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FINAL REPORT:
NATIONAL CRITICAL LOADS MAPPING PROGRAMME
PHASE III

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EXECUTIVE SUMMARY

This report summarises the work of the National Critical Loads Mapping Programme from April 1998 until the end of June 2001. The work carried out under this contract has contributed to UK (DEFRA) and European (United Nations Economic Commission for Europe Convention on Long Range Transboundary Air Pollution: UNECE CLRTAP) policy on the control and reduction of pollutant emissions that give rise to acidification and eutrophication. The key achievements under the contract are listed below:

- The planning of the second review of the effects-oriented activities of the UNECE Working Group on Effects (WGE).
- Activities leading to the development of a strategy for the future work of the WGE.
- The planning and production of the WGE Report on "Trends in impacts of long-range transboundary air pollution".
- Establishment, via WGE, of the UNECE CLRTAP Joint Task Force on Health Aspects of Air Pollution.
- The promotion and presentation of the work of the National Critical Loads Mapping Programme and associated DEFRA contractors (eg, Terrestrial Umbrella, Critical Loads Acidity and Metals umbrella) at the annual workshops of the Coordination Centre for Effects (CCE) and Task Force meetings of the International Cooperative Programme on Modelling and Mapping (ICPMM).
- The design and development of a website for the UK National Focal Centre (NFC) to provide access to information on the derivation and calculation of critical loads, both online and as downloadable reports and documents, and to provide a discussion forum for UK critical loads experts via restricted access pages.
- The preparation of "UK Status Reports" to provide transparency of the methods and data used in the calculation of national critical loads.
- The preparation of UK contributions to the bi-annual CCE Status Reports.
- The active involvement of the UK NFC, in collaboration with DEFRA's umbrella projects, in the further development of the methods for the calculation of national critical loads, in particular the use of the Simple Mass Balance model for acidity critical loads for terrestrial ecosystems.
- The completion of three "help-in-kind to the CLRTAP Mapping Programme" projects proposed by the UK NFC:
  (i) Transparency of methods and data used in the calculation of critical loads throughout Europe;
  (ii) Organising, hosting and preparing a CLRTAP WGE report of an Expert Workshop on Chemical Criteria and Critical Limits used in steady-state and dynamic critical load models;
  (iii) Harmonisation of the definitions of ecosystems for which countries calculate critical loads.
  Each study entailed collaboration with NFCs in 24 countries. The results were reported at CCE workshops and meetings of the ICPMM and summary reports of the work included in the CCE bi-annual Status Reports.
- The provision of national critical loads data sets and associated documentation to the CCE in accordance with the CLRTAP "calls for data".

- The maintenance of national critical loads and exceedance databases and maps; updated and revised as necessary, as developments in methodologies have been made.
- The continual development of software to keep up to date with developments in the calculation of critical load exceedances under CLRTAP, in particular, for examining the combined effects of sulphur and nitrogen deposition in terms of acidification, and the separate consideration of the effects of excess nitrogen as a nutrient (eutrophication). The software provides maps and statistics on the areas where critical loads for sensitive ecosystems are exceeded, in England, Wales, Scotland, Northern Ireland and the UK as a whole.
- The continual development of Geographic Information System (GIS) techniques for the spatial analysis of critical loads data.
- The assessment of the impacts of more than 50 deposition scenarios on critical loads exceedance (acidity and nutrient nitrogen). The majority of these were scenarios for 2010 and the work included carrying out comparisons of the effects of different sets and combinations of modelled deposition.
- The completion of a preliminary study on the effects of acidification and eutrophication on Biodiversity Action Plan broad and priority habitats. The results showed that the critical loads were exceeded over significant areas of the habitats using 1990 deposition, but these were greatly reduced using the 2010 deposition scenario available at the time. However, it should be noted that this was carried out before the latest developments in the modelling of deposition values for 2010.
- The completion of a study to assess the number and area of designated sites (Special Areas of Conservation (SACs), Specially Protected Areas (SPAs), Sites of Special Scientific Interest (SSSIs)) where critical levels (SO_2 and NOx) or critical loads (acidity and nutrient nitrogen) are exceeded in 1995-97 and 2010. For SO_2 <0.01% of SAC and SPA areas and <0.1% of SSSI areas remain exceeded in 2010. The areas remaining in exceedance of the NOx critical level in 2010 are the same as for SO_2 for SACs and SPAs, and slightly higher (2.6%) for SSSI areas. The results for critical loads exceedance in 2010 are much higher, with 23% SAC, 32% SPA and 39% SSSI areas exceeded for acidity, and 14% SAC, 21% SPA and 23% SSSI areas exceeded for nutrient nitrogen.
- The generation of maps for the dynamic modelling group at CEH Wallingford. These show the location of the sites to which the MAGIC model has been applied in relation to the classes of a map showing the sensitivity of surface waters to acidification.
- The creation of preliminary maps at the UK-scale showing the potential for chemical recovery from acidification. The maps give three classes of the relative rates of potential recovery, but no actual timescales for recovery. The simple methods used do not however replace the need for dynamic models.
- The provision of critical loads data, maps and advice to DEFRA, the devolved administrations, DEFRA umbrella projects, Environment Agency, Conservation agencies, power industry, county councils, universities, students.
- The provision of maps, statistics and associated text on critical loads methods for inclusion in the report of DEFRAs National Expert Group on Transboundary Air Pollution (NEGTAP).

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1 INTRODUCTION

This report summarises the work carried out under the National Critical Loads Mapping Programme (Phase III) from April 1998 until the end of June 2001. The main activities are described under three headings: "Working Group on Effects" (WGE), "UK National Focal Centre" (NFC) and "National Activities". These cover the work of the Chairman of the WGE (Keith Bull) up until March 2000; the UK NFC data activities, "help-in-kind to the Mapping Programme" projects and representation at UNECE CLRTAP meetings; the further development of methods for the calculation of national critical loads and exceedances; development of a UK NFC website; and activities related to dynamic modelling work in the UK.

In addition to these "core" activities, the results of a study to assess the impacts of critical levels and critical loads exceedances on designated sites (Special Areas of Conservation, Specially Protected Areas, Sites of Special Scientific Interest) are included and discussed.

A summary of work carried out to contribute to the report of DEFRA's National Expert Group on Transboundary Air Pollution (NEGTAP) is included, together with a summary of the links to related research such as the NERC Environmental Diagnostics Programme, the SNH study on the impacts of acidification and eutrophication on broad habitats in Scotland, and the BTO study on birds and acidification and the related PhD at Cambridge University.

- The report also includes eight annexes consisting mainly of summary reports or papers prepared on individual activities under the contract.

2 WORKING GROUP ON EFFECTS (WGE)

This section describes the activities carried out under this contract for the Working Group on Effects, during the time Keith Bull was chairman of WGE.

2.1 Strategy development of the Working Group on Effects

The strategy for future work of the effect-oriented activities under the Convention, i.e. those activities that are the responsibility of the Working Group on Effects (WGE) and its subsidiary bodies (Task Forces of International Cooperative Programmes and other Task Forces), has been developed formally through "Further Development" papers that have been submitted routinely for consideration by WGE at its annual meetings since 1994 (i.e. after KRB was elected chairman in 1993). These were prepared by the Bureau of WGE (chair and vice chairs) in collaboration with secretariat in Geneva; KRB has played a significant role in the drafting of the documents and leading the discussions on them at Bureau and WGE meetings. The papers have sought to take into account the priorities of the Executive Body (EB) for the Convention, as well as the proposals from, and the capabilities of, the subsidiary bodies of WGE. In addition to the strategy documents, KRB was able to be instrumental in the development of the strategy through chairing WGE and WGE Bureau meetings, his participation in International Cooperative Programme (ICP) meetings, his work as a vice-chair of the Executive Body, and his involvement with related activities under the Convention, eg integrated assessment modelling.

An important element for developing the strategy over the last seven years was the first external review of the effect-oriented activities that took place in 1993. This drew attention to shortfalls in the work of individual programmes and highlighted important issues to be addressed by the WGE and its Bureau. As a result of review:

a) The first "Further developments" paper was prepared;

b) Joint reporting to WGE on common issues from the ICPs was initiated (and has continued yearly since);

c) A plan to produce substantive reports every 3-4 years was commenced (a first substantive report, published in 1996, summarized the effects of nitrogen and ozone and was intended as part of the process of substantiation for the development of the 1999 Gothenburg Protocol);

d) Regular meetings of the Extended Bureau of WGE (the Bureau, Task Force chairpersons and programme center representatives) were initiated; and,

e) Activities to develop brochures, etc were started by each of the programmes.

These activities have continued to the present day as part of the strategy for effective operation and reporting of the effect-oriented activities to WGE and the Executive Body.

Under KRB's leadership the Bureau of the WGE proposed a second review to be conducted in 1998, the WGE and the Executive Body agreed this. In collaboration with the secretariat, KRB organized the preparations for the review and planned the subsequent meetings to discuss the reviewers comments and subsequent actions. The review took place in late 1998/early 1999.

Actions were implemented through the "Future priorities and objectives" paper (EB.AIR/WG.1/1999/3, appended as Annex 1 to this report), presented to WGE at its eighteenth session in August 1999, which replaced the "Further Developments" paper for that year. The WGE Bureau in collaboration with the secretariat again drew up the paper.

The report from the second external review was much more positive than the first. In his report and in discussions with the WGE Extended Bureau (in January 1999) the reviewer noted the significant improvements that had been achieved in all programmes and their increased outputs, both results and documents. He also acknowledged the reporting to WGE had much improved. The scientific quality of the work was generally high, and the programmes were delivering what the Convention required. Results such as the critical loads maps had played a major role in the development of recent protocols. However, the technical literature was not always easy for the non-expert to understand, and there was a risk that the increasing complexity of the science might make effects-based approaches less acceptable.

As noted above, the review identified communication as a particular issue to be addressed in the future. The plan for WGE to produce a Report on Trends (see below) was consistent with efforts to produce documentation that was attractive and relevant for the policy maker and NGOs. Several ICPs also took steps to produce or update brochures describing their activities. In addition, increased emphasis was placed on developing web site material to provide easy access to information. KRB was responsible for drafting and collating the material that was placed on the WGE web page on the Convention's web site (www.unecce.org/env/lrtap), he also was instrumental in encouraging ICPs to develop their own web sites that are linked through the LRTAP pages. All ICPs now have operational web sites.

2.2 The Trends Report

Following the first substantive report, WGE accepted a proposal from the Extended Bureau that a second report should prepared identifying the trends in effects both past and future predictions that have been identified by the ICPs in their work. Some funding was available from the European Commission through a project led by ITE/CEH and involving the programme centers of the ICPs. A draft report was prepared and submitted to WGE and subsequently CEH took on the task of publishing the report. KRB was responsible for collating the text, editing the submissions, and preparing additional text for the introduction and appendices. The report (Bureau and ICPs of WGE, 1999) was published in readiness for the adoption of the multi-pollutant, multi-effect protocol in Gothenburg in December 1999.

2.3 The Joint Task Force on the Health Aspects of Air Pollution

WGE has, since its earliest days, relied upon WHO to provide all necessary input to its deliberations on human health issues. However, it was not until 1996 that WGE and WHO coordinated activities to hold a joint workshop to address issues of relevance to the Convention. At KRB's request this was hosted by the UK (sponsored by DETR) and organized by the Institute for Environment and Health. The report of the workshop that was held in Eastbourne, was published in 1997 (UN/ECE and

WHO, 1997). Stimulated by the effective collaboration between WGE and the WHO European Centre for Environment and Health (WHO/ECEH), the Executive Body of the Convention agreed with a proposal from WGE in 1997 to establish a Joint Task Force on the Health Aspects of Air Pollution to deal specifically with human health issues that are important for the work under the Convention. The first meeting took place in 1998 under the chairmanship of WHO/ECEH and with support from the secretariat and KRB who helped provide direction to the Task Force to enable it to develop its work-plan in line with the needs of the Convention. The Task Force is now well established and has produced a report on particulate matter (Task Force on the Health Aspects of Air Pollution, 1999) and is planning reports on heavy metals.

