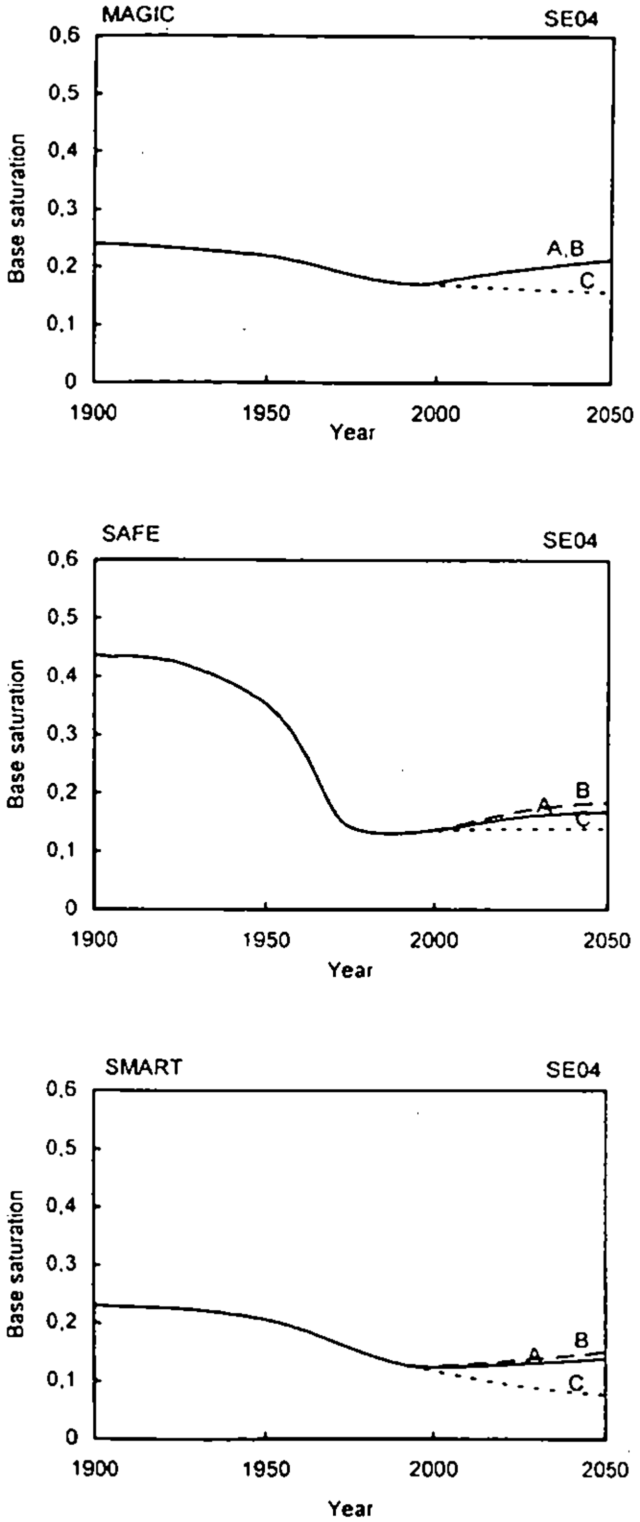

Figure 2.5. Simulated soil base saturation (fraction) for SE04 Gårdsjön using three dynamic models and scenarios A-C (see Table 2.1).

