THE NATIONAL CRITICAL LOADS MAPPING PROGRAMME PHASE IV

FINAL REPORT (July 2001 – June 2004)

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CONTENTS **PAGE**

REFERENCES

APPENDIX 1
Draft manuscript: A Review of Uncertainties in Inputs for UK Acid and Nutrient Nitrogen Critical Loads Calculations. Elizabeth Heywood, Jane Hall, Brian Reynolds, Geoff Smith, Bridget Emmett, Mike Hornung, Chris Curtis and Mike Ashmore.

APPENDIX 2
Draft manuscript: Visual Presentation of Uncertainty in Critical Load Exceedances Across Wales. E. Heywood, J. Hall, T. Page, J.D. Whyatt, and R. Wadsworth.

EXECUTIVE SUMMARY

This report summarises the activities carried out under Phase IV of the National Critical Loads Mapping Programme from July 2001 until June 2004. 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 to date are listed below:

- Representing the UK National Focal Centre (NFC) for critical loads modelling and mapping activities, and associated Defra contractors at annual workshops of the Coordination Centre for Effects (CCE) and at Task Force meetings of the International Cooperative Programme on Modelling and Mapping (ICPMM).
- Contributions in kind to the CLRTAP:
  - (i) Preparation and participation in the UNECE Expert Workshop on nitrogen critical loads.
  - (ii) Assisting in drafting sections of the revised UNECE Mapping Manual.
- The active involvement of the UK NFC, in collaboration with the Defra Terrestrial Umbrella, in the further development of steady-state critical loads.
- Completion of a major update in 2003 to the UK critical loads databases including mapping the UK Biodiversity Action Plan Broad Habitats and calculating and applying acidity and nitrogen critical loads to these habitats of high conservation value.
- Completion of minor updates in 2004 to the UK critical loads databases including changes to: (i) the habitat distributions for managed woodlands and calcareous grassland, (ii) the allocation of critical load values to fenland peat soils and (iii) the UK critical loads of acidity for freshwaters.
- Meeting the UNECE deadlines for delivery of updated UK critical loads to the Coordination Centre for Effects in March 2003 and March 2004. The March 2004 submission included, for the first time, dynamic modelling outputs for 109 freshwater sites.
- Preparation of UK reports for inclusion in the CCE Status Reports for 2003 and 2004. The 2003 report included a summary of the uncertainties in the inputs to UK critical load calculations.
- Preparation of "UK Status Reports on Critical Loads" and "Addendums on Critical Load Exceedances" and their publication on the NFC website, providing transparency of the methods and data used in the calculations of national critical loads and exceedances.
- Continued maintenance and development of the UK NFC web site.
- Assessment of the effects of emission and deposition scenarios on critical load exceedances, including current, Gothenburg Protocol and National Emissions Ceilings Directive. Provision of summary exceedance statistics by habitat and country to Defra and the Devolved Administrations and other bodies on request.
- Provision of data and maps to assist in the identification of key areas, soil and habitat types for the focus of UK national-scale dynamic modelling activities.
- Completion of a formal assessment of uncertainties in critical loads and their exceedances, including a literature review, sensitivity analyses and uncertainty estimations.
- Provision of advice, data and maps to Defra, the Devolved Administrations, Defra contractors, Stakeholders and other users of critical loads information.

1. UK NATIONAL FOCAL CENTRE (UK NFC)

1.1 Head of UK NFC

Jane Hall is Head of the UK NFC and represents the NFC at international and national meetings (see Sections 1.2, 2.1, 2.2), including the SNIFFER critical loads and levels workshop in February 2003. During the last year she has also contributed to the revision of the UNECE ICP Modelling & Mapping (ICPMM) Mapping Manual:

(i) Editing draft text for Chapter 5 (Critical Loads).
(ii) Editing new annex on land cover and land use data.

1.2 Representation at UNECE meetings

1. CCE workshop and Task Force meeting of International Cooperative Programme on Modelling and Mapping (ICPMM) (Sorrento, April 2002). Jane Hall presented a poster on “A comparison of UK and EMEP deposition and the impacts on critical loads exceedances”.

2. UNECE Expert workshop (Berne, November 2002): Empirical critical loads for nitrogen. Jane Hall was on the scientific committee for this meeting and gave a presentation on “Harmonisation of ecosystem definitions using the EUNIS habitat classification”. A background document on this subject is published in the proceedings (Hall *et al.*., 2003a).

3. CCE workshop and Task Force meeting of ICPMM (Estonia, May 2003). Jane Hall gave two presentations at this meeting: (i) Application of EUNIS in the UK. (ii) Uncertainties in UK critical loads.