2.4 Critical levels for ozone – development of Level II maps

During the preparations for, and agreement of, the text of the 1999 Gothenburg Protocol, before it was adopted in December 1999, it was recognized that it was only possible to include ozone effects in a very superficial way in the integrated assessment models defining national obligations. A workshop under the Convention was therefore organized in Gerzensee, Switzerland in April 1999 to discuss the scientific issues to be addressed in the future. The report (Annex 2) defined areas for future work after the adoption of the Gothenburg Protocol. Care was taken to ensure that the results of the workshop focused on the future beyond the protocol, and that the results of the workshop did not disrupt the negotiations of the protocol text and national obligations.

3 The UK National Focal Centre (NFC)

This section describes the activities of the UK National Focal Centre for critical loads modelling and mapping. Jane Hall has continued as Head of the NFC.

3.1 UK NFC representation at international meetings

For each year of the contract Jane Hall has represented the UK NFC at CCE Workshops, meetings of the Task Force on Mapping and other UNECE workshops. Presentations have been given at these meetings (Annex 3) to highlight the progress made with critical loads activities in the UK and to propose and report on "help-in-kind" activities (see Section 3.2). In addition, the UK NFC has written contributions to the 1999 and 2001 CCE Status Reports (Section 7).

3.2 Help-in-kind activities

At the 16th session of the Working Group on Effects (August 1997) the UK NFC first made an offer of "help-in-kind" to the Mapping Programme. This was to "contribute to ongoing studies on uncertainties, and to consider possible methods for presenting data and results so as to make them more transparent". A proposal of work was drawn up by the UK NFC and agreed with members of the Mapping Programme (ie Coordination Centre for Effects (CCE) and the Task Force on Mapping (TFM)). Initial work based on the UK data alone was presented to the 14th meeting of the Task Force on Mapping in May 1998. Access to critical loads data for individual countries was gained via correspondence and negotiations with the CCE and individual NFCs. There were four aims to the work carried out on the European critical loads data:

- to build upon the work carried out by the CCE (Hettelingh & Posch, 1997) and on work by the UK NFC on UK data only;
- to improve confidence in critical loads and exceedance maps and data;
- to explore methods for the presentation and visualisation of data and information;
- to provide transparency in critical loads data and methods.

The results of this study were presented at the 15th meeting of the Task Force on Mapping in May 1999 and reported in Hall *et al.*, 1999. To summarise, some of the key conclusions of the study were as follows:

(i) Based on the responses to the UK NFC questionnaires, most countries are using the Mapping Manual methods, equations and recommended values.

(ii) Critical loads (acidity and nutrient nitrogen) are calculated for a wide range of ecosystems across Europe, with coniferous and deciduous woodland being reported the most.

(iii) There may still be some ecosystem areas that are "grid based" (ie, the same as the grid size for which critical loads are calculated) rather than "real" ecosystem areas.

(iv) Care is needed in the application of critical loads to specific ecosystems to ensure values are representative of that ecosystem. Definitions of both nationally selected ecosystems and the CCE categories would assist this.

(v) Nitrogen immobilisation values used by most countries are greater than the recommended values of 0.5 – 1.0 kg N ha^{-1} $year^{-1}$. However, they are generally supported by literature or by expert judgement. The recommendations in the Mapping Manual may need to be revised in the light of this.

(vi) Clearer guidance is needed for the calculation of $CL_{min}(N)$ and $CL_{max}(N)$. Some countries include denitrification in the calculation while others do not. The reasons for this are not given in the questionnaire replies and the Mapping Manual is also not clear on this issue.

(vii) Maps of 5-percentile critical loads ($CL_{max}(S)$), for single ecosystems, in particular forest ecosystems, highlight some cross-border differences.

(viii) Ecosystem categories, critical load inputs, critical loads and exceedance data can be presented in a variety of formats that enable complex information to be visualised.

This work also highlighted two issues that the UK NFC considered to need further investigation:

- Harmonisation of definitions of ecosystems for which critical loads are calculated across Europe;
- The validity of chemical criteria and critical limits used in the calculation of critical loads.

The UK NFC therefore proposed, at the 16th Meeting of the Task Force on Mapping in April 2000, to carry out further "help-in-kind" work to address these issues. These studies are described below.

Harmonisation of ecosystem definitions

The above study showed that critical loads data are currently submitted for 26 different ecosystem types (Table 3.1). The Task Force of the International Cooperative Programme on Modelling and Mapping (TF ICPMM) has always held the view that it is the responsibility of individual countries to select the ecosystems for which they calculate critical loads. However, no information was held on the definitions of these different ecosystem types, so it was not possible to determine if they were all different or if some were the same. This currently makes no difference to the way the data are used for European "mapping" purposes, including Protocol discussions, where data for all ecosystems are combined. However, analysis of the data on an ecosystem basis may produce anomalies, for example, when estimates of individual exceeded ecosystems are considered. Being able to estimate areas of individual ecosystems exceeded across Europe could be important for eutrophication effects as well as acidity. Furthermore, it is often assumed, especially by policy makers, that European critical loads maps are based on the same ecosystems and critical loads methods, when this is not the case.

The UK NFC proposed to run a project to review the ecosystems selected throughout Europe for the calculation and mapping of critical loads of acidity and of nutrient nitrogen. The results of this study were presented at the CCE Workshop (April 2001) and the Task Force meeting of the ICP on Mapping (May 2001). A summary report of the work has been prepared (Annex 4) for inclusion in the CCE 2001 Status Report and a full report will be completed and posted on the UK NFC web site.

Table 3.1: Ecosystems for which critical loads data are currently calculated and submitted to the Coordination Centre for Effects in the Netherlands

Forest
Coniferous forest
Deciduous forest
Mixed forest
Unspecified forest
Mediterranean forest
Grassland
Acid grassland
Agricultural grassland
Alpine grassland
Calcareous grassland
Natural grassland
Grassland/reed/marsh
Heath
Heathland
Moors and heathland
Semi-natural ecosystems
Semi-natural vegetation
Tundra
Lake
Lake/stream
Freshwaters
Alpine lakes
Bog
Oligotrophic bog
Other

Expert Workshop on Chemical Criteria and Critical Limits

The original help-in-kind study highlighted the range of different chemical criteria and critical limits applied by different countries across Europe when calculating acidity critical loads for forest soils using the Simple Mass Balance (SMB) equation. Following this, staff at the UK NFC explored the use of different criteria and limits in the calculation of acidity critical loads for forest soils in the UK (see Section 4.2.1). This revealed the different ranges of critical loads that could result from applying different criteria and limits and raised questions about the basis on which these were selected in different countries for similar ecosystems. The TF ICPMM Mapping Manual was also found to be lacking in guidance over the use of the different criteria and limits and the UK NFC suspected that scientists in other countries may also not be aware of the differing critical loads that could result from applying the different methods. The UK NFC in collaboration with other UK experts (under DEFRAs Terrestrial Umbrella) prepared two papers (Hall *et al.*, 2001a; Hall *et al.*, 2001b) for the Copenhagen Conference in November 1999. A presentation of the work was given to the “Criteria workshop” group at the Conference. Questions were also raised at the Copenhagen Conference about criteria such as the critical molar base cation (or calcium) to aluminium ratio, a common default criteria used in the SMB equation by many countries. Following the Copenhagen Conference the UK NFC decided to propose organising an Expert Workshop on Chemical Criteria and Critical Limits. This proposal was put to the 16th Meeting of the Task Force on Mapping and agreement obtained to proceed. The Workshop was held at York University on 19-21 March 2001. The key aims of the workshop were:

- To examine the chemical criteria and critical limits currently used for acidification and eutrophication critical load models (steady-state and dynamic).
- To consider new or alternative chemical criteria and critical limits.
- To consider what guidance is needed in their application.
- To draw up conclusions and recommendations to be presented for consideration to the meeting of the Task Force on ICP Mapping in May 2001.

A summary report of the workshop has been prepared for the Working Group on Effects (Annex 5) and from this, a summary report provided to the CCE for inclusion in their 2001 Status Report. In addition, a full workshop report, containing discussion group reports and abstracts of the presentations, as well as the conclusions and recommendations is to be completed and made available via the UK NFC web site.

3.3 UK Critical loads data submission February 2001

In June 2000, the CCE announced that it would propose a call for data at the 19th session of the Working Group on Effects (August 2000) to update and verify the European critical loads database. An official call for updates and revisions to national critical loads data was received from the CCE at the end of November 2000. The UK NFC met with national experts under DEFRAs Terrestrial Umbrella in September 2000 to discuss possible revisions and updates to the critical loads for terrestrial ecosystems. Relevant members of DEFRAs CLAM Umbrella were also notified that there was likely to be an official call for data at the end of 2000. Following the official call for data, new calculations and updates to data sets were carried out at the UK NFC (and at UCL for the freshwaters critical loads data). A revised data set for each ecosystem was compiled into the specified format requested by the CCE with the longitude and latitude and EMEP grid coordinates. Annex 6 contains the UK NFC contribution to the CCE Status Report 2001, which summarises the changes made to the critical load calculations since the last data submission in 1998 and includes the ranges of critical loads values and the justification for the methods and values used. In addition, an update to the UK Status Report (Hall *et al.*, 2001c) has been prepared. This is awaiting final comments from other UK experts and will then be posted on the public pages of the UK NFC web site. Details of the revisions made to the acidity and nutrient nitrogen critical loads calculations for the UK are also discussed in section 4.1.

3.4 UK NFC activities linked to the external review of WGE

The UK NFC took note of the comments made by the second external review of the effect oriented activities (see Section 1.1). In keeping with this and the wishes of DEFRA it has sought to publish its work, disseminate information (such as the UK critical loads data on request) and produce material that is understood by the non-specialist. The UK NFC has encouraged transparency of data and methods through its "help-in-kind" activities, the production of the UK Status Reports (Hall *et al.* 1998, Hall *et al.*, 2001c, Hall *et al.*, 2001d) and development of its web site (see Section

4.4). Critical loads were singled out in the external review as needing to be understood, and accepted, by the policy maker and public.

4 NATIONAL ACTIVITIES

4.1 Development of UK critical loads

The UK NFC maintains its links with the other UK experts on critical loads by attending meetings of the Terrestrial Umbrella and Critical Loads and Metals (CLAM) projects, also funded by DEFRA. In addition, when necessary the UK NFC arranges meetings directly with specific experts from these groups to discuss the critical loads models used and the appropriate input data and parameters.

4.1.1 Acidity critical loads

Meetings were held with soil critical loads experts from the Terrestrial Umbrella during the three years of the contract to address the issues of chemical criteria and critical limits used in the Simple Mass Balance (SMB) equation for calculating acidity critical loads for woodland ecosystems. As described in 3.2.2 above, preparation for the Copenhagen Workshop included running the SMB equation using different criteria and limits. The results of this work are given in Hall *et al.*, 2001a; Hall *et al.*, 2001b; Aherne *et al.*, 2001.

This work suggested that:

(i) Aluminium criteria, for example, a critical molar ratio of calcium to aluminium of one in soil solution, are more appropriate for mineral soils.

(ii) pH criteria, for example, a critical pH of 4.0, are more appropriate for organic soils.

In addition, the gibbsite equilibrium constant (K_{gibb}) used in the SMB equation to simulate the relationship between aluminium and hydrogen ions in soil solution, is acknowledged by a number of authors to have limitations but continues to be used due to its simplicity and a lack of better models. Therefore, when updating the national critical loads data for woodland ecosystems, we also addressed these issues. More than 20 runs of the SMB model were carried out for coniferous woodland and 10 for deciduous woodland to examine the effects on critical loads values of changes to some of the input parameters or criteria used. A summary of the overall agreed changes to the methodology and parameterisation of the SMB for conifers and deciduous woodland is given in Table 4.1.