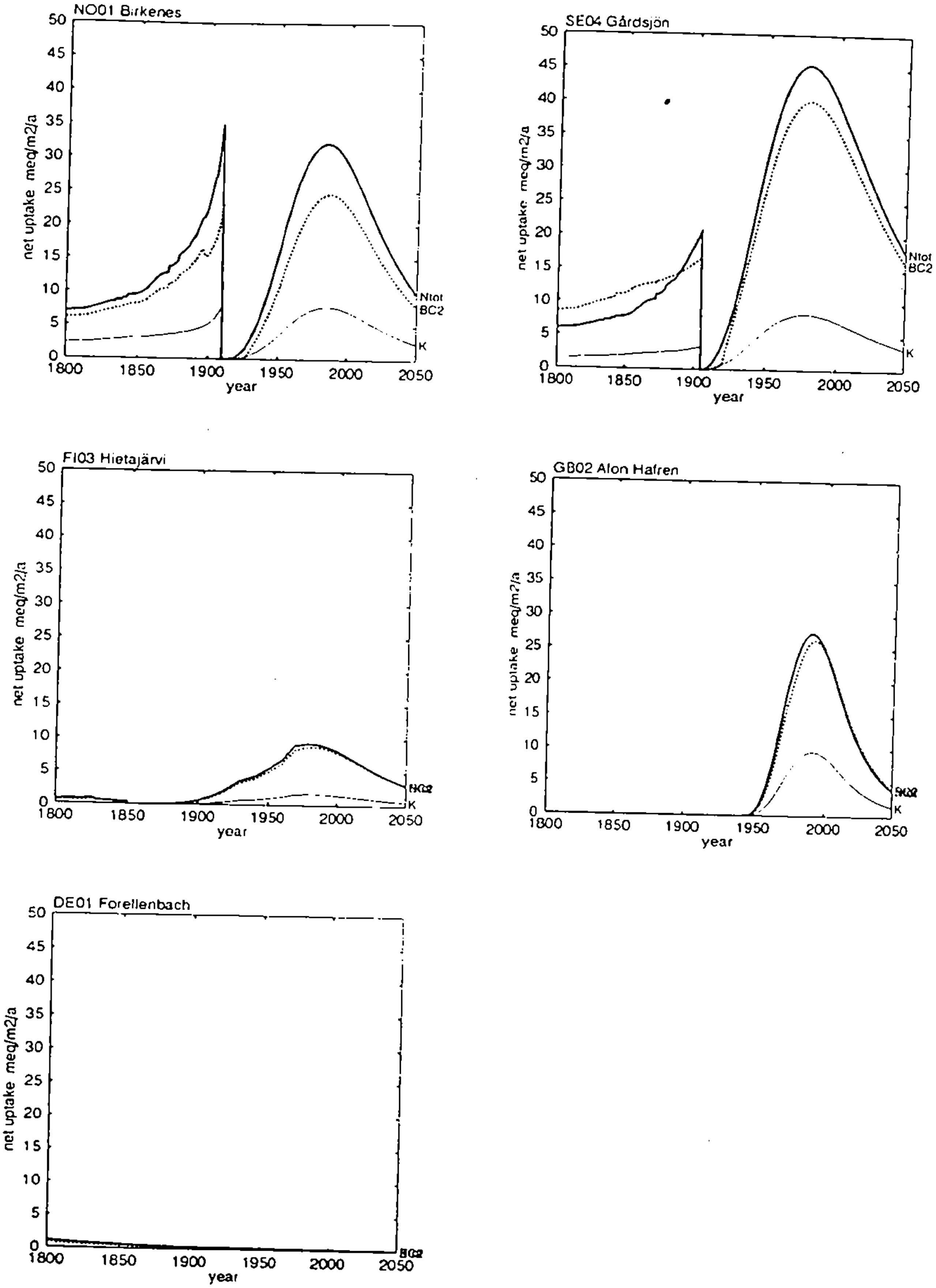

Figure 2.2. Estimated average net uptake of divalent base cations (BC2=Ca+Mg), potassium and total nitrogen by forest at the five IM sites.

simulations of MAGIC and SMART again indicate continued acidification (as well as SMART for DE01) using this scenario.

The model results demonstrate that these ecosystems respond in a dynamic way to changes in deposition (Figures 2.3-2.5). The deposition load a site can tolerate therefore depends on the time taken for a response to occur (see also Wright *et al.* 1991). Dynamic models are therefore needed in addition to steady-state techniques, which presently are used for mapping of critical loads and their exceedance. However, the large amount of input data required by the dynamic models limits the possibility to use them on the regional scale.

The three models applied here give in most cases consistent results. The same result has been obtained also in a previous study (Wright *et al.* 1991). Although the models contain in many cases similar process descriptions there are still important differences in the model structure, e.g. in the estimation of weathering rates. The similarity of the predictions gives confidence in the use of such models for scenario assessments and other policy oriented work.

It should still be recognised that much work is still needed regarding the modelling of nitrogen processes. All models applied in this study contain rather crude descriptions for nitrogen cycling and saturation. Different more detailed concepts are presently being developed and should be used for scenario assessment when properly tested and evaluated. It is likely that nitrogen processes in the long-term also will be affected by future climate change. Synergistic effects between atmospheric deposition and climate change should therefore be considered in future model development and scenario assessment.

2.7 Conclusions

- Dynamic models can be successfully applied to data from ICP IM sites.

- Catchments/plots respond in a dynamic way to changes in emissions/deposition. Dynamic models should therefore complement to steady-state techniques, when adequate data is available.

- The three models applied in this study yielded generally consistent results, which gives confidence in the scenario assessment.

- The 'Best prediction'-scenario (including the effects of the Second S-protocol and present level for NO_x- and NH_x-emissions), resulted in many cases in a stabilisation in the soil acidification, although significant improvements were not always shown.

- The models should be applied to more ICP IM sites to increase the sensitivity gradient and geographical coverage. This would require that more sites report complete datasets according to agreed formats.

- More work is needed to improve the description of N processes in the dynamic models.

Acknowledgements

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APPENDIX II. Outputs from UK IM programme

As presented in the previous report on this programme, under EPG 1/3/10, abstracts of papers derived from research in the two UK IM catchments are included in this report.

Water, Air and Soil Pollution **85**: 565-570, 1995.

SURFACE WATER ACIDIFICATION IN THE UK; CURRENT STATUS, RECENT TRENDS AND FUTURE PREDICTIONS

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Abstract. Data collected at 22 lake and stream sites under the UK Acid Waters Monitoring Network, established in 1988, are assessed. Non-marine sulphate concentrations in surface waters largely reflect the sulphur deposition gradient across the country. Time series analysis indicates an increase in non-marine sulphate concentrations at sites in SW Scotland, the Lake District and in Wales. No similar trends have been detected in deposition data for the same period. Predictions of water chemistry response at each site to the new UNECE sulphur protocol have been made using a long-term, dynamic acidification model (MAGIC). The results indicate that the agreed emissions reductions will lead to recovery at many sites over a 15-20 year timescale but will have little effect at the most impacted sites, within the next 15 years.

Hydrological Processes, **10**: 183-203 (1996)

WATER QUALITY TRENDS AT AN UPLAND SITE IN WALES, UK, 1983–1993

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ABSTRACT

Ten years of detailed upland stream and bulk deposition water quality data from Plynlimon, mid-Wales, are examined for trend. A robust statistical test (the seasonal Kendall test) is applied and data are presented graphically. Smoothing techniques are used to highlight the patterns of change which underlie high data scatter. The graphs show long-term cycles within the data which violate the assumptions of common statistical tests for trend. These cycles relate to fluctuations in the weather patterns at Plynlimon. Even though the seasonal Kendall test is significant for some determinands, the evidence from the graphs suggests that many of these 'trends' are unlikely to continue.