4. CCE workshop and Task Force meeting of ICPMM (Vienna, May 2004).

1.3 Maintain and update national critical loads databases and provision of data to the CCE

At the start of the contract the critical loads data in use were those prepared for the February 2001 data submission to the CCE. These data continued to be used for all work up until March 2003, when they were superseded by the updated “February 2003” data set. Work began in the summer of 2002 on updating and revising the national databases in preparation for the CCE call for data in March 2003. The main areas updated were:

(i) the habitats for which critical loads are mapped
(ii) the habitat distribution maps
(iii) changes to some of the underlying data
(iv) changes in some of the methods to calculate or assign critical loads

In January 2004, further minor updates were made to the national critical load databases in preparation for the CCE call for data in March 2004. The key updates were:

(i) Minor changes to the woodland habitat distribution maps.
(ii) Minor changes to the calcareous grassland habitat distribution for acidity critical loads.
(iii) Revision to the methods for identifying and mapping lowland arable/fen peats and the allocation of critical loads values to these soils.
(iv) Updating the critical chemical criterion used in the calculation of acidity critical loads for woodlands occurring on organo-mineral soils.
(v) Increasing the number of freshwater sites to which acidity critical loads are applied in acidified regions of the UK.
(vi) Changing the critical chemical threshold of acid neutralising capacity (ANC_{crit}) from zero to 20 μeq l^{-1} for all freshwater sites, except naturally acidic sites where a value of zero μeq l^{-1} has been retained.

Updated data sets of acidity and nutrient nitrogen critical loads, referenced to the EMEP grid, were submitted to the CCE in March 2003 and in March 2004, together with summary reports for inclusion in the CCE Status Reports (Hall *et al.*, 2003b; Hall *et al.*, 2004a). Both the 2003 and 2004 calls for data from the CCE requested steady state critical loads (acidity and nitrogen) and target loads (acidity), the latter being outputs from dynamic models. For the 2004 data submission the UK NFC included dynamic modelling outputs for 109 freshwater sites.

Detailed reports (Hall *et al.*, 2003c, 2003d, 2004b and 2004c) documenting the revisions and updates made to the national critical loads data were also prepared and are available from the UK NFC web site (http://critloads.ceh.ac.uk):

(i) Status of UK Critical Loads: Critical loads methods, data and maps (February 2003).
(ii) Addendum: Preliminary assessment of critical load exceedances (February 2003).
(iii) Update to: The status of UK critical loads: critical loads methods, data & maps (February 2004).
(iv) Addendum: The status of UK critical load exceedances (April 2004).

A summary of the updates to national critical loads is given in Section 3 and a summary of the exceedance results in Sections 5.4 and 5.5.

The national critical loads data are made freely available on request from the UK NFC in Arc/Info GIS export format or Ascii format via a dedicated password-protected FTP site. The data are provided to users under a CEH data licence agreement. Although no charge is made for the data, CEH reserves the right to make a charge for staff time if users require data to be extracted for specific areas of the country or in non-standard data formats.

To date, the February 2003 data have been provided (free of charge) to several independent environmental consultants, the UK Integrated Assessment Modelling (IAM) group at Imperial College London (see Section 2.4), the Environment Agency and the Joint Energy Programme (JEP) companies (Innogy, British Energy, Powergen, AEP, EAS corporation (Drax), International Power and EDFE). For the latter the data were provided to Powergen for distribution to the other JEP companies as required. The February 2004 data are currently being prepared for release and will replace the 2003 data on the FTP site by the end of June 2004.

The national critical load databases are maintained and stored at CEH Monks Wood within the Arc/Info Geographic Information System and associated databases and files. Quality assurance of data and methods has been maintained following the procedures outlined in the contract. The February 2004, 2003 and 2001 data sets are stored on a UNIX system for immediate access (and also held on backup systems). All earlier national critical load data sets and associated data, some going back to 1990, have been archived onto CD, documented and stored in secure fire safes. The QA procedures in place allow the maintenance of audit trails for changes in data and methods used in previous and current contracts.

1.4 Maintain UK NFC web site

The UK NFC web site (http://critloads.ceh.ac.uk) continued to act as a central point of reference, referral and information for members of the public, research scientists and collaborators, especially those working under the Defra Terrestrial Umbrella and CLAM projects. The web site is continually maintained, improved and developed. This includes adding new links, cosmetic alterations, removing old files and streamlining its functionality. User emails to the web site are sent to a dedicated email account and queries dealt with promptly.