Members of CLAM recalculated the freshwater acidity critical loads (ie, maximum critical loads of sulphur and nitrogen and minimum critical loads of nitrogen) using the First-order Acidity Balance model. Changes in the minimum, maximum and mean values of these are given in Annex 6. The freshwater data now includes an additional 25 sites in GB and 140 in NI, giving a total for the UK of 1610. The critical limit used for calculating UK freshwater critical loads remains at a critical ANC value of zero, which is based on Norwegian data for the occurrence of adult brown trout in lakes and represents a 50% probability of finding an undamaged population.

Table 4.1
Summary of changes made to SMB equation parameters for coniferous and deciduous woodland

Parameter	Old	New
ANCweathering	Empirical acidity critical loads for soils (mid-range values), with peat squares set to zero	Unchanged
Calcium deposition	20km 1992-94 total (non-marine + marine) calcium deposition for woodland	5km 1995-97 total calcium deposition for woodland
Calcium uptake*	0.117 keq/ha/year for conifers (all soils) 0.516 keq/ha/year for deciduous on Ca-rich soils 0.076 keq/ha/year for deciduous on Ca-poor soils	0.120 keq/ha/year for conifers (all soils) 0.700 keq/ha/year for deciduous on Ca-rich soils 0.330 keq/ha/year for deciduous on Ca-poor soils
Map used to define Ca-rich and Ca-poor soils	1km map where: Ca-rich = soils with pH > 4.5 & base saturation >20% Ca-poor = soils with pH < 4.5 & base saturation <20%	1km map where: Ca-rich = soils with Ca weathering > 0.5 keq/ha/year Ca-poor = soils with Ca weathering < 0.5 keq/ha/year
Chemical Criteria & Critical Limits	Critical molar Ca:Al ratio of 1 (all non-peat soils) [use empirical acidity critical loads for peat soils]	Critical molar Ca:Al ratio of 1 for mineral soils Critical pH 4.0 for organic soils [use empirical acidity critical loads for peat soils]
K_{gibb}	950 m^6/eq^2 for all soils	950 m^6/eq^2 for mineral soils 9.5 m^6/eq^2 for organic soils

* New calcium uptake values provided by Fiona Kennedy of Forest Research, based on data from their Level II forest sites.

4.1.2 Nutrient nitrogen critical loads

Since January 1998 the UK nutrient nitrogen critical loads ($CL_{nut}(N)$) have been based on empirical values for acid grassland, calcareous grassland and heathland, mass balance values for coniferous woodland and the minimum of the mass balance or empirical value for deciduous woodland (Hall *et al.*, 1998). European maps of the 5th-percentile nutrient nitrogen critical loads (ie the critical load values that will protect 95% of the ecosystems present in a grid square) show the UK to have some of the highest critical loads in Europe (Fig 4.1). In the south of the UK the 5th-percentile ($CL_{nut}(N)$) values are driven by mass balance critical loads for woodland ecosystems (850 eq ha^{-1} year^{-1} which equates to 11.9 kg N ha^{-1} year^{-1}) and elsewhere by empirical values for acid grassland and heathland (714 eq ha^{-1} year^{-1} = 10 kg N ha^{-1} year^{-1}). Grid squares in neighbouring countries have 5th-percentile critical loads of approximately 340 to 500 eq ha^{-1} year^{-1}, where data are most likely based on mass balance critical loads for woodlands. The mass balance equation for nutrient nitrogen critical loads is as follows:

$$CL_{nut}(N) = N_u + N_i + N_{de} + N_{le}$$

Where:
N_u = nitrogen uptake
N_i = nitrogen immobilisation
N_{de} = denitrification
N_{le} = nitrogen leaching

Cumulative distribution functions of N_u, N_i and N_{le} for each country are given in de Smet & Posch (1999). These show the UK values of N_u and N_i to fall within the ranges of values used by other countries and the values of N_{le} to be towards the upper end of values applied elsewhere. We do not have access to information on the values of N_{de} used across Europe. However, as there appears to be nothing especially unusual about the other values used in the UK or in other countries, this does not explain the large differences observed on the European 5th-percentile maps.

As a consequence of this, European-scale exceedance maps of the 5th-percentile nutrient nitrogen critical loads, show higher exceedance values in neighbouring countries than in the UK (Figure 4.2), with only one EMEP 150 x 150km grid square remaining exceeded in the UK in 2010 (Figure 4.3). This map therefore suggests that in 2010 eutrophication is not a problem for UK ecosystems. This contradicts the view of UK experts and UK current and 2010 exceedance maps (for example, Figure 4.4) and statistics, which show 40% of sensitive ecosystems exceeded in 1995-97 and 32% remaining exceeded in 2010 (table 4.2).

At the same time, there has been debate between UK experts about the empirical nutrient nitrogen critical load values recommended in the Mapping Manual (UBA, 1996) and some discussion about the need to reduce some of these critical loads, which would increase the areas of ecosystems exceeded. One of the conclusions of the Chemical Criteria and Critical Limits workshop (Section 3.2) was the need to formally review the values for empirical critical loads of nutrient nitrogen. As a result a UNECE workshop will be held in Switzerland in Autumn 2002.

Table 4.2
Exceedance of nutrient nitrogen critical loads by total nitrogen deposition for 1995-97 and for 2010 (Gothenburg Protocol). NB. 2010 deposition values based on latest "scaled" method (see Section 4.2.3).

Ecosystem	Ecosystem area (km^2)	% area exceeded 1995-97	% area exceeded 2010
Acid grassland	54573	27	19
Calcareous grassland	10163	0	0.1
Heathland	9914	56	42
Coniferous woodland	7379	88	79
Deciduous woodland	10330	96	92
All ecosystems	92359	40	32

As this issue of differences between UK and European maps has not been resolved, the UK NFC will examine the information to be provided in the newly published CCE Status Report 2001. This contains the latest European scale maps and contributions from most countries on the methods and values they are using in their current critical load calculations.

For the recent critical loads data submission, only minor adjustments were made to the calculations because of the need for further discussion on the methods. Revised nitrogen uptake values for coniferous and deciduous woodland were provided by Forest Research based on their level II sites, for use in the mass balance calculations. Nitrogen uptake values were increased from 0.278 keq ha^{-1} $year^{-1}$ to 0.5 keq ha^{-1} $year^{-1}$. In addition, the minimum of the mass balance derived, or empirical critical loads were used for both coniferous and deciduous woodland (Annex 6). No other changes were made.

4.2 Critical loads exceedance calculations

To assess the impacts of acidification and eutrophication on "sensitive" ecosystems in the UK, the amount of excess atmospheric deposition above the critical load, ie the exceedance, is calculated. The detailed methods by which exceedances are calculated are described elsewhere (Hall *et al.*, 2001d) and will not be repeated here. Exceedances are calculated separately for acidity and for eutrophication (ie nutrient nitrogen). In addition, the areas of individual ecosystems exceeded can also be determined. This section describes four areas of work related to the calculation of exceedances.

4.2.1 Comparison of 20km and 5km deposition and critical loads exceedances

In 1999 the first 5km resolution deposition data became available from CEH Edinburgh, all earlier measured deposition data had been at 20km resolution. The 5km deposition data for 1996 were compared with 20km deposition data for 1992-94. For non-marine sulphur, oxidised and reduced nitrogen and non-marine base cations, the 5km maps for 1996 showed significantly higher deposition in some of the upland areas in north and west Britain, ie in areas of higher altitude and higher rainfall.

Whereas central and eastern lowland Britain generally had lower deposition values in 1996 compared to 1992-94. As the average altitude within smaller grid squares may be greater in some areas, this difference may be expected. However, it was unclear what proportion of the differences reflected the between year differences and how much was due to differences in the methods used to calculate deposition for different resolution grids. Exceedances of acidity and nutrient nitrogen critical loads also appeared higher in 1996, particularly in the upland regions of north and west Britain. This also reflects the differences observed in the deposition maps. To enable a better comparison to be made between the use of 20km and 5km resolution deposition data, it would be necessary to have data sets at both resolutions for the same year(s). A full description of the work carried out is given in Iliffe *et al.*, 1999.

In the Autumn of 2000, 5km deposition data for 1995-97 were provided to the UK NFC by CEH Edinburgh and these replace the 1996 data. However, when using these data to update the calculations of the maximum critical loads of sulphur for the UK data submission (Section 3.3), it became apparent that the non-marine base cation deposition values for 1995-97 were about double those of 1992-94. This is due either to an error in the measurements or subsequent calculations and has been referred back to NETCEN by CEH Edinburgh for further investigation. In the meantime, mean non-marine base cation data for 1986-91 are to be used instead of the 1995-97 values. There was also concern about the 1995-97 non-marine chloride values and these have now been revised.

4.2.2 The effects of acidification and eutrophication on biodiversity

In 1999 a study was carried out for DETR under this contract to examine the effects of acidification and eutrophication on biodiversity (Morton *et al.*, 1999), as preparation for a DETR workshop. The study matched 11 of the Biodiversity Action Plan (BAP) broad habitats to the ecosystem types for which we hold national critical loads data. The distribution of the BAP habitats were defined from classes of the CEH Land Cover Map (Fuller *et al.*, 1994) and the critical loads of the corresponding closest ecosystem assigned to these areas. Exceedances of acidity and nutrient nitrogen critical loads were calculated using three deposition scenarios derived from the Hull Acid Rain Model (HARM) v11.4:

(i) Based on 1990 emissions;
(ii) Deposition forecast for 2010 with emission reductions in accordance with recommendations from the 1997 UNECE Kyoto Earth Summit;
(iii) Deposition forecast for 2010 with maximum feasible emission reductions according to the IIASA 7th Interim Report (ref).

The areas of the 11 broad habitats exceeded under the three deposition scenarios were calculated. In addition, the distributions of 11 BAP priority habitats were defined using a combination of classes from the CEH Land Cover Map, the National Vegetation Classification (Rodwell, 1991, 1992 and 1995) and the species database of the Biological Records Centre at CEH Monks Wood. Acidity and nutrient nitrogen critical loads for the ecosystem type that most closely matches the habitat type, were applied to these distributions and exceedances calculated for the three scenarios listed above. The tables of the full results are given in Morton *et al.* (1999). They show significant areas of broad and priority habitats exceeded in 1990 for acidity and smaller areas exceeded for nutrient nitrogen. The 2010 scenarios show large improvements in the areas exceeded. However, caution is now required in the interpretation of these results as it has recently come to light that the HARM model is underestimating ammonia deposition, resulting in underestimates of exceeded areas for both acidity and nutrient nitrogen critical loads (Section 4.2.3).

4.2.3 Deposition scenario analyses

Throughout the duration of this contract the UK NFC have assessed the impacts of more than 50 deposition scenarios, a few of which are for present day deposition and the remainder forecasts of deposition for 2010. The exceedance results for these scenarios were provided to DEFRA in Excel spreadsheets and are not all included in this report. This section will describe the calculations carried out for DEFRA and present some of the results. First though we will discuss the deposition data used in this work.

Deposition data

At the beginning of this contract the Hull Acid Rain Model (v11.4) was the agreed model for producing forecasts of deposition for 2010, together with modelled output for 1990. This enabled comparisons to be made between exceedance maps for 2010 with those for 1990, the base year on which emission reductions are based for the 1999 Gothenburg Protocol on Acidification, Eutrophication and Ground-level Ozone.