For solutes in rainfall, there is no convincing long-term trend. There is a possible increase in ammonium concentrations, which may indicate an increasing atmospheric source generated by farming activities, but this will require a longer data series for confirmation. Several trace metal concentrations increased significantly part way through the study period, but later returned to the original levels. The bulk precipitation sea salt input has been uneven over the 10-year sampling period, with the highest inputs occurring during the wetter winters.

For solutes in streamwaters, there are clear trends in dissolved organic carbon (DOC), iodine and bromide, which increase over time and may be attributed to an increase in organic decomposition in the catchment. Previous studies in Wales have shown similar behaviour for colour, which is related to DOC, but the corresponding changes for bromide and iodine are new. For most other streamwater determinands, any changes are masked by the effects of year to year variations in the quality and quantity of rainfall. For example, zinc and chromium variations parallel the corresponding rainfall quantity variations. The effect of rainfall quality variation is marked for marine-derived elements such as chloride. For sulphate, streamwater variations are inverted relative to chloride. This suggests that dry deposition may vary with weather conditions: high when the wind direction is from the land and low when weather systems are predominantly frontal and laden with sea salts. Alternatively, high sea salt rainfall may be affecting absorption/solubility reactions in the soils.

There are four main conclusions. Firstly, there is no indication of changing acid deposition inputs or changing acidity within the runoff, despite a decline in UK sulphur dioxide emissions. Secondly, streamwater DOC has shown an increase over time, but there is no clear corresponding decrease in pH as might be expected from acidification theory. Thirdly, there are cyclical variations in bulk precipitation inputs and in streamwater quality, which mean that trends cannot be established even with 10 years of data. Long-term cycles are likely to exist in other environmental data and extreme care is required for the interpretation of trend, especially if data sets are short. This aspect strongly supports the continuation of long-term monitoring programmes over several decades. Finally, the graphical application strongly enhances data analysis and should be considered an essential component of trend investigation.

KEY WORDS trends; water quality; Plynlimon, Wales; seasonal Kendall; robust regression

Science of the Total Environment, In Press.

Dissolved chromium pollution in rainfall and surface waters in mid-Wales during the mid 1980s

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Abstract

Atmospheric pollution by dissolved chromium occurred in the mid 1980s in a rural part of upland Wales with no local industrial sources and some 100 to 200 km distance from the major industrial centres of south and north Wales and the English midlands. The pollution peaked in rainfall, throughfall and stemflow during 1986-87 when average dissolved chromium concentrations tripled from a background of 2 µg/l. Correspondingly, there were large increases in the concentrations in runoff from streams in the area, annual mean values quadrupling during 1986-87 from 1983-85 values of about 2µg/l. Subsequently, the stream concentrations declined approximately exponentially to less than 0.2µg/l. Thus, the peak stream concentrations have to be set against a declining long term background trend presumably related to general improvements in emission controls for UK industry and changing industrial production patterns.

The annual average dissolved chromium concentrations in the stream during the peak years approached and in some cases surpassed values which are thought damaging to sensitive aquatic organisms. For the period prior to 1992, the dissolved chromium concentrations in the streams were higher than in the rainfall, throughfall and stemflow by about 30 to 40% and background weathering sources are probably small. Since evapotranspiration of rainfall should increase dissolved chromium concentrations in the stream by about 25 to 30%, it seems that most of the atmospheric chromium supplies are not being significantly inhibited on transport from the atmosphere to the stream other than by physical storage: differences between input and output are probably related to errors in flux estimation. This means that the dissolved chromium is relatively inert within the catchment, implying that it exists either in the hexavalent anionic state or in a highly complexed trivalent form in both the atmospheric input and the stream output. If it is the hexavalent form which predominates, which seems most likely, then this is particularly disturbing as it is in this state that it is at its most environmentally harmful. Subsequent to 1991, the rainfall input of chromium is over four times higher than the stream outflow and in this case the catchment is retaining much of the chromium input. This implies that the chromium input differs for this later period: the predominance of trivalent chromium is thus inferred. The reason for the pollution incidents throughout the study period is unclear as dissolved chromium concentrations are not correlated with determinands linked either to general air circulation patterns or to the usual sources of chromium such as the steel industry and cement manufacture.

APPENDIX III. Agenda and Minutes of the Fourth ICP IM Task Force Meeting

Agenda for the Task Force meeting:

Tuesday 26 March

Evening Registration
Unorganised get together at the Hotel Stefanie

Wednesday 27 March

09.00 1. Welcome adress by representative of host country. Opening of the meeting by chairman of Task Force.

2. Reports
   - a) UN/ECE (WGE, EB etc).
   - b) Other ICPs, TFs etc.
   - c) Chairman and Programme Center.
   - d) Changes in the programme network (short presentation by national representatives, only if there are changes in the network).

3. Presentation of IM Annual Synoptic Report 96 (draft version).

12.00 Lunch

14.00 4. Presentation of Joint ICP Report 96 (draft version) and further plans for the joint ICP report on "Effects of Nitrogen and Ozone".

5. Discussion and adoption of the programme to revise the Manual.
   - a) Presentation of outline prepared by the Programme center.
   - b) Discussion in groups and in plenum.