The password protected domain allows restricted access to documents for selected users, for example Defra and Defra contractors. This facility was used for the circulation of discussion documents on critical loads and exploratory methods for mapping BAP broad habitats in 2002/2003, before finalising methods and placing the information in the public domain.

Prior to the critical loads data submissions to the CCE in March 2003 and March 2004, the web site was used to enable external reviews by Defra, the devolved administrations and stakeholders (eg, Environment Agency, conservation agencies, power industry) of the methods and data used. The UK Status Reports (Hall *et al.*, 2003c, Hall *et al.*, 2004b) and Addendums (Hall *et al.*, 2003d, Hall *et al.*, 2004c) were published on the web site providing the reviewers with detailed information on the results of UK critical load and exceedance calculations. The final versions of these reports remain on the web site, together with earlier Status Reports and Updates providing transparency of the methods and data used in UK critical loads work. The reports can be read online or downloaded in pdf format.

2. CO-ORDINATION OF CRITICAL LOAD ACTIVITIES

2.1 Attendance at Umbrella meetings

The UK NFC has been represented at all meetings of the Defra Terrestrial Umbrella (TU) and all except one meeting of the Defra Critical Loads Acidity and Metals (CLAM) project. NFC staff update the critical loads community on the international timetables of the UNECE Working Group on Effects, ICPMM and CCE, and the on the work of the NFC, including the deadlines by which we require inputs from this community to update the national databases and submit data to the CCE.

In addition, NFC staff regularly liaise with, and hold informal meetings with other experts and scientists from the Umbrella projects. The NFC has collaborated with these experts in the development of mapping habitats sensitive to acidification and eutrophication and in the further development of data sets and methods to calculate critical loads. NFC staff also attended a meeting hosted by Bradford University in October 2002 to discuss habitat mapping issues prior to the UNECE workshop in Berne on empirical nitrogen critical loads.

2.2 Preparation for UNECE workshop on empirical nutrient nitrogen critical loads (Berne, November 2002)

Earlier work by the UK NFC (Hall, 2001) recommended the use of EUNIS (EUropean Nature Information System, Davies & Moss, 2002) to classify and assign codes to different habitat types. The use of EUNIS was subsequently adopted by ICPMM and NFCs were asked to include the EUNIS habitat code with critical loads data submitted to the CCE.

The review of the scientific literature carried out for the UNECE workshop (Achermann & Bobbink, 2003) assigned ranges of empirical nitrogen critical loads for habitat groups classified according to the EUNIS habitat classification. A background paper was prepared for this workshop, building on the earlier work of the UK NFC on harmonising ecosystem definitions. The paper was circulated to participants prior to the meeting and published in the workshop proceedings (Hall *et al.*, 2003a). At the meeting Jane Hall gave a presentation on the application of EUNIS in respect of the habitats sensitive to eutrophication.

Following the meeting, UK experts recommended appropriate mapping values from the new critical load ranges for the EUNIS classes. The NFC assigned each EUNIS class of relevance to the UK to one of the UK BAP Broad Habitats and produced new maps of empirical nutrient nitrogen critical loads. Full details on the relationships between EUNIS classes and BAP Broad Habitats, the methods used to map the Broad Habitats and the critical load values applied, are given in Hall *et al.* (2003c).

2.3 Provision of advice, data, maps to Defra and the Devolved Administrations

The UK NFC continued to provide advice, guidance, data and maps in response to requests from Defra and the devolved administrations. This included the provision of text and maps for the Defra Digest of Environmental Statistics.

2.4 Provision of critical loads data for UK Integrated Assessment Modelling (IAM) activities

The UK NFC met with the UK IAM from Imperial College in Autumn 2001 to discuss data requirements and the methods used by the NFC for calculating critical loads, exceedances and exceeded ecosystem areas. The February 2001 national ecosystem-specific critical loads and ecosystem area data were provided to them, together with the C programs used to calculate critical load exceedances. In July 2003, the February 2003 habitat-specific critical loads data, habitat areas and updated programs were provided to UK IAM. A joint paper has been produced by the UK IAM group and the NFC (Oxley *et al.*, submitted). The February 2004 data will be provided to UK IAM when the data are ready for release in June 2004.