Between August 1998 and March 1999 15 deposition scenarios were analysed. Initially the first six scenarios were run using modelled deposition from HARM v11.4. Then, in discussions at that time it was realised that HARM v11.4 was under-predicting dry ammonia (NHx) deposition. To compensate for this, the FRAME model (Singles *et al.*, 1995; Sutton *et al.*, 1998) at CEH Edinburgh was run for four deposition scenarios (current, future, F1 and MFR) to provide the dry ammonia deposition. These values were then combined with the wet ammonia deposition, oxidised nitrogen and non-marine sulphur deposition from HARM and the first six scenarios re-run. All subsequent deposition scenarios were also run using the combination of HARM and FRAME deposition. However, the output from FRAME at that time did not include Northern Ireland, so HARM data only had to be applied in the exceedance calculations for NI.

The HARM modelled deposition is not specific to particular ecosystems. Dry deposition to woodlands is greater than that to moorland or low vegetation. Therefore some deposition values may be underestimated with the HARM model. The effects this may have on the exceedance results was explored for the 1990 scenario by using FRAME modelled dry ammonia deposition, calculated specifically for, and applied to, moorland and woodland ecosystems. The results showed a total increase of 7% in exceeded ecosystem areas. However, this was not repeated for the other scenarios at that time.

By June 1999, a new version of HARM (v11.5) was being used. This incorporated an alpha factor that improved the estimates of dry ammonia deposition (Metcalfe *et al.*, 2001). Comparisons were made between the exceedance results for the deposition scenarios “New REF” and “J1” using (a) HARM v11.4 sulphur, oxidised and wet ammonia deposition and FRAME dry ammonia deposition, and (b) all deposition from HARM v11.5. None of the deposition values used in these calculations were ecosystem-specific. The results for the "New REF" scenario are shown below in Table 4.3. The methods used to calculate these statistics are outlined below under *"Scenario analyses"*. It should be noted that the exceedance results for freshwater ecosystems in this table and others in this report, are based on the catchment areas of the ~1500 headwater lake or stream sites sampled by UCL, and not all freshwaters in the UK.

Table 4.3
Exceedance results comparing the use of HARM v11.4 sulphur, NOx and wet NHx with FRAME dry NHx and using HARM v11.5 sulphur, NOx and NHx for the "New REF" scenario (emissions: 980 kt SOx, 1186 kt NOx, 297 kt NHx).

Deposition used and ecosystem type	Acidity exceedance results			Nutrient nitrogen exceedance results		
	Area exceeded (km^2)	% area exceeded	AE (keq $year^{-1}$)	Area exceeded (km^2)	% area exceeded	AE (keq $year^{-1}$)
HARM v11.4 with FRAME						
Acid grassland	13437	25	378310	2354	4	39915
Calcareous grassland	14	0.1	92	0	0	0
Heathland	1580	16	29055	504	5	9291
Coniferous woodland	441	6	9609	335	5	3589
Deciduous woodland	1071	10	2474	2003	19	22760
Freshwaters	146	4	5966	-	-	-
All ecosystems	16688	17	447406	5197	6	75556
HARM v11.5						
Acid grassland	10743	20	243230	1585	3	18259
Calcareous grassland	0	0	0	0	0	0
Heathland	1051	11	13972	283	3	4133
Coniferous woodland	365	5	7054	56	1	652
Deciduous woodland	612	6	9738	257	3	2801
Freshwaters	130	4	4273	-	-	-
All ecosystems	12901	14	278267	2181	2	25844

These results show that in terms of total percentages of ecosystems exceeded, both give values in the same order of magnitude. At that time it was decided that using HARM v11.5 deposition alone would be appropriate. However, if the values of Accumulated Exceedance (ie AE, the exceedance value multiplied by the exceeded ecosystem area) are compared, they are significantly different and suggest that HARM v11.5 may still be underestimating dry ammonia deposition. Unfortunately this was not recognised at that time, when AE, although calculated, was rarely used. As a consequence HARM v11.5 continued to be used for all deposition scenario analyses for DEFRA from June 1999 until Autumn 2000.

In the Autumn of 2000, exceedance maps were prepared for NEGTAP (National Expert Group on Transboundary Air Pollution). These included exceedances of acidity critical loads for coniferous woodland by total acid deposition (ie sulphur plus nitrogen) for 2010 (Gothenburg Protocol scenario), with one map including, and the other excluding ammonia deposition. The results showed virtually no difference in the number of 1km grid squares where the critical loads were exceeded, when one would have expected a greater number of exceeded squares when ammonia deposition was included in the calculations. However, the calculations were checked and found to be correct. To investigate this further, we calculated the ratio of HARM 2010 deposition to HARM 1995 deposition and applied these ratios to the measured 1995-97 average, moorland and woodland deposition values. This provided us with ecosystem-specific estimates of deposition for 2010, based on scaling the 1995-97 data. The results of using these new estimates of deposition for 2010 on critical loads exceedance calculations are shown in table 4.4.

Table 4.4
Exceedance results for the Gothenburg Protocol (REF2_REF8) based on using the ratios of HARM 2010/HARM 1995 deposition and applying them to the ecosystem-specific 5km measured data for 1995-97, to give ecosystem-specific estimates of the deposition for 2010. Moorland deposition values applied in the exceedance calculations to acid grassland, calcareous grassland and heathland; woodland deposition values to both woodland ecosystems and average deposition applied to freshwater ecosystems.

Ecosystem	Acidity exceedance results			Nutrient nitrogen exceedance results		
	Area exceeded (km^2)	% area exceeded	AE (keq $year^{-1}$)	Area exceeded (km^2)	% area exceeded	AE (keq $year^{-1}$)
Acid grassland	22416	46	1188866	5436	10	201913
Calcareous grassland	602	7	10304	0	0	0
Heathland	3681	38	130708	2382	25	58115
Coniferous woodland	2149	31	131911	4823	70	252780
Deciduous woodland	5552	55	427935	9527	95	817091
Freshwaters	240	7	16253	-	-	-
All ecosystems	36640	40	1905977	22168	25	1329899

This method increased the deposition estimates and significantly increased the percentage of ecosystems exceeded and the AE values, from those obtained using HARM v11.5 alone or the HARM v11.5/FRAME combination (Table 4.3). However, there was concern that this method would still underestimate ammonia deposition. To resolve this, it was decided to use a combination of HARM v11.5 sulphur and oxidised nitrogen deposition, together with FRAME ammonia deposition. The exceedance calculations were re-done and the results are also shown in table 4.5.

The percentage area of ecosystems exceeded and the AE values using this method were lower than those in Table 4.4 because with this scenario only the dry NHx deposition values were ecosystem-specific, whereas the previous method gave ecosystem-specific estimates for sulphur, NOx and NHx deposition.

Table 4.5
Exceedance results for the Gothenburg Protocol (REF2_REF8) based on HARM v11.5 wet + dry sulphur and wet + dry NOx and FRAME wet + dry NHx. The dry NHx deposition is ecosystem-specific. Ecosystem-speciific deposition applied to critical load ecosystems as for table 4.4.

Ecosystem	Acidity exceedance results			Nutrient nitrogen exceedance results		
	Area exceeded (km^2)	% area exceeded	AE (keq $year^{-1}$)	Area exceeded (km^2)	% area exceeded	AE (keq $year^{-1}$)
Acid grassland	18495	34	903560	6022	11	235155
Calcareous grassland	2397	24	87425	0	0	0
Heathland	2618	26	98958	2264	23	75307
Coniferous woodland	1347	18	61766	2811	38	133457
Deciduous woodland	4300	42	275708	9209	89	670078
Freshwaters	173	5	8994	-	-	-
All ecosystems	29330	31	1436411	20306	22	1113997

There was now concern that FRAME was underestimating ammonia deposition, so yet another method was derived for producing the best estimates of deposition for 2010. This was essentially the same as the use of ratios and scaling the 1995-97 data as described above (Table 4.4), with the exception that ratios were calculated separately for wet and dry sulphur, oxidised nitrogen and ammonia deposition. In addition, this time the HARM data used to calculate the ratios were for 1995-97 and 2010, and the FRAME data for 1996 and 2010. To provide the ecosystem-specific deposition values for 2010:

- the HARM ratios were applied separately to the 1995-97 average, moorland and woodland wet and dry sulphur and oxidised nitrogen deposition;
- the FRAME wet ammonia ratios were applied separately to the 1995-97 average, moorland and woodland wet ammonia deposition;
- the FRAME ecosystem-specific ratios for dry ammonia were applied separately to the 1995-97 average, moorland and woodland dry ammonia deposition.

This provided 18 deposition fields: wet and dry sulphur, oxidised nitrogen and ammonia deposition for all vegetation types (average), moorland and woodland. The exceedance results are given in Table 4.6. In this and the following tables the exceedance calculations are also based on the revised (February 2001) critical loads data (Section 3.3). The combination of these deposition data and the new critical loads values led to larger areas exceeded and larger AE values, than obtained using the ratio method of Table 4.4.

Table 4.6
Exceedance results for the Gothenburg Protocol (REF2_REF8) based on the ratios of HARM 2010/HARM 1995-97 and FRAME 2010/1996 wet and dry deposition and applying these ratios to the ecosystem-specific measured deposition for 1995-97, to provide estimates of deposition for 2010. Ecosystem-speciific deposition applied to critical load ecosystems as for table 4.4.

Ecosystem	Acidity exceedance results			Nutrient nitrogen exceedance results		
	Area exceeded (km^2)	% area exceeded	AE (keq $year^{-1}$)	Area exceeded (km^2)	% area exceeded	AE (keq $year^{-1}$)
Acid grassland	28560	52	1768298	8873	16	368511
Calcareous grassland	2002	20	56415	0	0	0
Heathland	4684	47	228739	3791	38	131253
Coniferous woodland	3008	41	251475	5682	77	444080
Deciduous woodland	7130	69	747641	9839	95	1279259
Freshwaters	273	8	21099	-	-	-
All ecosystems	45656	48	3073668	28186	31	2223104

In May 2001, further modifications were made to the FRAME model. As a consequence the above calculations were repeated to give 18 new deposition fields and the exceedances re-calculated (Table 4.7). These changes to the deposition had little effect on the overall results, compared with Table 4.6.

Table 4.7
Re-run of exceedance calculations as in Table 4.6, but with updated values from the FRAME model.

Ecosystem	Acidity exceedance results			Nutrient nitrogen exceedance results		
	Area exceeded (km^2)	% area exceeded	AE (keq $year^{-1}$)	Area exceeded (km^2)	% area exceeded	AE (keq $year^{-1}$)
Acid grassland	27411	50	1836621	10311	19	442595
Calcareous grassland	1844	18	75572	13	0.1	1625
Heathland	4818	49	252619	4143	42	170678
Coniferous woodland	2803	38	213699	5811	79	479964
Deciduous woodland	7041	68	770238	9540	92	1144998
Freshwaters	338	9	26391*	-	-	-
All ecosystems	44256	46	3148750*	29817	32	2239860

* Excluding AE values for freshwaters in Northern Ireland

In addition, the exceedances were also calculated using the actual modelled deposition data with no scaling applied (Table 4.8). However, when comparing these results with those in Table 4.7, it must be remembered that when using the direct modelled output, only the dry NHx deposition from FRAME is ecosystem specific. Therefore, the areas exceeded and the AE values for this scenario are smaller than when using the latest scaled data (Table 4.7), in which all the deposition parameters used are ecosystem specific as a result of applying the deposition ratios to average, moorland and woodland 1995-97 data.

Table 4.8
Exceedance of Gothenburg Protocol (REF2_REF8) by HARM v11.5 wet + dry sulphur and Nox and FRAME wet + dry NHx, incorporating the latest revisions to the FRAME estimates.