20.00 Opening Reception at the Hotel Stefanie

Thursday 28 March

09.00 6. Poster Session and National Presentations

12.00 Lunch

14.00 7. Tour to Vienna

20.00 Formal Dinner (Town Hall)

Friday 29 March

09.00 8. Presentation of LIFE-project and discussion on other financial instruments for further development of the IM-programme.

	9.	Discussion and adoption of the Work programme and reporting procedures for the coming year.
	10.	Other business/next meeting
	11.	Closing of the meeting
12.00	Lunch	

Notes from specific Agenda Items

Agenda Item 2c

Report from Chairman and Programme center

During the Working Group on Effects (WGE) meeting in Geneva in July 1995 the Chairman and the Programme Manager presented the further development of the Programme, and the Annual Synoptic Report, including the different asessments of results from Integrated Monitoring sites and the dynamic modelling project. The work-programme for 1995/96 was also presented.

The ongoing activities concerning cooperation between different ICPs etc were presented at the meeting, and were strongly welcomed.

On request from IM, the meeting once again emphasised the need for proper funding of the monitoring activities on the national level.

During the meeting IM also strongly supported the proposal for a Trust Fund for the ICPs etc, in order to ensure funding for coordination costs, Programme Centers etc. This question was also put forward to the EB. During the autumn, however, EB could not agree on a financial instrument for the effect oriented activities, other than voluntary contributions.

The IM Programme has during the year continued with asessments of results from selected IM-sites. These are:

- Evaluations of patterns of Nitrogen leaching and its possible causes.
- Ion-mass balances and proton budgets for IM-catchments (including the role of Nitrogen).
- Application of geochemical dynamic models, using different deposition scenarios.
- Effects of air deposition on vegetation.
- Calibration of deposition models with IM-results.

Results from these evaluations have been/will be:

- Presented during the TF meeting.
- Presented in the Annual synoptic report.
- Presented in the 1995 Substantive report to WGE.
- Presented during the Acid Reign-meeting in Gothenburg in June
- Presented at the EMAN-meeting in Canada.

Some of these evaluations are funded by the Nordic Council of Ministers.

Together with other ICPs etc IM has participated in discussions with WGE Bureau on further streamlining activities, including a Joint Report to the WGE meeting from all ICPs etc and a so called Substantive Report on Effects of Nitrogen and Ozone.

Continued discussions with ICP - Forests and ICP - Waters has resulted in plans for harmonisation of manuals and joint inter-laboratory comparisons.

IM laboratories have participated in inter-laboratory comparisons together with ICP-Waters on water chemistry, with ICP-Forest on foliage chemistry and crown conditions and with EMAP on depositon chemistry.

IM has presented information on IM-sites to ICP-Forest, in order to investigate the possibilities for cooperation between ICP-Forest level III and IM. ICP - Forest has approached IM National Focal Points with questions concerning future cooperation with ICP Forest.

The LIFE-project, in which Finland, Denmark, United Kingdom, Spain and Sweden participates, has received funding from EU and has subsequently started these activities.

The Dynamic Modelling Project, funded by the Nordic Council of Ministers, will finalise its work before the summer. However Dynamic modelling activities will continue for selected IM-sites.

IM participated in the EMAN (Environmenntal Monitoring and Asessment Network) meeting in Canada, resulting in closer cooperation with Canadian scientists and more sites to be included in the IM-network.

Discussions with representatives responsible for monitoring programmes in USA has resulted in plans for future cooperation, both with respect to the revision of manuals and scientific cooperation on joint asessments of results.

Discussions with representatives for the UN programme Man and the Biosphere (MAB) has started, and will continue in order to investigate the possibilities for cooperation concerning shared sites.

The National Focal points reported results from 1994 to the programme center in October 1995. The results have been quality controlled to a certain degree and incorporated into the IM data-base.

In connection to the above mentioned evaluations, the IM data-base has been controlled for the sites participating in the evaluations. This work has included incorporation of additional background information and site-descriptions.

Agenda Item 5a

ICP IM Programme Centre Helsinki 7.3.1995

Outline for revision of the IM-manual

1. Background

The present IM-manual is valid for the programme phase 1993-96. On the last ICP

IM Task Force meeting in Oslo 8-9 March, 1995 it was agreed that the Programme Centre should for the TF-meeting 1996 prepare a draft proposal for the revision of the manual. This proposal should include an outline of suggested changes and a timetable for the implementation of the work.

Particular attention should be paid to the harmonisation of activities between the effect-oriented programmes of the UN/ECE Working Group on Effects (ICPs Forests, Waters and IM).

ICP Waters is presently in the process of revising their manual. The present IM-manual has been distributed to the reviewing group, and the methods in the IM-manual will be considered in developing the new ICP Waters manual. In general, the water chemistry methods are so well standardised internationally already, that harmonisation is done fairly easily. However, biological methods need more attention.

Also the ICP Forests and IM have decided to intensify the integration of activities. This includes the development of a common strategy for the utilization of IM plots as Level III plots of ICP Forests. In bilateral communication besides the recent WGE Extended Bureau meeting the Programme Centres agreed on the following steps towards the elaboration of a common strategy:

1. Circulation of an inquiry among the NFPs of ICP IM on the precence of forests on IM sites (January/February 1996).
2. Collection and evaluation of the replies to the inquiry and preparation of a catalogue of plots and activities by PCC West (February/March 1996).
3. Presentation of the catalogue at the IM TF-meeting (March 1996).
4. Establishment of a joint expert group for the harmonisation of methods on common forest sites, submission of the the catalogue and manuals to the group members (April 1996).
5. Meeting of the joint expert group and elaboration of recommendations of the methods for common forest sites to the two Task Forces (May 1996).
6. Presentation of the recommendations of the expert group at the 12th TF-meeting of ICP Forests for further consideration (June 1996).