2.5 Provision of data to other users

In addition to the provision of critical loads data to the users identified in Section 1.3, specific critical loads data sets have been provided for three particular applications:

<u>Air Pollution Information System (APIS).</u> This system is being developed by CEH Edinburgh via a project funded and managed by a consortium of the UK's statutory nature conservation agencies and pollution regulators (Countryside Council for Wales, Environment Agency, Environment Heritage Service (Northern Ireland), English Nature, Joint Nature Conservation Committee, Scottish and Northern Ireland Forum for Environmental Research, Scottish Environment Protection Agency, Scottish Natural Heritage). APIS is a web-based system, providing information on the effects of a wide range of pollutants on habitats and species. For acidity and eutrophication it includes information on critical loads and hence, in the last two years the UK NFC has provided the following data for use in APIS:

(i) February 2003 critical loads and exceedances:

- 1km empirical acidity critical loads for soils.
- 1km simple mass balance acidity critical loads for woodland habitats (managed conifers, managed broadleaves, unmanaged woodland) and exceedances based on measured 1995-1997 deposition data.

(ii) February 2004 critical loads and exceedances:

- 1km empirical acidity critical loads for soils.
- 1km simple mass balance acidity critical loads for woodland habitats (managed conifers, managed broadleaves, unmanaged woodland) and exceedances based on measured 1999-2001 deposition data.

The time required for the provision of data for use in APIS was funded by the APIS project.

EA funded work on uncertainties. The EA have funded two pieces of research on uncertainties in critical loads, both led by Netcen. The first project was set up in 2002 and CEH were not directly involved but provided input data (February 2001 version) to the simple mass balance equation for a selected area of the country to enable Monte Carlo analysis to be carried out by Skeffington Consultants as a sub-contractor to Netcen (Abbott *et al.*, 2003). In May 2004 a second contract commenced, with both CEH and Skeffington Consultants as sub-contractors. This current project is focused on assessing and comparing uncertainties in critical loads at the national and site-specific scales. The February 2004 national critical loads data will be used for this work.

Defra funded contracts. Defra requested the NFC to provide Netcen with habitat distribution data to maintain consistency between habitat data used for different Defra contracts. Netcen required these data for: (i) Defra contract SPU-13: Preparation of Regulatory Impact Assessments, and (ii) Defra contract EPG1/3/200: Modelling Tropospheric Ozone. Netcen required information on the area of semi-natural and forestry habitats across the UK. The habitats mapped for critical loads tend to be more specific than this, so data sets composed of aggregations of the critical load habitat data were provided as follows:
(i) Semi-natural vegetation: digital map giving the total area of acid grassland, calcareous grassland, dwarf shrub heath, bog, montane and supralittoral sediments (dune grasslands) in each 1km grid square of the UK.
(ii) Forestry: digital map giving the total area of managed coniferous, managed broadleaved, unmanaged woodland and Atlantic Oak woodland in each 1km square of the UK.
In each case the data sets were composed from the habitat maps generated for nutrient nitrogen critical loads work in the UK (Hall *et al.*, 2003c).

3. STEADY-STATE CRITICAL LOADS

The steady-state empirical and mass balance methods are used to define long-term critical loads for systems at steady-state. Despite the focus on and the need for the further development of dynamic models, regular updates of steady-state critical loads are also required to incorporate new knowledge and data. This section briefly describes the main developments in mapping steady-state critical loads in preparation for the CCE calls for data in March 2003 and March 2004. Full details on the updates to national critical loads, including habitat mapping, can be found in the February 2003 and February 2004 UK Status Reports (Hall *et al.*, 2003c; Hall *et al.*, 2004b) on the UK NFC web site.

3.1 Habitats for which steady-state critical loads are mapped

Prior to March 2003 the national critical loads data were mapped for six ecosystem types: acid grassland, calcareous grassland, heathland, coniferous woodland, deciduous woodland and freshwaters. The areas of the terrestrial ecosystems were defined using aggregations of classes from the CEH Land Cover Map 1990 and some additional data sets. However, in 2002 CEH completed their new Land Cover Map (LCM 2000, Fuller *et al.*, 2002) also based on classified satellite imagery, but this time mapped in classes analogous to the Biodiversity Action Plan (BAP) Broad Habitats. It was therefore decided that in updating the critical loads data for the CCE March 2003 submission, the new LCM 2000 would be used to determine BAP broad habitat distributions to which the critical loads methods would be applied. The NFC consulted scientists from within CEH and from the Defra Terrestrial Umbrella as well as other habitat experts to determine and agree the best and most appropriate methods for mapping the BAP broad habitats for critical loads applications. A combination of LCM 2000 classes and other data sets including species distributions, soils and altitude were used to produce the final habitat maps. Using a combination of data from Forest Research (FR) and LCM 2000 data, a distinction has been made between areas of managed and unmanaged woodland. The unmanaged woodland refers to woods "managed" for biodiversity or amenity, but not timber production. All other woodland is assumed to be primarily managed as productive forest where harvesting and removal of trees takes place.