Ecosystem	Acidity exceedance results			Nutrient nitrogen exceedance results		
	Area exceeded (km^2)	% area exceeded	AE (keq $year^{-1}$)	Area exceeded (km^2)	% area exceeded	AE (keq $year^{-1}$)
Acid grassland	16732	31	885812	5842	11	252785
Calcareous grassland	1981	20	122904	60	0.6	3283
Heathland	2489	25	100173	2197	22	79319
Coniferous woodland	1006	14	39585	2894	39	145032
Deciduous woodland	4317	42	261017	8112	79	507144
Freshwaters	3482*	6*	10100*	-	-	-
All ecosystems	26746*	28*	1419590*	19105	21	987564

* Values exclude freshwater data for Northern Ireland

It should be noted that the changes made to FRAME led to small increases in the exceeded area, percentage area exceeded and AE values for some ecosystems. Of particular note are the exceedances of nutrient nitrogen critical loads for calcareous grassland. Using the measured 1995-97 deposition data and the 2010 estimates prior to the latest FRAME modifications, no exceedance of these critical loads occurs, but including these changes in the 2010 deposition leads to very small areas of calcareous grass being exceeded (0.1% using scaled deposition (Table 4.7) and 0.6% using direct model output (Table 4.8)). This suggests that the FRAME values for some grid squares may be greater for 2010 than those for 1996. This is currently being investigated and discussed with Mark Sutton (CEH Edinburgh).

At the time of writing, the method described above to generate ecosystem specific deposition parameters (ie, Table 4.7), is the national method agreed with DEFRA for providing the best estimates of deposition for 2010. The UK NFC will continue to use this approach for all future deposition scenarios until advised to do otherwise.

Scenario analysis

To assess the impacts of different deposition scenarios on critical loads exceedance, the NFC designed a suite of programs in ARC/INFO macro language (AML), linked via a C program. The program suite is referred to as EXCEED and was originally created in November 1998, but has since undergone a series of modifications to continually address the needs of DEFRA. However, the additional calculations of deposition ratios, to generate the “scaled” wet and dry deposition values described are not currently included in EXCEED, so these data calculations are carried out separately prior to running EXCEED.

EXCEED imports the appropriate deposition fields and together with the 1km ecosystem areas and 1km ecosystem-specific critical loads (CLmaxS, CLminN, CLmaxN, CLnutN) it calculates acidity exceedances via the Critical Loads Function and nutrient nitrogen exceedances separately. The exceedances are calculated at 1km resolution for each ecosystem. Therefore deposition data are also treated as 1km data by assuming that the deposition values remain constant across the larger grid squares on which they are provided (ie, 5km and 10km). This exceedance information is stored and used by the program to calculate:

- The area of each ecosystem exceeded in England, Wales, Scotland, NI, GB and UK.
- The Accumulated Exceedance values for each ecosystem in England, Wales, Scotland, NI, GB and UK.

In addition, this information is summed for each 5km grid square, to produce maps which show:

- The total area of ecosystems exceeded in each 5km square of the UK.
- The total Accumulated Exceedance values for all ecosystems in each 5km square.

Accumulated Exceedance (AE) is calculated as:
AE = exceeded area * exceedance value
(keq/year = ha * keq/ha/year)
This parameter therefore takes account of both the area exceeded and the magnitude of exceedance. AE can be useful when comparing the results of different deposition scenarios. For example, the total exceeded ecosystem area for two scenarios could be the same whether the exceedance is small or large, whereas AE will highlight the overall difference in the magnitude of exceedance.

Table 4.9 shows the summarised statistics for the UK for acidification and eutrophication based on the 1995-97 5km deposition data and Figure 4.5 shows maps of areas of ecosystems exceeded and accumulated exceedance for acidity that accompany the statistics.

Table 4.9
Exceedance results based on measured deposition for 1995-97.

Ecosystem	Acidity exceedance results			Nutrient nitrogen exceedance results		
	Area exceeded (km^2)	% area exceeded	AE ($keq\ year^{-1}$)	Area exceeded (km^2)	% area exceeded	AE ($keq\ year^{-1}$)
Acid grassland	43810	80	4289264	14932	27	742620
Calcareous grassland	3256	32	211123	0	0	0
Heathland	6883	69	613326	5497	56	254224
Coniferous woodland	5106	69	530272	6473	88	687225
Deciduous woodland	8425	82	1343843	9891	96	1378905
Freshwaters	651	18	70960*	-	-	-
All ecosystems	68132	71	6987828*	36793	40	3062974

* Excluding AE values for freshwaters in Northern Ireland.

4.2.4 Uncertainty analysis: the effects of variations to nitrogen and sulphur deposition on exceedance calculations

Preliminary investigations have been carried out to examine the effects of uncertainties in deposition data on the calculation of critical loads exceedances. Two types of analysis were undertaken: fixed value analysis (perturbing sulphur and/or nitrogen deposition values by ± 40%) and Monte Carlo simulation analysis. In each case nitrogen deposition was the sum of oxidised plus reduced nitrogen deposition, and sulphur deposition, the non-marine values; consistent with the deposition used in national exceedance work (Section 4.2.3). Exceedances based on deposition data for 1995-97 (measured) and 2010 were both examined. For 2010, deposition data are based on the Gothenburg Protocol with the values for sulphur and oxidised nitrogen taken from HARM and the reduced nitrogen from FRAME. Note that the deposition data used at the time of the analysis were the direct model output values and not scaled from the measured 1995-97 data (Section 4.2.3).

The results of these analyses suggest that we may be currently underestimating the area of sensitive ecosystems exceeded in the UK. However, further work is required to study the size and shape of deposition distributions, and to examine the other sources of uncertainty in the calculation of both critical loads and their exceedances.

The results of this work have been previously supplied to DEFRA but are also summarised in Annex 7, in a draft paper prepared for and presented by Liz Heywood at: Uncertainty in Remote Sensing and GIS, University of Southampton, 3rd-4th July 2001. The final version of the paper will be refereed for inclusion as a book chapter in "Uncertainty in Remote Sensing and GIS", to be published by Wiley Ltd.

4.3 Data Centre role

The UK NFC updates and maintains the databases and maps (in GIS format in ARC/INFO) of national critical loads and exceedance data. In addition, the agreed national deposition data sets, measured and modelled, provided by CEH Edinburgh, Edinburgh and Lancaster Universities, are also held at the NFC. The NFC is also responsible for providing national data sets and information on methods used, to the CCE for work under CLRTAP (Section 3.3). The data are securely stored on appropriate media that are regularly backed up by CEH Computer Support.

The NFC deals with a significant number of data requests and provides data, maps and advice on their use to:

- DEFRA and the devolved administrations. This includes the provision of maps for use in the DEFRA Digest of Environmental Statistics and the Office of National Statistics Trends Report.
- Other DEFRA contractors working on critical loads, especially the Terrestrial Umbrella and the Critical Loads and Metals (CLAM) project.
- Other scientists, including requests from universities and from MSc and PhD students.
- The Environment Agency.
- Conservation Agencies.
- County Councils.
- The power industry (members of JEP).
- Consultancies carrying out environmental impact assessments.

Data are provided free of charge under a CEH Licence Agreement. However, a charge may be made to users (eg consultancies, industry) for the staff time required to prepare data sets in user-specific formats.

The UK NFC website (Section 4.4) is also a valuable resource for users and potential users of critical loads data, providing detailed information on the derivation of the data.

4.4 UK NFC website

The UK NFC website was first set up in 1999. This version outlined the work of the NFC but had limited functionality in the form of a series of static online documents. Reports were provided online as embedded text and associated figures, which were available for printing but not as downloadable files.

In late 2000 the NFC decided to update, overhaul and re-launch the website with a new design and new objectives. The concept for the new website was for it to function as both the public face of the UK NFC, providing details of our work and online copies of reports as before, but also to act as a forum for communication between the UK NFC and internal and external collaborators. The website address is: http://critloads.ceh.ac.uk

The public-access domain on the new website allows visitors to:
- view and download UK Status Reports and other documents
- access general critical loads information, e.g. background information, critical loads definitions and summaries of the methods used to calculate critical loads
- provide feedback to the UK NFC
- follow links to the websites of other UK and international bodies involved in critical loads research
- access an extensive list of reading material on critical loads

The restricted-access domain on the new website allows collaborating scientists to:
- view and download maps and data
- receive notification and minutes of meetings
- access information on the activities of UK NFC
- access a bulletin board
- share information (eg, methods, results, publications for "further reading" web page)

The NFC will encourage UK experts to use the restricted access pages as a discussion forum, by providing a means by which methods and results can be shared and discussed. It has already been used by NEGTAP members to view maps and statistics considered for inclusion in the NEGTAP report (Section 5).

The website will continue to be maintained and updated on a regular basis. The figure (4.6) below shows the front page of the website.

4.5 Dynamic modelling

The UK NFC is not directly involved in running dynamic models, but has assisted others under the Critical Loads and Metals (CLAM) project by preparing maps of the sites to which the dynamic model MAGIC has been applied. In addition, to keep the NFC informed of dynamic modelling activities, a member of staff attended the expert group meeting on dynamic modelling. Finally, using national data sets the NFC has carried out some work to try and map the potential for chemical recovery across the UK. These activities are described briefly below.

4.5.1 Expert Group Meeting on Dynamic Modelling

This meeting was held from 3-5th October 2000 in Ystad (Sweden). It was attended by 26 experts from 10 countries. Mark Toal from the Risk Assessment and Critical Loads Group at CEH Monks Wood attended on behalf of the UK NFC. The workshop report prepared by the organisers for the Working Group on Effects is appended in Annex 7.

4.5.2 Maps of MAGIC modelled sites in the UK

The MAGIC (Model of Acidification of Groundwaters in Catchments) dynamic model has been applied to 460 stream, lake and reservoir catchments across the UK. The modelling work itself has been carried out at CEH Wallingford and is being used to assess several time related factors affecting the possible future recovery of acidified waters, such as land use change, forestry practice and regional characteristics that determine critical loads.

The UK NFC has produced maps of the 460 MAGIC sites according to:

(i) the site type (stream, lake or reservoir)
(ii) the number of water sample collected at each site
(iii) the classes of the "freshwater sensitivity" map (Hornung *et al.*, 1995)

The map by Hornung *et al.* (1995) is divided into five classes representing the relative sensitivity of surface waters to acidification (Figure 4.7) and is based on a combination of soil and geology information. To show the distribution of the MAGIC sites across sensitive areas of the UK, the three most-sensitive classes of the map have been combined into one class, and the MAGIC sites overlaid on the resulting map (Figure 4.8). Due to the large number of sites in some areas, larger scale maps were also generated of south-east England, south-west England, Lake District, Pennines, Wales, northern Scotland and Galloway, with symbols denoting the number of times water samples had been collected at each site. Table 4.10 summarises the number of MAGIC sites in categories (i) and (iii) above and their distribution across the UK. This work was presented at the Expert Group Meeting in Sweden by Chris Evans of CEH Wallingford.

Table 4.10
Type and distribution of MAGIC sites across the UK and their location with respect to classes of the surface water sensitivity map

	England	Scotland	Wales	Northern Ireland	Total (UK)
Stream sites	33	21	140	3	197
Lake sites	86	108	7	1	202
Reservoirs	60	-	1	-	61
Total number of sites	179	129	148	4	460
Sites in freshwater sensitivity classes[#]					
High sensitivity	55	106	49	4	214
Medium high sensitivity	34	11	51	-	96
Medium low sensitivity	71	3	21	-	95
Low sensitivity	11	1	10	-	22
Non-sensitive	8	-	17	-	25
"No data"	-	8	-	-	8

[#] Sensitivity classes: where high = highly sensitive to acidification (ie, low buffering capacity) and low = low sensitivity to acidification (ie, high buffering capacity). "No data" represents areas on the map where no class is given due to a lack of soils and/or geology information.

4.5.3 Mapping the potential for chemical recovery

Dynamic models enable the timescales for chemical recovery to be calculated. However, due to the large data demands of such models they are often only applied at the site-specific level, or if data permit, the regional level. Whilst this provides information for selected sensitive areas it does not give a country-wide picture. Therefore at the UK NFC we have developed some very simple maps that attempt to show the potential for chemical recovery from acidification at the national scale. Note that this simple approach is not intended to replace dynamic modelling activities, since the maps cannot give actual timescales for chemical and/or biological recovery, only dynamic models can provide such detailed information.