The work above obviously needs to be closely coordinated with the work to prepare the new IM-manual.

2. Comments by the National Focal Points and contact persons

During the TF-meeting it was decided that also the ICP IM National Focal Points and contact persons should send the Programme Centre comments for revision of the manual.

3. Comments by the Programme Centre

General

The work to revise the manual has to be done in cooperation with nominated experts from both ICP Forests and ICP Waters. This is clearly essential for the harmonisation of methods between these programmes.

The work also needs to be discussed and carried out at two different levels of detail:

(a) Programme objectives and programme levels, distribution of tasks between Programme Centre, Expert Institutes and NFPs.

(b) Amendments and technical corrections to subprogrammes.

A. Programme objectives and levels

*The programme objectives should be discussed.

Comment: Since the preparation of the last manual several new environmental issues are receiving increased attention. These problems include the effects of heavy metals, POPs and so called multipollutant-multieffects considerations (e.g. acidification-eutrophication-ozone). It is also likely that the diverse effects of climate change will become increasingly important. A decision has therefore to be taken which issues should be addressed and which variables measured and reported.

*The different categories of sites need to be redefined.

Comment: These categories must be based on the above programme objectives and be on a reallistic level regarding financial requirements. Moreover, the ICP Forests/EU Level II network already comprises many of the sub-programmes of the 'Biomonitoring sites', and there is obviously no need to run several overlapping programmes. A decision must therefore be taken how the different site categories should be defined. It also needs to be decided what to do with sites which do not fulfill the requirements on site characteristics and monitored variables and/or for which data is not reported. The lack of relevant data in the IM-database is presently the most difficult problem for any more advanced data assessment on the international level.

*Organisational levels and responsibilites needs (possibly) to be redefined.

Comment: The division of work between the different organisational levels (Task Force, Programme Centre, Expert Institutes, NFPs) is obvioulsy closely related to the need for international funding of the activities. Presently, most of the more detailed assessment activities carried out on the IM-data has been financed by the Nordic Council of Ministers and the Finnish and Swedish Governments. Funding on a project basis has also recently been obtained from the EU/LIFE financial instrument. However, the continued development of the Programme is not possible to carry out through project funding only, and therefore there is possibly a need to redefine the responsibilities of the different programme levels (ie. to increase the responsibilities of the NFPs to carry out data assessment and reporting).

B. Amendments and technical corrections to the manual

General

There is a clear need to make several amendments and technical corrections to the present manual. Most of the comments by the NFPs and contact persons concerned such questions, and they must be considered by the manual revision groups. Any amendments should be carefully considered and be direcly related to the programme objectives. The IM-programme is already expensive to carry out and any new additions must be well justified. A few key comments by the Programme Centre are listed below:

* Soil water flow and moisture measurements clearly need adequate descriptions. Such measurements are needed e.g. for quantifying element fluxes on the plot scale.

* Methods for calculating pools and fluxes of elements should be defined. The forest stand inventory (AR) should be an obligatory subprogramme.

* Variables necessary for agreed models for evaluation and prediction should be given priority (e.g estimates of forest growth and nutrient uptake).

* The biological subprogrammes need continued standardisation.

4. Suggested time schedule

Action	Time
Decisions on future priorities of ICP IM (TF-meeting)	March 1996
Nomination of expert groups	March 1996 (TF-meeting)
Nomination of joint expert group for the harmonisation of methods with ICP Forests	March 1996 (TF-meeting)
Meeting of joint expert group	May 1996
Presentation of the recommendations of the expert group at the TF meeting of ICP Forests	June 1996
Additional comments by NFPs to expert groups	June 1996
Draft editions by expert groups to Programme Centre	15 November 1996
Draft manual to NFPs for comments	15 January 1997
NFP comments to Programme Centre/ expert groups	15 February 1997

Final draft manual	15 March 1997
Draft manual presented to TF meeting for approval	March/April 1997
Printing of manual	May 1997

Agenda Item 8

1. IM-sites could join other international programmes as well, if this increases their possibilities to receive funding on the national level, provided that the monitoring activities in these programmes are comparable with the IM-manual.

   Examples of such programmes are:

   - ICP-Forest
   - GTOS
   - Man and the Biosphere

2. The discussion on the Funding of the International Cooperative Programs and the Mapping Programme within the UN/ECE LRTAP will continue. However, such funding will only be designated to coordination costs for Programme Centers.

   IM will investigate the possibility to receive volountary contributions from individual countries for the work of the Programme Center.

Agenda item 9

Discussion and adoption of the work programme and reporting procedures for the coming year.

The work within the Working Group on Effects (WGE) and its ICP:s etc has increased during the last year and a lot of complimentary things has been said about this work, for example from the Executive Body (EB).

When discussing the Work-Programme for the next year it is important to focus on some items:

- The Work Programme should focus on the needs of the Convention, especially emphasising the needs of future protocols on emission reductions for different substances.

- There is an increased interest from the Convention in obtaining information on environmental effects of Heavy Metals, Persistant Organic Pollutants, Volatile Organic Compunds and Ozone.