From March 2003 the national mapping activities have therefore been focused on BAP Broad Habitats. However, following an earlier study by the UK NFC on harmonisation of ecosystem definitions (Hall, 2001), the ICPMM adopted the European Nature Information System (EUNIS, Davies & Moss 2002) and countries are now required to submit critical loads data to the CCE by EUNIS habitat classes. The BAP Broad Habitats and EUNIS systems identify and name ecosystems using different methods and there is rarely a direct relationship between the two schemes. In addition, the new empirical critical loads for nutrient nitrogen were assigned at the Berne workshop (Achermann & Bobbink, 2003) to EUNIS habitat classes. Therefore, for nutrient nitrogen the UK NFC identified the corresponding BAP Broad Habitat (or sub-division of a broad habitat) for the EUNIS classes. Conversely for all other critical loads (ie, acidity and mass balance nutrient nitrogen) mapped at the BAP Broad Habitat level, the corresponding EUNIS classes have been identified and applied. This has enabled the UK NFC to represent critical loads data nationally using BAP Broad Habitats, and to submit data to the CCE by EUNIS habitat class.

The paragraphs below summarise updates made to the UK habitat maps since March 2003.

3.1.1 Changes to managed woodland habitat maps

In preparation for the March 2004 data submission to the CCE minor changes were made to the habitat distributions for managed woodlands. The original Forest Research (FR) data sets on woodland habitat areas included some areas of managed broadleaved woodland in areas dominated by peat soils. On reflection FR suggested these were more likely to be young coniferous trees, which in their 2002-03 mapping exercise were included in the managed broadleaved woodlands category. FR recommended that these woodland areas were removed from the managed broadleaved woodland map and instead added to the managed coniferous woodland map. The original data sets were duly modified and the habitats re-mapped using the combination of FR and LCM 2000 data using the methods described in Hall *et al.* (2003c). This resulted in a 5.1% increase in the area of managed coniferous woodland mapped and a 1.4% decrease in the area of managed broadleaved woodland mapped.

3.1.2 Changes to the calcareous grassland habitat map

This map was revised prior to the March 2004 data submission as a result of updates to the map of acidity critical loads of peat soils (see Section 3.3.1). This is because some of the 1km calcareous grassland squares mapped for nutrient nitrogen coincide with 1km squares that have low empirical soil critical loads (ie, below 2.0 keq ha^{-1} $year^{-1}$). The soil acidity critical loads are based on the dominant soil type in each 1km square; soils derived from base-poor rocks are more acid and result in low critical loads. Calcareous grassland may therefore occur in 1km grid squares that have a low acidity critical load, but it is unlikely to be found on the acid soil determining the low critical load. Changes to the acidity critical loads map for peat soils have resulted in more squares where the critical load value would be inappropriate (ie, too low) for calcareous grassland, and hence the area of this habitat mapped for acidity has been reduced. The area of calcareous grassland mapped for acidity critical loads has therefore decreased by 0.2%.

3.1.3 Changes to the freshwater mapping data set

For the 2004 update, the number of freshwater sites for which acidity critical loads are calculated was increased from 1163 to 1722 based on new survey information for acidified regions of the UK. The freshwater habitat area (ie, catchment areas) represented in the UK subsequently increased from 2417 km^2 to 7791 km^2. This expansion of the data set improved consistency between sites with steady-state critical loads and sites at which dynamic models could be applied, now or in the future. It also enabled the NFC to submit both steady-state and dynamic model outputs for 109 freshwater sites to the CCE in 2004, together with steady-state critical loads for the remaining freshwater sites (see Section 3.3.3).

3.2 Changes to the underlying data

This section provides an overview of changes made to the underlying data used in the critical loads calculations.

3.2.1 National soil databases

One of the major databases underpinning the acidity critical loads maps was revised in 2002. The soil surveys for England, Wales and Scotland had made revisions to their 1km soils databases, resulting in changes to some of the percentage areas of the different soil types in each 1km grid square. As a consequence, the dominant soil association or map unit, on which the empirical acidity critical loads map is based, had changed for some grid squares. This led to changes in the acidity critical loads map where the critical load for the new dominant soil association differed to that of the previous dominant soil. Changes in this database also led to revisions in the data sets of calcium weathering rates, base cation weathering rates, nitrogen immobilisation, denitrification and acidity critical loads for peat soils, which are all dependent on the dominant soil type.