One key factor determining chemical recovery of an ecosystem from acidification is a long-term supply of base cations, such as the cation exchange capacity (CEC) of the soil. Other factors that require consideration are:

- Runoff: the rate at which base cations may be removed from a system.
- Presence of forestry: if the woodland is harvested base cations will be removed from the system, otherwise base cations can be recycled.
- other land use types and base cation deposition.

The first attempt at mapping the potential for chemical recovery used data on base cation weathering rates (ANC_w) to represent base cation availability, and runoff to represent the rate at which base cations may be removed through leaching. A matrix of ANC_w values against runoff values was drawn up (Table 4.11) to define three classes of relative recovery rates: slow, medium and fast.

Table 4.11
Matrix of ANC_w values versus runoff values to give potential recovery rate classes

		ANC_w classes (values in keq ha^{-1} $year^{-1}$)		
		Low (<= 0.5)	Medium (0.5-2.0)	High (> 2.0)
Runoff classes (values in metres)	Low (<= 0.5)	***Medium***	***Fast***	***Fast***
	Medium (0.5 – 1.0)	***Medium***	***Medium***	***Medium***
	High (> 1.0)	***Slow***	***Slow***	***Medium***

Notes:
ANC_w = 1km data of base cation weathering rates based on dominant soil in each 1km square. These are the data on which 1km empirical acidity critical loads for soils are based and they are also an input to the Simple Mass Balance equation for acidity critical loads for woodland ecosystems.
Runoff = 1km runoff data based on 30-year (1941-70) rainfall data.

Classes of "fast" potential recovery are defined by having medium to high base cation weathering rates and low runoff, so such areas are assumed to have large amounts of base cations available with small losses through runoff. This class also includes areas of the country not considered to be sensitive to acidification (Hornung *et al.*, 1995). Conversely, the classes of "slow" potential recovery are those with low to medium base cation weathering rates and high runoff, assuming there are lower amounts of base cations available with further base cations being lost due to the high runoff. Areas that fall between these extremes are classified as having "medium" potential recovery rates.

The mapped data on ANC_w and runoff are re-classified within the GIS to produce a map of the three potential recovery rate classes (Fig 4.9a). The map clearly shows the areas predicted to have the slowest rates of chemical recovery are in the uplands of the north and west of the country, where runoff values are high and base cation weathering rates low.

Two further maps have been generated that attempt to include the impacts of forestry on the supply of base cations. The first assumed all forest is harvested, so base cations are removed from the system, while the second assumed no harvesting and all base cations recycled within the system. The three potential recovery rate classes defined in the matrix above (Table 4.11) were modified as follows:

Assuming all forest is harvested
Where woodland (coniferous and/or deciduous) occupies more than 5% of a 1km square, the recovery rate class was decreased as follows:

Fast ⇒ Medium
Medium ⇒ Slow
Slow ⇒ Slow (ie, no change)

Assuming no harvest and all base cations recycled
Where woodland (coniferous and/or deciduous) occupies more than 5% of a 1km square, the recovery rate class is increased as follows:

Fast ⇒ Fast (ie, no change)
Medium ⇒ Fast
Slow ⇒ Medium

The results of the increases or decreases in base cation availability due to forestry presence and activity (harvested or not harvested) are shown in Figures 4.9b and 4.9c. This shows that if all woodlands were harvested, resulting in base cation removal and depleting the amount of base cations available, the area of the country mapped in the "slow" recovery rate class increases substantially and the areas of "medium" and "fast" classes are reduced. Conversely assuming the base cation availability is increased as a result of no woodland areas being harvested and base cations being recycled, the areas of the "slow" and "medium" classes are reduced and the area of the "fast" recovery class substantially increased. Table 4.12 summarises the number and percentage of 1km squares assigned to each potential recovery rate class for each of the three maps.

Table 4.12
The number and percentage of 1km grid squares occurring in each recovery rate class for the three maps of the potential for chemical recovery.

Map	Number & percentage of 1km squares in each potential recovery rate class.		
	Slow	Medium	Fast
Excluding impacts of woodland	44654 18.7%	90638 38.0%	103189 43.4%
Assuming all woodland harvested	83498 35.0%	83678 35.1%	71305 29.9%
Assuming all base cations recycled	30747 12.9%	65701 27.5%	142033 59.6%

However, in reality, a percentage of woodland would be harvested, so information on the woodland yield in different areas of the country would be required to give a better estimate of the impact of forestry on base cation availability.

These simple methods give a general picture of what the potential for chemical recovery of soils from acidification may be across the country. The results may be improved by using cation exchange capacity data to better represent base cation availability. In addition, the inclusion of base cation deposition could also be important. Statistical approaches such as cluster analysis could be used to incorporate all these data and re-examine the classification for mapping the potential for chemical recovery at the UK scale.

5 NATIONAL EXPERT GROUP ON TRANSBOUNDARY AIR POLLUTION (NEGTAP)

Following the departure of Keith Bull in March 2000, Jane Hall took his place as an interim member on NEGTAP. Jane attended the meetings and provided advice on critical load and their exceedances. The UK NFC provided the following information for inclusion in the NEGTAP report:

Soils chapter

- Maps of exceedance of empirical acidity critical loads for soils by (a) HARM non-marine sulphur deposition for 1970, 1983, 2010; (b) measured non-marine sulphur deposition for 1995-97.
- Statistics of the number and percentage of 1km grid squares in each critical load exceedance class for each of the above maps.
- Maps of exceedance of acidity critical loads for coniferous woodland (calculated using the Simple Mass Balance equation) by (a) measured acid deposition for 1995-97; (b) HARM/FRAME "scaled" deposition for 2010. In each case two maps were provided, one including and the other excluding NHx deposition.

Vegetation chapter

- Maps of empirical critical loads for nutrient nitrogen for grassland (acid and calcareous combined), heathland and woodland (coniferous and deciduous combined).
- Maps of exceedance of the above empirical critical loads for nutrient nitrogen based on 1995-97 and 2010 total (oxidised + reduced) nitrogen deposition.
- Maps of exceedance of nutrient nitrogen empirical critical loads, mass balance critical loads and the minimum of empirical and mass balance critical loads for coniferous and for deciduous woodland, for both 1995-97 and 2010.
- Statistics of the area and percentage area exceeded for the above empirical, mass balance and combined critical load maps.

Recovery chapter

- Statistics of the areas of ecosystems where critical loads are exceeded for acidity and for nutrient nitrogen, for 1995-97 and 2010. These results are also given in Section 4.2.3 of this report.

The results for 2010 were updated several times to take account of the modifications made to the deposition estimates for 2010 (Section 4.2.3) during the writing of the NEGTAP report.

In addition, Jane Hall has prepared an Appendix to the NEGTAP report outlining the critical loads methods used in the UK.

6 EXCEEDANCES OF CRITICAL LEVELS & LOADS FOR AREAS OF SACs, SPAs AND SSSIs

The nationally designated areas in the UK are classified into three groups: Special Areas of Conservation (SACs), Specially Protected Areas (SPAs) and Sites of Special Scientific Interest (SSSIs). In Spring 2001 DEFRA asked the UK NFC to calculate the areas and numbers of designated sites where critical levels and critical loads were exceeded. This work consisted of the following tasks:

- Assess the number and area of SACs, SPAs and SSSIs where the critical level for NO_x (30µg m^{-3}) is exceeded using NO_x concentration data (from NETCEN) for 1998 and 2010 (Gothenburg Protocol). Statistics were required both for the UK as a whole and for areas falling outside the exclusion zone ("national mask") provided by NETCEN. This "national mask" puts a buffer around the largest urban settlements and other major sources of low-level emissions, such as the motorways.
- Assess the number and area of SACs, SPAs and SSSIs where the critical level for SO_2 (20µg m^{-3}) is exceeded using SO_2 concentration data (from NETCEN) for 1998 and 2010. Statistics were required both for the UK as a whole and for areas falling outside the exclusion zone provided by NETCEN.
- Assess the number and area of SACs, SPAs and SSSIs where the critical loads for acidity (1km 5^{th}-percentile critical loads based on all terrestrial ecosystem data combined) are exceeded using 1995-97 and 2010 acid deposition data.
- Assess the number and area of SACs, SPAs and SSSIs where the critical loads for nutrient nitrogen (1km 5^{th}-percentile critical loads based on all terrestrial ecosystem data combined) are exceeded using 1995-97 and 2010 acid deposition data.

The concentration data show the NOx values (Figure 6.1) to be greatest, and above the critical level, around the urban areas of central and southern England, south Wales and around Glasgow and Edinburgh, with the extent of high values significantly reduced in 2010. By contrast the SO_2 concentrations (Figure 6.2) are below the critical level across most of the country, both in 1998 and 2010. The concentration data were "clipped" to the coast so that no data were supplied over the sea. Some of the largest SPAs and SACs, such as the Wash and Pembroke coast include a significant area of sea (Figure 6.3). No concentration data were supplied over the Scilly Isles where there are a number of terrestrial conservation areas.

Conservation areas were supplied by JNCC, EN, SNH, CCW and EHS in three different formats (ARC/INFO export files, ARCView shape files and MapInfo "mif" files). Many conservation areas consist of a cluster of separate patches (polygons), which may be adjacent or non-adjacent, but sharing the same name and identification number. The conservation organisations are inconsistent with the information they record and the terms they use for each polygon, but, in *all* cases leave a significant number of polygons (~10%) unlabelled. Affiliation of a polygon to a cluster can only be inferred visually from their spatial location. Due to the structure and topology of the data received, the transfer of the polygons into ARC/INFO format led to:
(i) An increase in the overall number of polygons (but not the area).
(ii) Polygons less than 100m across (eg rivers) not being accurately transferred.
We have not undertaken to update their records, as it would require the manual editing of several thousand items. SACs and SPAs are primarily aggregations of SSSIs so that

a polygon may be in both a SAC and a SPA as well as being a SSSI. The structure of the designated site boundary data is given in Tables 6.1 and 6.2.

Table 6.1
Structure of SAC and SPA data

Site type	Totals
SACs:	
Number named sites	519
Total number polygons	3778
Total area (km^2)	22478
SPAs:	
Number named sites	219
Total number polygons	2176
Total area (km^2)	12712

Table 6.2
Structure of SSSI data

SSSIs:	Country				Totals
	England	Scotland	Wales	NI	
Number named sites	3895	1429	983	182	6489
Total number polygons	15258	13392	2648	1119	32417
Number named polygons	12679	13006	2150	860	28695
Number unlabelled polygons	2579	387	498	259	3723
Total area (km^2)	11094	10125	2393	909	24521

6.1 Exceedance of critical levels

A slightly different analysis approach was adopted for the SACs and SPAs to the SSSIs.

Treatment of SACs and SPAs
Assessment of SACs and SPAs followed a two-stage process:

- Stage 1 - a "sieving" process to identify which sites are at least partially exceeded
- Stage 2 - estimation of the exceeded area and the effect of the national mask.

In stage 1, each polygon was extracted and used to "cut" out the four (two pollutants * two scenarios) concentration fields. The range of concentrations within the patch was examined and the maximum, minimum and mean concentration recorded.

Stage 2 - those polygons where the maximum concentration is above the critical threshold in any of the four permutations were extracted. The concentration field was re-sampled to a resolution of 10 metres and the area of the polygon where the critical level is exceeded was calculated. This process was repeated after applying the national mask to the concentration field to give the exceeded area inside and outside the mask.

Results were provided to DEFRA in the form of Excel spreadsheets and maps and are summarised in the tables below.