- The already started Streamlining activities should continue, for ICP-IM that means in particular closer cooperation with the ICP:s Waters and Forests, but also with TF Mapping and EMEP

- The EB has stressed the importance of the work of the National Focal Centers, in Streamlining activities, in Assessments of results and in Preparation of information relevant to the work with future protocols on emission reductions

- The activities should be possible to perform within the given time-frame, in order to avoid broken promises

It is obvious that most of the energy and work, both in Programme Center and on national level, will focus on the revision of the manual during the coming year. Most of the participants will be involved in this work. However, there is also a need for further development of the programme in other aspects, such as continued asessments of results, national and international, improved site descriptions and compiling of background information etc. Some countries will be deeply involved with the different tasks in the LIFE project.

Also this year, there is a need for a decission on different activities, national and international that are essential for the continuation and further development of the programme, to some extent also in close cooperation with other ICP:s.

The coming year will also be the very last opportunity for contributions to the background information needed for the negotiations on protocols on nitrogen, heavy metals, POP:s and VOC:s.

Below is listed some of the activities that should be considered for the work programmed for 1996/97. The activities should be discussed, amended, reduced and finally decided by the TF-meeting. The most important part, however, is that we are able to fullfill the requirements, once decided.

Still, one of the main obstacles for joint assessments of results, biological or chemical, is the lack of sufficient data in the IM-database at the Programme Center. If countries can monitor the required subprogrammes and submitt the results in a quality controlled format together with adequate site descriptions and background information to the Programme Center, the strength of the assessments would improve considerably.

The Work Programme could be divided in two parts:

- Tasks that should be carried out as joint activities for all of the national focal points, under the leadership of the Programme Center or one appointed National Focal Point.

- Tasks that should be carried out as activities on the national level.

National Focal Points are asked to consider whether their country might volunteer for any of the tasks in the work-programme.

Proposed preliminary Work-Programme 1996/97.

Activity	Time-frame	Responsible
Preparing the IM-parts of the		

Joint ICP-Report 1995	March 1996	Programme Center
Finalisation of Annual Synoptic Report 95/96	June 1996	Programme Center
Finalisation of Dynamic modelling project	June 1996	Programme Center in collaboration with model-centers
Development of new project on linking geochemichal models with biological effect models	1996/97	Programme Center and activities of at national Focal Points according to funding from LIFE
Evaluation of factors affecting Nitrogen leaching	1996	National Focal Points
Evaluation of IM-sites, status, standards, present monitoring activities	Task-Force Meeting 1997	Programme Center in collaboration with National Focal Points
Comparison of sites, exchange of data with other ICP:s, optimising joint network of sites with other ICP:	1996	Programme Center in cooperation with other ICP:s. Similar activity at national level.
Revision of IM-Manual, presentation of draft proposal	Task-Force meeting 1997	Programme Center in cooperation with national experts and other ICP:s
Inter laboratory comparisons on water-chemistry and macro-invertebrates, under leadership of ICP-Waters	Decided at later stage	Programme Center in cooperation with ICP Waters and National Focal Points
Inter laboratory comparisons on foliage analyses, crown condition, and soil chemistry under leadership of ICP Forests	Decided at later stage	Programme Center in cooperation with ICP Forests and National Focal Points
Inter laboratory comparisons on precipitation chemistry, under leadership of EMEP	Decided at later stage	Programme Center in cooperation with EMEP and National Focal Points
Training courses in field methods	Decided at later stage	Voluntary activities at National Focal Points
Training courses in data handling	Decided at later stage	Voluntary activities at National
Training courses in application of models on IM-sites	Decided at later stage	Voluntary activities at National

Application to LIFE financial instrument for 1997	May 1996	Voluntary activities at National
Focal Points Submission of quality controlled results for year 1995 to Programme Center	October 1996	National Focal Points
Specifying methods for quality control of national results	Summer 1996	Programme Center
Assess dose-response relationships for biological effects (for example vegetation) on IM-sites	Task-Force meeting 1997	Voluntary activities at National Focal Points
reporting additional information required for intensive monitoring sites to Programme center (background information/site description sufficient for model-use)	October 1996	National Focal Points
Assess multi pollutant - multi effect relationships (NO_x, O_3, Acidity, etc)	Task-Force meeting 1997	Voluntary activities at National Focal Points
Prepare Work-Shop on application of Dynamic Models on intensive monitored small catchments	Decided at later stage	Programme Center in collaboration with model-centers and USA

APPENDIX IV. Contribution to the 1996 Joint Report of the ICP's and Mapping Programme

ICP Integrated Monitoring
ICP IM Programme Centre

Contribution to 1996 Joint Report of the ICPs and the Mapping Programme

I. Introduction

(Prepared by the ECE Secretariat).

II. Monitoring

At present the ICP IM database contains data from 59 sites in 20 countries. There are some differences in the level of implementation of the activities of ICP IM by individual countries. Fifteen countries have at least one intensive monitoring site; seven countries have set the objective of carrying out the biomonitoring programme at their national sites. One country has chosen a site where monitoring will start monitoring in the near future, and another country is intending to increase the network with several new sites.

The cooperation between the two other effect-oriented ICPs (Forests and Waters) has been strengthened. Some laboratories participating in the activities of ICP IM took part in joint intercalibrations on water chemistry carried out by ICP Waters and EMEP, and in an intercalibration on three crown defoliation organised in the framework of ICP Forests.

The Programme centres of ICP IM and Forests have also started cooperation regarding site selection for the implementation of the ICP Forests Level III Programme. ICP IM and the ICP Forests already have common sites in several countries regarding the ICP Forests Level II approach. The ICP IM manual will be revised in 1996/97.