3.2.2 National deposition data used in critical load calculations

The calculations of acidity critical loads require non-marine base cation deposition, non-marine chloride deposition (for maximum critical load of sulphur for all terrestrial habitats) and total (marine plus non-marine) calcium deposition (for SMB critical loads for woodland habitats). For the March 2003 data submission, the deposition data were updated to the values for the year 2000. In March 2004 (and for the data submission) they were updated again using a revised deposition data set for 1998-2000.

3.2.3 Updates to calcium, base cation and nitrogen uptake values

The values for the uptake of calcium, base cations and nitrogen by the harvesting of woodlands were updated for the March 2003 data submission. Prior to this time these values were based on data from just three woodland sites (one oak and two Sitka) in the UK. The values were updated by Forest Research based on uptake data for ten, instead of the previous three, Level II sites in the UK, monitored under the UNECE Intensive Forest Health programme. Data from four Sitka sites provide the new uptake values for coniferous woodland, and data from three oak sites are used for broadleaved woodland, with two of these representing trees on Ca-rich soils and one for Ca-poor soils.

3.3 Changes in the methods used to calculate or assign critical loads

3.3.1 Acidity critical loads for peat soils

The method used to calculate acidity critical loads for peat soils was reviewed prior to the March 2003 data submission and a new method based on critical soil solution pH 4.4 adopted. The rationale for the change in methods is described in Hall *et al.* (2003c). This method is applicable to upland and lowland acid peat soils, but not to the lowland/arable fen peats which are less sensitive to acidification. The critical loads for the lowland/arable fen peat areas are re-set to 4.0 keq ha^{-1} $year^{-1}$; this value being at the upper end of the empirical range of critical loads for soils (Hornung *et al.*, 1995).

In December the method for identifying and mapping the lowland/arable fen areas was reviewed and updated. Previously the lowland/arable fen areas were defined by selecting any 1km square that was dominated by peat soil and contained any area of arable land as defined by LCM 2000. On review it was agreed that some of these areas would not in fact be considered lowland/arable fen, so the map was redefined by selecting 1km squares where peat was the dominant soil and arable land the dominant land cover as defined by LCM 2000. As this process reduced the number of 1km squares requiring the critical load to be re-set to the higher value of 4.0 keq ha^{-1} $year^{-1}$, the mean acidity critical load for the peat dominated squares across the UK was reduced from 1.1 ha^{-1} $year^{-1}$ to 0.8 ha^{-1} $year^{-1}$.

3.3.2 Acidity critical loads for woodland habitats

Prior to the data submission in 2003 acidity critical loads were calculated for coniferous and deciduous woodland ecosystems. However, in 2003 the classification and mapping of woodland habitats was updated in light of new data and information, so that acidity critical loads could be mapped for managed coniferous woodland, managed broadleaved woodland and unmanaged coniferous and broadleaved woodland (Hall *et al.*, 2003c). In December 2003 the methods for calculating acidity critical loads for woodlands occurring on different soil types were reviewed. The methods for calculating critical loads for all woodlands on mineral soils remain unchanged. For woodlands occurring on organo-mineral soils the critical chemical criterion was updated to the critical molar ratio of calcium to aluminium equal to one in soil solution. This was a result of reconsidering the soil types previously classified as “organic”, and agreeing they were really mineral soils with a peaty top and therefore better classified as “organo-mineral” soils. Consequently it is important that soil water aluminium is accounted for when considering acidification processes in these soils and included via the calcium-aluminium ratio in the critical load calculations. This is also consistent with the approach used for mineral soils in the UK. For woodlands occurring on peat soils the method as described in Section 3.3.1 was applied. In addition, for the managed woodlands occurring on organo-mineral or peat soils, the application of phosphate and potassium fertilisers as a contribution to the base cation budget, was also incorporated into the critical load calculations.

Further details on the methods and the impact of the updates on the critical loads values are given in Hall *et al.* (2004b).

3.3.3 Critical loads of acidity for freshwaters

Prior to the 2004 data submission Defra hosted a stakeholder workshop to discuss and agree the most appropriate critical limit values to be applied in the calculation of acidity critical loads for freshwaters, based on new scientific evidence. Previously the critical Acid Neutralising Capacity (ANC_{crit}) value of zero μeq l^{-1} was applied to all freshwater sites in the UK. The workshop concluded that an ANC_{crit} value of 20 μeq l^{-1} should be applied to all sites, except those where site-specific data suggest that the pre-industrial value was lower, in which case ANC_{crit} of zero μeq l^{-1} should be used. Of the 1722 sites in the UK that critical loads are currently (March 2004) calculated for, the ANC_{crit} of zero μeq l^{-1} was applied to 43 sites.