Table 6.3
Exceedance of critical levels for NOx (30µg m^{-3})

Designated areas	Year	Areas exceeded (km^2) and percentage, and number of polygons exceeded and percentage	
		No mask (ie, UK)	With mask applied*
SACs	1998	1119 km^2 (5%) 523 polygons (14%)	60 km^2 (<0.01%) 38 polygons (0.01%)
	2010	64 km^2 (0.01%) 77 polygons (0.02%)	none
SPAs	1998	1279 km^2 (0.1%) 378 polygons (0.2%)	88.0 km^2 (0.01%) 31 polygons (0.01%)
	2010	17 km^2 (0.01%) 21 polygons (0.01%)	none

* Areas and polygons exceeded outside the exclusion zone

Table 6.4
Exceedance of critical levels for SO_2 (20µg m^{-3})

Designated areas	Year	Areas exceeded (km^2) and percentage, and number of polygons exceeded and percentage	
		No mask (ie, UK)	With mask applied*
SACs	1998	7 km^2 (<0.01%) 6 polygons (<0.01%)	none
	2010	4 km^2 (<0.01%) 2 polygons (<0.01%)	none
SPAs	1998	30 km^2 (0.01%) 33 polygons (0.02%)	none
	2010	15 km^2 (<0.01%) 15 polygons (0.01%)	none

*Areas and patches exceeded outside the exclusion zone

These tables show that when looking at all sites across the UK, the areas exceeded are much reduced in 2010 compared to 1998. For sites in areas outside the exclusion zone, exceedances only occur for NOx concentrations for 1998, with no exceedances for NOx or SO_2 for 2010. These results are to be expected given the locations of the SACs and SPAs (Figure 6.3), mainly in the more upland, semi-natural areas, away from conurbations; and the highest concentrations of NOx generally around urban areas (Figure 6.1) and the highest SO_2 concentrations (Figure 6.2) limited to a few areas in northern England.

Treatment of SSSIs

The geometric centre of each polygon was calculated and the concentration at each point was estimated for the four permutations of pollutant and scenarios. SSSIs where the concentration at the point was exceeded or was sufficiently close (>50%) to the critical level were identified. Because of the number of polygons involved data were presented separately for Scotland, Wales, Northern Ireland and England. For this analysis all sites in the UK were examined; the exclusion zone mask was not applied. The results are summarised in Table 6.5 below.

Table 6.5
Exceedance of critical levels (SO_2 = 20µg m^{-3}, NO_x = 30µg m^{-3}) for SSSIs.

Country	Number (and percentage) of SSSI polygons exceeded by country for the different concentration scenarios			
	SO_2 1998	SO_2 2010	NO_x 1998	NO_x 2010
England	38 (0.26%)	19 (0.13%)	5104 (34.8%)	811 (5.5%)
Scotland	0	0	51 (0.38%)	3 (0.02%)
Wales	12 (0.45%)	4 (0.15%)	243 (9.2%)	4 (0.15%)
NI	5 (0.45%)	2 (0.18%)	17 (1.5%)	1 (0.09%)
Total (UK)	55 (0.17%)	25 (0.08%)	5415 (17.0%)	819 (2.6%)

As for the SACs and SPAs the area of SSSIs where the NOx critical level is exceeded is greater than the areas where the SO_2 critical level is exceeded, because larger areas of the country have NOx concentrations above the critical level compared to SO_2 (Figure 6.1 and 6.2). These results are consistent with the concentration data, which show the areas of critical levels exceedance to be significantly reduced in 2010. In addition, these results show that although there are many SSSIs in Scotland (ie, 1429, see Table 6.2) the SO_2 critical level is not exceeded in any of the SSSI locations and the NOx critical level only exceeded for a small percentage of polygons.

6.2 Exceedance of critical loads

The critical load exceedance maps chosen for this exercise were based on the 1km 5th-percentile critical loads for all terrestrial ecosystems combined. Exceedances for 1995-97 used the latest 5km deposition data and the exceedances for 2010 the latest "scaled" deposition for the Gothenburg Protocol (Section 4.2.3). The exceedance maps were generated at 1km resolution by assuming that the deposition values remain constant for all smaller grid squares within each larger deposition square.

The concentration data used in the above critical level exceedance exercise covers all land-based grid squares of the UK. By comparison the critical loads exceedance maps only cover grid squares containing sensitive ecosystems. The difference required modification to the programs used to extract the information for the designated sites, to ensure that any areas of exceedance within a site were found, rather than a "no-data" result being returned due to "holes" in the exceedance maps.

For the SACs and SPAs the exceeded areas of each site were determined. However, due to the large number of SSSI polygons, the exceeded areas were only calculated for those sites greater than $0.5km^2$ in size (Table 6.6). For the smaller polygons, the exceedance value was selected for the centre point of the polygon, but the exceeded area not determined. It is interesting to note that although the percentages of polygons $>0.5km^2$ are small (<=9%), the percentage area they cover is about 95% (Table 668) of the total area.

Table 6.6
The structure of the SSSI polygons by country. This also shows (i) the total area of SSSIs, the total area of polygons $>0.5km^2$ and their percentage of the total area; (ii) the total number of polygons, the number of polygons $>0.5km^2$ and their percentage of the total number.

Country	Total area SSSIs (km^2)	Total area polygons > $0.5km^2$	% of total area with polygons $>0.5km^2$	Total number polygons	No. polygons > $0.5km^2$	% of polygons with area $>0.5km^2$
England	11094	10331	93	15258	1632	11
Wales	2393	2258	94	2648	265	10
Scotland	10125	9910	98	13392	925	7
NI	909	863	95	1119	99	9
UK	24521	23362	95	32417	2921	9

The results of the critical load exceedance calculations for the SACs and SPAs are given in Tables 6.7 and 6.8 and the results for the SSSIs in Tables 6.9 and 6.10.

Table 6.7
Exceedance of 1km 5^{th}-percentile acidity critical loads for SACs and SPAs by total acid deposition (ie, sulphur + oxidised and reduced nitrogen) for 1995-97 and 2010

Designated areas	Exceedance map	Area exceeded (km^2)	% area exceeded	No. polygons exceeded	% polygons exceeded
SACs	1995-97	8581	38	2396	63
	2010	5225	23	1816	48
SPAs	1995-97	6883	54	1157	53
	2010	4097	32	879	40

Table 6.8
Exceedance of 1km 5^{th}-percentile nutrient nitrogen critical loads for SACs and SPAs by total nitrogen deposition (ie, oxidised + reduced) for 1995-97 and 2010

Designated areas	Exceedance map	Area exceeded (km^2)	% area exceeded	No. polygons exceeded	% polygons exceeded
SACs	1995-97	4208	19	1681	44
	2010	3259	14	1370	36
SPAs	1995-97	3288	26	739	34
	2010	2708	21	609	28

These results show the exceeded areas of SACs and SPAs are larger for acidity than nutrient nitrogen and also that there is a greater reduction in the areas exceeded between 1998 and 2010 for acidity compared to nutrient nitrogen. This may be an indication of the larger reductions likely in sulphur deposition over this time period compared to total nitrogen deposition, and in particular NHx deposition. Since NHx deposition, both for 1995-97 and for 2010, is much greater than NOx, it is the NHx that is responsible for much of the critical loads exceedance due to nitrogen deposition alone. Significant areas of SACs and SPAs remain exceeded in 2010 for both acidity and nutrient nitrogen, reflecting their locations across the country, in mainly upland semi-natural areas, which are sensitive to both acidification (eg, low soil critical loads) and eutrophication (eg sensitive species/habitats).

Table 6.9
Exceedance of 1km 5^{th}-percentile acidity critical loads for SSSIs (where polygons > $0.5km^2$) by total acid deposition (ie, sulphur + oxidised and reduced nitrogen) for 1995-97 and 2010

Country	Exceedance map	Area exceeded (km^2)	% area exceeded	No. polygons exceeded	% polygons exceeded
England	1995-97	5461	55	1210	74
	2010	4847	47	995	61
Wales	1995-97	1549	69	234	88
	2010	1467	65	203	77
Scotland	1995-97	6527	66	752	81
	2010	2594	26	481	52
NI	1995-97	157	18	52	53
	2010	114	13	46	46
UK	1995-97	13694	59	2248	77
	2010	9022	39	1725	59

Table 6.10
Exceedance of 1km 5^{th}-percentile nutrient nitrogen critical loads for SSSIs (where polygons > $0.5km^2$) by total nitrogen deposition (ie, oxidised + reduced) for 1995-97 and 2010

Country	Exceedance map	Area exceeded (km^2)	% area exceeded	No. polygons exceeded	% polygons exceeded
England	1995-97	4621	45	1030	63
	2010	3776	37	868	53
Wales	1995-97	1121	50	179	68
	2010	846	37	154	58
Scotland	1995-97	1255	13	270	29
	2010	741	7	177	19
NI	1995-97	98	11	31	31
	2010	75	9	25	25
UK	1995-97	7095	30	1510	52
	2010	5438	23	1224	42

These results for the SSSIs also show larger reductions in the areas exceeded from 1995-97 to 2010 for acidity (20% reduction for the UK) compared to nutrient nitrogen (7% reduction for the UK). This again reflects the differences in sulphur and nitrogen deposition values, both for 1995-97 and 2010. However, there are differences between the individual countries, with Scotland having the largest exceeded area for acidity in 1995-97 but also the largest reduction in the area exceeded for 2010 (~40%). Despite this substantial areas of SSSIs remain exceeded in 2010, and as for the SACs and SPAs, it reflects the sensitive nature of the sites. Overall, larger areas of designated sites are, and remain exceeded in 2010, for critical loads (acidity and nutrient nitrogen) compared to critical levels.

In parallel to this study, the UK NFC, in collaboration with UK critical load experts, has started work on a project for the Environment Agency, to assign critical loads to the habitats of the designated features of the SACs and SPAs in England and Wales. The results of this work will also be made available to DEFRA.

7 PUBLICATIONS

This section lists the publications produced during the contract.

UK Status Reports

- Part 1: Critical Loads and Critical Loads Maps
  (Hall, J., Bull, K., Bradley, I., Curtis, C., Freer-Smith, P., Hornung, M., Howard, D., Langan, S., Loveland, P., Reynolds, B., Ullyett, J. & Warr, T.)
  Completed in 1998 and available to read online or download from UK NFC web site.
- Update to Part 1: Critical Loads and Critical Loads Maps
  (Hall, J., Ullyett, J., Hornung, M., Kennedy, F., Reynolds, B., Curtis, C., Langan, S. & Fowler, D).
  Completed in 2001: documents changes made to UK critical loads methods in February 2001 in preparation for submission of UK data to CCE.
- Part 2: Exceedances
  (Hall, J., Broughton, R., Bull, K., Curtis, C., Fowler, D., Heywood, E., Hornung, M., Metcalfe, S., Reynolds, B., Ullyett, J. & Whyatt, D.)
  Drafted in 2000/2001. Final edits to be made for consistency with NEGTAP report.

CCE Status Report contributions (reports published every 2 years)

- 1999: Hall, J. UK National Focal Centre Report. In: Calculation and mapping of critical thresholds in Europe. Status Report 1999, Coordination Centre for Effects (Eds, M.Posch, P.A.M. de Smet, J.-P. Hettelingh & R.J.Downing) RIVM, Netherlands. pp 150-154.
- 1999: Hall, J., Cooper, J., Hornung, M., Morton, D., Reynolds, B., Ullyett, J. & Warr, T. UK Help-in-Kind to the Mapping Programme. In: Calculation and mapping of critical thresholds in Europe. Status Report 1999, Coordination Centre for Effects (Eds, M.Posch, P.A.M. de Smet, J.-P. Hettelingh & R.J.Downing) RIVM, Netherlands. pp 35-44.
- 2001: Hall, J. UK contribution to: Modelling and mapping of critical thresholds in Europe. Status Report 2001, Coordination Centre for Effects (eds. M Posch, PAM de Smet, J-P Hettelingh & RJ Downing). pp 175-180.
- 2001: Hall, J. Harmonisation of ecosystem definitions. In: Modelling and mapping of critical thresholds in Europe. Status Report 2001, Coordination Centre for Effects (eds. M Posch, PAM de Smet, J-P Hettelingh & RJ Downing). pp 63-66.
- 2001: Hall, J., Ashmore, M., Curtis, C., Doherty, C., Langan, S. & Skeffington, R. UNECE Expert Workshop: Chemical Criteria and Critical Limits. In: Modelling and mapping of critical thresholds in Europe. Status Report 2001, Coordination Centre for Effects (eds. M Posch, PAM de Smet, J-P Hettelingh & RJ Downing). pp 67-71.