III. Assessments of Effects

An evaluation on the effects of N and S deposition on vegetation was carried out (by SLU, Sweden) using data from ICP IM sites. Main aims of the project were to examine the validity of the ICP IM data for assessing the effects on vegetation, and the current state of vegetation at the IM sites in relation to environmental conditions and pollutant deposition. Correlation and regression techniques were used. The results are summarised in the ICP IM Annual Synoptic Report 1996 and main conclusions were:
(i) Vegetation monitoring is useful in reflecting the effects of atmospheric deposition and soil water chemistry, especially regarding S and N, and can be used in impact assessement;
(ii) Epiphytic lichen species composition on tree stems varied among the sites, especially between the northern countries and Central Europe. The *mean sensitity index* of epiphytic lichens on tree stems was well correlated to the observed deposition gradient; (iii) The *mean acid-intolerance score* and the *mean nitrogen demand score* were correlated to N and S concentrations in soil water, but not to those in deposition;
(iv) With improvements in the ICP IM data reporting and in the combination of different subprogrammes carried out at the sites, the power of vegetation monitoring would increase considerably.

IV. Determination of dose-response relations

The work to assess the effects of N-deposition on ICP IM sites has been continued during the last year. The main aim has been to derive empirical critical tresholds for N-deposition, and to identify different ecosystem variables associated with N-saturation and leaching. The results from the calculations have been presented in the ICP IM Annual Synoptic Report 1996.

Input-output budgets were calculated separately for plot and catchment-scale. Both bulk and throughfall deposition measurements were used in order to obtain the best possible estimate of total N-deposition. A correlation analysis was performed between the N-output and other ecosystem fluxes and pools of nitrogen. For the statistical analysis data from two ecosystem experiments, EXMAN and NITREX was also included in order to increase the number of observations and the gradient of N-deposition. Main conclusions from these assessments were:
(i) A critical deposition threshold of ca. 9-10 kg N/ha/a was indicated by the input-output budgets, and comparable results have been obtained in several previous assessments. It should, however, be recognized that these systems are not necessarily in a steady-state, and even low-deposition sites may eventually become saturated unless nitrogen is removed from the system;
(ii) The output flux of nitrogen was strongly correlated with key ecosystem variables like N-deposition, N-concentration in organic matter and current year needles, and N-flux in litterfall. Similar results have been obtained in the EXMAN and NITREX studies;
(iii) There is a great potential for using such statistical relationships from intensively studied sites in conjugation with regional monitoring data (e.g. ICP Forests and ICP Waters data) in order to link process level data with regional-scale questions;
(iv) A continuos effort should be devoted to improve collection and reporting of data in the ICP IM framework, in order to increase the number of sites with sufficient data for detailed effects assessments.

The performance of the EDACS deposition model was evaluated using throughfall and bulk deposition data from ICP IM-sites and other sites in Europe. The EDACS model is used for the derivation of deposition estimates for calculations of critical loads and their exceedance on the European scale. In EDACS dry deposition is estimated with the inference method (i.e. inferred from the concentration and deposition velocity). The model testing and development has been carried out at the RIVM (The Netherlands). A summary of the results is presented in the ICP IM Annual Synoptic Report 1996. Main conclusions were:
(i) Significant relationships were found between modelled dry deposition and dry deposition and deposition estimated from throughfall and bulk precipitation mesurements. However, especially for SO_x and NO_y the scatter was found considerable. This was assumed to be to a large extent due to the poor spatial resolution of the EMEP model, which calculates the air concentration values used in EDACS;
(ii) For NH_x, Ca and K the model seems to underestimate dry deposition at higher deposition levels, probably because 'background' air concentrations are used while additional input by local sources may occur;
(iii) If only ICP IM data was considered, significant relationships between modelled and measured dry deposition were found for all components except NH_x.
(iv) Largest uncertainty in wet deposition was estimated in areas with low measurement density, leading to relatively large interpolation errors (i.e. in southern and eastern Europe).

V. Determination of critical levels and loads

The dynamic model applications of the ICP IM (see Chapter VII below) have contributed to the assessment of site-specific critical load exceedances and their dynamics.

VI. Mapping of critical levels and loads

(No contribution from ICP IM).

VII. Dynamic modelling

Three well-known process-oriented dynamic models (MAGIC, SAFE, SMART) have been calibrated to data to five selected ICP IM-sites. The main aim of the project has been to assess the dynamic response of different deposition scenarios, including the effects of the Second sulphur protocol and two scenarios for NO_x emissions. These site-specific model applications also provide a reality check for the planned regional-scale modelling exercise coordinated by the Coordination Center for Effects (CCE/RIVM). The project has been funded by the Nordic Council of Ministers and carried out as joint project between the Programme Centre and four modelling centres (CCE/RIVM, Institute of Hydrology, Lund University, Norwegian Institute for Water Research).

The five selected sites receive varying deposition loads and have different catchment characteristics. Therefore these sites represent a wide range of possible future responses to the atmospheric loadings. A summary of the results are present in the ICP IM Annual Synoptic Report 1996. Main conclusions from the project were:
(i) Dynamic models can be successfully applied to data from ICP IM sites;
(ii) Catchments/plots respond in a dynamic way to changes in emissions/deposition. The deposition load a site can tolerate therefore depends on the time for which the response can be awaited for. Dynamic models are therefore needed as a complement to steady-state techniques used for critical load calculations, where adequate data is available;
(iii) The three models applied in this study yielded generally consistent results, which gives confidence in the scenario assessment.
(iii) The 'Best Prediction'-scenario (including the effects of the Second S-protocol and present level for NOx-emissions), resulted in many cases in a stabilisation in soil acidification, although significant improvements were not always shown;
(iv) The models should be applied to more ICP IM sites in order to increase the sensitivity gradient and geographical coverage;
(v) More work is needed to improve the description of N processes in dynamic models

Dynamic modelling activities will be continued in the ICP IM framework on a project basis through funding from the EU/LIFE financial instrument.