Additionally, for the 2004 data submission, a reformulated version of the First-order Acidity Balance (FAB) model (Henriksen & Posch, 2001) was used. This version of FAB takes account of direct deposition to the lake surface, whereas the previous version assumed that all deposited nitrogen had first to pass through the terrestrial catchment before reaching surface waters.

A summary report of the stakeholder workshop is presented in Appendix 2 of Hall *et al.* (2004b). Further information on the screening of sites to determine the appropriate ANC_{crit} value and on the revised FAB model is also given in Hall *et al.* (2004b).

3.3.4 Empirical critical loads of nutrient nitrogen

The UK critical load maps for habitats sensitive to eutrophication were updated and revised in light of the results of the UNECE workshop (Achermann & Bobbink, 2003; see Section 2.2). These new values formed part of the UK data submissions to the CCE in March 2003 and March 2004.

3.4 Critical Loads Function

Deposition of both sulphur and nitrogen compounds can contribute to exceedance of the acidity critical load. The Critical Load Function (CLF), developed under the UNECE CLRTAP (Posch *et al.*, 1999; Posch & Hettelingh, 1997; Posch *et al.*, 1995; Hettelingh *et al.*, 1995) defines combinations of sulphur and nitrogen deposition that will not cause harmful effects. The CLF is a three-node line graph representing the acidity critical load. The intercepts of the CLF on the sulphur and nitrogen axes define the “maximum” critical loads of sulphur and nitrogen. The maximum critical load of sulphur ($CL_{max}S$) is the critical load of acidity expressed in terms of sulphur only, ie, when nitrogen deposition is zero. Similarly, the maximum critical load of nitrogen ($CL_{max}N$) is the critical load of acidity in terms of nitrogen only (when sulphur deposition is zero). The acidity critical loads defined in Section 3.3 above are used in the derivation of $CL_{max}S$ and $CL_{max}N$. The long-term nitrogen removal processes in the soil (eg, nitrogen uptake and immobilisation) define a “minimum” critical load of nitrogen ($CL_{min}N$).

Uncertainties in the calculations of $CL_{max}S$, $CL_{min}N$ and $CL_{max}N$ are addressed in Section 6.1 of this report.

4. DYNAMIC MODELLING ACTIVITIES

The dynamic modelling work for terrestrial and freshwater systems is currently being carried out under other Defra projects, not the National Critical Loads Mapping Programme. However, consistency is required in the data and methods used to calculate steady-state and dynamic critical loads. Therefore the UK NFC has liaised with the Defra Terrestrial Umbrella and (a) assisted in identifying the areas of the UK on which terrestrial dynamic model runs should be focused; (b) provided appropriate national data for selected regions from the UK databases held for steady-state modelling.

For the national-scale dynamic modelling of terrestrial habitats the focus will be on those 1km grid squares where critical loads are either currently exceeded or have been exceeded in the past. To provide the location of these areas, exceedances were calculated using the February 2003 critical loads data and calibrated FRAME 1970 (grid-average) deposition data, when acidifying deposition was significantly higher than the present day.

Initially two exceedance maps were generated:
(i) Exceedance of acidity critical loads for all habitats combined, by taking the minimum habitat critical load values in each 1km grid square and calculating exceedances using the FRAME 1970 total acid deposition (ie, sulphur plus oxidised and reduced nitrogen). This resulted in 76.2% (140456) of the 1km squares for which we hold critical loads data in the UK being exceeded.
(ii) Exceedance of the minimum of the habitat $CL_{max}S$ values in each 1km grid square by FRAME 1970 sulphur deposition. For this, 72.8% (134325) 1km grid squares were exceeded. The percentage of squares exceeded is not very different to the number of squares exceeded by total acid deposition because sulphur deposition was much higher in 1970, so adding nitrogen deposition into the calculations in (i) simply increases the magnitude of exceedance.
The deposition values used in these calculations were the average values for all vegetation types, since the critical loads were for a combination, rather than a single habitat.