Critical Loads Copenhagen, 21-25 November 1999

- Hall, J., Hornung, M., Kennedy, F., Langan, S., Reynolds, B. & Aherne, J. 2001. Investigating the uncertainties in the Simple Mass Balance equation for acidity critical loads for terrestrial ecosystems. Water, Air and Soil Pollution: Focus **1**: 43-56.

- Hall, J., Reynolds, B., Aherne, J. & Hornung, M. 2001. The importance of selecting appropriate criteria for calculating acidity critical loads for terrestrial ecosystems using the Simple Mass Balance equation. Water, Air and Soil Pollution: Focus **1**: 29-41.
- Aherne, J., Farrell, E.P., Hall, J., Reynolds, B. & Hornung, M. 2001. Selecting chemical criteria for critical loads of acidity in maritime regions. Water, Air and Soil Pollution: Focus **1**: 75-90.
- Langan, S., Hodson, M., Kennedy, F., Hornung, M., Reynolds, B., Hall, J. & Donald, L. 2001. The role of weathering rate determinations in generating uncertainties in the calculation of critical loads of acidity and their exceedance. Water, Air and Soil Pollution: Focus **1**: 299-312.

Acid Rain, December 2000

- Hall, J.R., Reynolds, B., Sparks, T., Weidemann, A., Thornton, I. & McGrath, S.P. The relationship between topsoil and stream sediment heavy metal concentrations and acidification. Water, Air and Soil Pollution. In press.
- Bull, K.R., Hall, J.R., Cooper, J., Metcalfe, S.E., Morton, D., Ullyett, J., Warr, T.L. & Whyatt, J.D. Assessing potential impacts on biodiversity using critical loads. Water, Air and Soil Pollution. In press.
- Kernan, M., Hall, J., Ullyett, J. & Allott, T. Variation in freshwater critical loads across two upland catchments in the UK: implications for catchment scale management. Water, Air and Soil Pollution. In press.
- Ullyett, J.M., Hall, J.R., Hornung, M. & Kernan, M. Mapping the potential sensitivity of surface waters to acidification using measured freshwater critical loads as an indicator of acid sensitive areas. Water, Air and Soil Pollution. In press.

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- Bull, K.R. & Hall, J.R. 1998. Setting international targets for controlling atmospheric emissions of pollutants - now and in the future. Environmental Pollution, **102**(S1), 581-589.
- Bureau and ICPs of WGE. 1999. Trends in impacts of long-range Transboundary air pollution. CEH: Huntingdon.
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NB. The section may not include all of Keith Bulls' publications.

8 LINKS TO OTHER RESEARCH

This section briefly summarises our links to other areas of critical loads research not funded by DEFRA under this contract.

Environmental Diagnostics: Freshwater critical loads project led by Tim Allott (formerly UCL, now Manchester University)

Under this project, and in collaboration with other members of the project, Jane Hall and Jackie Ullyett compiled a range of detailed soils and geology data sets for two river catchments (Duddon in Cumbria, Glaslyn in Snowdonia). These data were used to derive detailed maps of the sensitivity of surface waters to acidification for each river catchment. Two Spring and two Autumn sets of water samples were collected from the main rivers and their sub-catchments; the water chemistry analysed and critical loads calculated. The critical loads values were statistically evaluated in relation to the classes of the sensitivity maps, to determine if using more detailed digital data improved this relationship; a previous national-scale study using low resolution data demonstrated a poor relationship for the most sensitive waters. The results of this study suggested that the catchment attribute versus critical load relationships can vary substantially between regions, and that increasing the resolution of the input data for the sensitivity maps does not lead to a significant improvement in these relationships.

The findings are published in:

- Environmental Diagnostics report: Allott, T.E.H., Reynolds, B., Chen, J., Collins, R., Curtis, C., Foster, H.J., Fowler, D., Hall, J., Harriman, R., Harris, P., Jenkins, A., Juggins, S., Kernan, M., Lees, M.J., McNish, J., Smith, R.I., Ormerod, S.J., Ullyett, J.M. & Wheater, H.S. 2000. The biological significance and uncertainty of critical load exceedance for freshwaters at the catchment scale. Environmental Diagnostics Thematic Programme Grant Reference GST/02/1572. Final report to the Natural Environment Research Council.
- Ullyett *et al.* (in press) and Kernan *et al.* (in press) papers listed under Acid Rain 2000 heading in Section7.

Birds and acidification project: British Trust for Ornithology (BTO) and Imperial College (IC)

The UK NFC provided advice and data on critical loads and critical loads exceedances for this project. At that time percentile critical loads were being used for national work for DETR, so 5th-percentile values of CLmaxS, CLmaxN and CLminN were provided to the BTO and IC, together with areas and percentages of ecosystems exceeded and accumulated exceedance values for a number of HARM deposition scenarios. The results of the study are published in:

- Chamberlain, D.E., Warren, R.W., Crick, H.Q.P, Hall, J., Metcalfe, S., Ormerod, S., Whyatt, D. & Vickery, J.A. 2000. Acidification and terrestrial birds. Final report to DETR. DETR Contract EPG1/3/135. 145pp.
- Chamberlain, D.E., Warren, R.W., Crick, H.Q.P., Hall, J., Metcalfe, S. & Whyatt, D. Spatial associations between acidification and bird species distribution in Britain. In preparation – for submission to the Journal of Applied Ecology.

Environment Agency – joint work with Sarah Metcalfe & Duncan Whyatt (led by SM at Edinburgh University).

This work involved assessing the impacts of a number of HARM deposition scenarios. The results are published in:

- Whyatt, D., Metcalfe, S., Hall, J., Cooper, J., Morton, D. & Warr, T. 2000. Assessment of the critical load impacts from the electricity supply industry in England and Wales. R&D Technical Report P287. Environment Agency, Bristol.

Scottish Natural Heritage – joint work with CEH Edinburgh (led by David Fowler)

For this project the impacts of critical loads exceedance on a number of Biodiversity Action Plan (BAP) broad habitats were assessed. Some habitat distributions were determined using the CEH Land Cover Map, whilst others were based on the distributions of particular species communities using 10km data from the Biological Records Centre and Biological Occupancy Database at Monks Wood. The BAP habitats were cross-matched where possible to the ecosystems for which national critical loads are derived, and those critical loads assigned to the habitat distribution maps. The areas exceeded for both acidification and eutrophication were subsequently assessed. The results are published in:

- Fowler, D., Dragosits, U., Pitcairn, C., Sutton, M., Hall, J., Roy, D., Weidemann, A. 2001. Deposition of acidifying and eutrophying air pollutants in Scotland. Mapping critical loads, critical levels and exceedances. Final report to Scottish Natural Heritage.

Jorn Scharlemann – PhD student at Cambridge University

Jorn's PhD is to examine the possible causes for eggshell thinning in birds, including acidification. His other supervisors are based at Cambridge University, the Natural History Museum, the Royal Society for the Protection of Birds and Manchester University. Jorn has measured the thickness of eggshells in museum collections in the UK, Netherlands, Norway, Sweden and Finland. He has also visited Monks Wood on several occasions to discuss the use of critical loads and deposition data in his analysis with his eggshell data.

The UK NFC has provided Jorn with the following data sets (on agreement with the data suppliers):

- 5km modal empirical critical loads of acidity for soils
- 5km 1995-97 mean deposition data (sulphur, oxidised and reduced nitrogen)
- 5km 1986-91 mean deposition data (non-marine base cations)
- 10km data on the areas of different land cover types (acid grassland, calcareous grassland, heathland, coniferous woodland, deciduous woodland, arable, urban)
- 10km HARM sulphur deposition hindcasts: 1955, 1970, 1983
- 20km HARM sulphur deposition hindcasts: 1815, 1880, 1900, 1930

In addition to providing these data for GB for Jorn to generate his own maps, the data values for all the locations of his eggshell data have been extracted for his data analysis.

As Jorn also needed data for the European countries for which he has collected eggshell measurements, Jane Hall contacted the relevant National Focal Centres who agreed to supply Jorn with their national critical loads data (referenced to the EMEP

50km grid). Permission was also obtained from EMEP for the use of their deposition data to generate exceedances for the specific countries in Europe. However, we have not needed to calculate exceedances since the CCE subsequently agreed to supply Jorn with exceedance data at the European scale, because we had already obtained permission to use both the critical loads and deposition data. The exceedances comprise the 1990 values (based on EMEP 150x150km deposition) and 1999 (based on EMEP 50x50km deposition).

Jorn is now completing his GB-scale and European-scale data analysis and writing up the chapters for his PhD; he is due to complete his thesis either Autumn 2001 or Spring 2002.

9 FUTURE WORK

The UK NFC has discussed possible future work with DEFRA for a Phase IV of the National Critical Loads Mapping Programme:

Act as the UK National Focal Centre (NFC) for critical loads activities

- Provide a head of the UK NFC
- Represent the UK NFC at UNECE meetings
- Maintain and update national critical loads databases and provide data sets to the CCE as required by the work plan of the Working Group on Effects and ICP Mapping
- Maintain UK NFC web site

Co-ordination of critical load activities

- Attend meetings of DEFRA Umbrella contractors
- Prepare for UNECE workshop on empirical nutrient nitrogen critical loads and for DEFRA workshop to review UK critical loads
- Provide advice, data, maps to DEFRA and the devolved administrations as required
- Provide critical loads data to UKIAM, with appropriate technical support
- Explore and apply methods for examining/presenting the impacts of ammonia deposition on exceedances of acidity and nutrient nitrogen critical loads

Steady-state critical loads

- Continue to develop and revise input parameters for the calculation of critical loads
- Revise and update UK critical loads following DEFRA review

Deposition scenario analyses

- Provide exceedance statistics and exceedance maps for deposition scenarios selected by DEFRA and the devolved administrations
- Provide information on the number and area of designated sites at risk from acidification and eutrophication for deposition scenarios selected by DEFRA and the devolved administrations

Exploration and application of methods to define critical loads and exceedances for:

- "natural units"
- Biodiversity Action Plan habitats

Dynamic modelling

- Develop data sets
- Presentation of dynamic model output
- Collation and preparation of dynamic modelling results for submission to the CCE
- Further explore the use of national data sets and methods to map the potential for chemical recovery from acidification

A*ssessment of uncertainties in:*

- Critical load models and critical load values
- Deposition data

- Critical load exceedance calculations
- The effects of data scale in the calculation of critical loads and exceedances

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Annex 1

Future priorities and objectives of the effect-oriented activities: note prepared by the Bureau of the Working Group on Effects in collaboration with the secretariat

Annex 2

Workshop on critical levels for ozone – Level II: Summary report prepared by the organizing committee

Annex 3
International meetings attended and presentations given

Annex 4
Harmonisation of ecosystem definitions

Annex 5

Expert workshop on chemical criteria and critical limits: Summary report prepared by the organizers

Annex 6
UK Contribution to CCE 2001 Status Report, including summary of UK critical loads data submitted to the CCE in February 2001.

Annex 7

Uncertainty analysis of deposition data used in the calculation of exceedance of acidity critical loads for UK ecosystems. Paper presented by Liz Heywood at Uncertainty in Remote Sensing and GIS, University of Southampton, July 2001.

Annex 8

Expert group meeting on dynamic modelling: Summary report prepared by the organizers with the assistance of the secretariat