VIII. Conclusions

(Prepared by the ECE Secretariat).

APPENDIX V. IM workshops and meetings, reports from the Programme Centre

Task Force Meetings

Since its inception, a number of Task Force meetings and Workshops on Integrated Monitoring (WIM's) have been held. The UK National Focal Centre, as part of its contract to DOE, have attended the bulk of these meetings acting as scientific advisors to the DOE representative. The timetable of events within the life span of the Integrated Monitoring Programme is set out below.

Workshop on Integrated Monitoring; Outline of the programme (WIM 1)
Sweden. **23 - 26 Jun 1987**

Workshop on Integrated Monitoring; data handling procedures (WIM 2)
Finland. **5 - 8 Oct 1988**

Technical Workshop on Integrated Monitoring; Field sampling techniques.
Humpolec, Czech. **11 - 15 Sep 1988**
UK Delegates; B. Reynolds (ITE), M. Sykes (ITE)

1st Task Force Meeting of the IM Pilot Programme.
Sigtuna, Sweden. **17 - 19 May 1989**
UK Delegate; R.B. Wilson (DOE)

Technical Workshop on Integrated Monitoring; Soil sample pretreatment and analysis.
Berlin, Germany. **3 - 5 Apr 1990**

Workshop on Integrated Monitoring; Evaluation of the first year of data (WIM 3).
Hindas, Sweden. **28 - 29 May 1990**
UK Delegates; A. Jenkins (IH), D. Waters (IH), R.B. Wilson (DOE)

2nd Task Force Meeting of the IM Pilot Programme.
Hindas, Sweden. **30 May 1990**
UK Delegates; A. Jenkins (IH), D. Waters (IH), R.B. Wilson (DOE)

1st Meeting of the IM Evaluation Group
Most, Czech Republic. **6 Nov 1990**
UK Delegate; A. Jenkins (IH)

3rd Task Force Meeting of the IM Pilot Programme.
Gimo, Sweden. **22 - 23 Jan 1991**
UK Delegates; R.B. Wilson (DOE)

2nd Meeting of the IM Evaluation Group
Helsinki, Finland. **16 May 1991**
UK Delegate; A. Jenkins (IH)

Workshop on Linking Hydrochemical and Biological Models (WIM 4).
Aberdeen, UK. **28 - 31 Oct 1991**
National Focal Centre (IH) Delegates; A. Jenkins, D. Waters, P. Whitehead

4th Task Force Meeting of the IM Pilot Programme.
Helsinki, Finland. **21 - 23 Jan 1992**
UK Delegates; A. Jenkins (IH), R.B. Wilson (DOE)

1st Task Force Meeting of the ICP IM.
Silkeborg, Denmark. **9 - 11 Feb 1993**
UK Delegates; A. Jenkins (IH), S. Coster (DOE)

Technical Workshop on Integrated Monitoring; Long term trends.
Prague, Czech Republic. **17 - 18 Sep 1993**
UK Delegates; C. Shaw (IH), R.B. Wilson (DOE)

Joint UNECE ICP Workshop on Effects.
Stockholm, Sweden. **24 - 27 Jan 1994**
UK Delegate; R.B. Wilson (DOE)

2nd Task Force Meeting of the ICP IM.
Grafenau, Germany. **18 - 20 April 1994**
UK Delegates; J. Wilkinson (IH)

Mettings attended since the last report to DoE.

Workshop on Effects of Nitrogen Deposition on Integrated Monitoring Sites.
Oslo, Norway. **6 - 7 March 1995**
UK Delegates; A. Jenkins (IH), J. Wilkinson (IH)

3rd Task Force Meeting of the ICP IM.
Oslo, Norway. **8 - 9 March 1995**
UK Delegates; J. Wilkinson (IH).

Meeting of the members of the LIFE Project.
Vienna, Austria. **25 - 26 March 1996**
UK Delegates; J. Wilkinson (IH)

4th Task Force Meeting of the ICP IM.
Vienna, Austria. **27 - 29 March 1996**
UK Delegates; J. Wilkinson (IH)

Data Summaries and IM reports

The main contribution of the UK to the UNECE IMP is the annual data time series for the two UK sites. This data is summarised in the context of the entire network at the EDC and forms the basis of regular "Annual Synoptic Reports".

Reports Under the Pilot Programme;

1. Annual Synoptic Report 1990 (Focusing mainly on site descriptions, spatial analysis of atmospheric deposition data, spatial analysis of input/output flux data, analysis of soil, soil water and ground water data and initial evaluation of biological data).

2. Annual Synoptic Report 1991 (Focusing mainly on time series and spatial analysis of deposition chemistry and runoff chemistry).

Reports Under the ICP;

3. Annual Synoptic Report 1994 (Focusing on analysis of temporal trends in deposition and output flux data and application of the dynamic model SMART to selected catchments).

4. Annual Synoptic Report 1995 (Focusing on the impacts of nitrogen deposition and introducing dynamic model applications at selected IM sites).

5. Annual Report 1996 (Focusing on dynamic modelling results at selected IM sites, the assessment of nitrogen processes at IM sites, evaluation of the EDACS model, and IM vegetation monitoring; the effects of N and S deposition).