Because of the high percentage of exceeded squares these maps did not really help in identifying the key areas to focus modelling activity on. Concern was also raised because ideally one needs to know something about the depletion of base cations, not just exceedance. Therefore we agreed to use the empirical map of acidity critical loads for soils, which is based on the weathering rate and mineralogy of the dominant soil type in each grid square. This still doesn't provide information about the base saturation status of the soils, but is more directly related to the soils than the habitat-specific critical loads. Hence maps of exceedance (Figure 4.1a) and exceedance ratio (exceedance divided by critical load, Figure 4.1b) were generated based on the empirical soil acidity critical loads (Figure 4.2) and FRAME 1970 total acid deposition (Figure 4.3). In addition to the maps a database was compiled for all exceeded squares in England and Wales giving information on the dominant soil (association, soil group and sub-group), acidity critical load, exceedance and exceedance ratio. The database and maps were provided to CEH Bangor who subsequently short-listed 44 soil associations for further study. The UK NFC then focused on the exceeded squares in England and Wales that were dominated by one of the 44 soil associations, and provided a new database table containing the information listed above plus the area of each BAP Broad Habitat mapped and the dominant BAP Broad Habitat for each exceeded square. Using this information a series of maps were produced to show the distribution of different soil types by habitat across England and Wales (eg, Figure 4.4). These latest maps and database were also provided to CEH Bangor to help with site selection for field sampling of soils (by soil type and habitat) and for identifying the key areas to focus dynamic modelling activities on.

The Macaulay Institute have short-listed the soil associations they intend to focus on for Scotland and the NFC have repeated the above exercise for Scotland. At present there are no plans to extend this work to Northern Ireland.

5. DEPOSITION SCENARIO ANALYSES

This section briefly describes the deposition data used in the calculation of critical load exceedances, how those exceedances are calculated and a summary of the main deposition scenarios analysed.

5.1 Deposition data

Current estimates of deposition are based on site measurements, referred to in this report as "measured data" or "DMP" data (see below). To examine the impacts of future or hindcast deposition scenarios, outputs from deposition models (eg, HARM, FRAME) are used. A brief summary of these data is given below.

5.1.1 Measured data

CEH Edinburgh use their Deposition Mapping Procedure (DMP) to provide deposition data for the UK based on interpolation of site measurements of gaseous concentrations and wet deposition. For work under this contract prior to March 2004 the mean deposition values for 1995-97 were used. Mean values for a period of three years are generally provided and used as this averages out between-year variations due to, for example, a single year being very wet or dry. In March 2004, CEH Edinburgh supplied three new deposition data sets, including a revised 1995-97 data set, all three derived using a consistent methodology. The other data cover the periods 1998-2000 and 1999-2001. The changes made to the procedures for calculating and mapping deposition are described briefly in Hall *et al.* (2004b). Exceedance results based on the March 2004 deposition data sets are summarised in Section 5.5 and the full exceedance statistics by individual country are given in Annexes 1 and 2 of Hall *et al.*, 2004c.

Each deposition data set consists of the following:
- (i) Average deposition values for all habitat types
- (ii) Deposition values assuming acid grassland (moorland) everywhere, (ie low-growing vegetation)
- (iii) Deposition values assuming Sitka spruce everywhere

When calculating critical load exceedances the "moorland" data are applied to all non-woodland terrestrial habitats, the Sitka spruce values to all woodland habitats and the average values to freshwater catchments which may consist of a mixture of habitat types.

When deposition data are received they are imported into the Arc/Info GIS. The deposition data for Northern Ireland (NI) are provided to us on a westerly extension of the Ordnance Survey grid for Great Britain. However, NI is officially mapped on a different grid to GB, with a different grid origin, and hence all our critical loads and other associated data (eg, soils, land cover) for NI are all provided on this Irish Grid. To maintain all critical loads and exceedance data for NI on the Irish Grid, we convert the deposition data to values for grid squares of the Irish Grid before use. This process is also carried out on all the modelled deposition data (HARM and FRAME), since these data are also provided on the GB grid.

5.1.2 Modelled data

The final report for our previous contract (Hall *et al.*, 2001a) documented the procedures agreed within NEGTAP (2001) for modelling and calibrating deposition data, using sulphur and oxidised nitrogen from HARM (Metcalfe *et al.*, 2001) and reduced nitrogen from FRAME (Single *et al.*, 1998). At the start of this project the following method was being used to provide the best estimates of deposition values for 2010:

<u>Sulphur deposition</u>
S deposition = (HARM 2010 / HARM current) * measured current
where current = 1995-97 data

<u>Oxidised nitrogen deposition</u>
NOx deposition = (HARM 2010 / HARM current) * measured current
where current = 1995-97 data

<u>Reduced nitrogen deposition</u>
NHx deposition = (FRAME 2010 / FRAME 1996) * measured current
where current = 1995-97 data

In each case wet and dry deposition values were calculated separately. In addition, values were derived for average, moorland and woodland by using the appropriate data in the calculations, resulting in a total of 18 deposition data sets for each 2010 scenario.

During this reporting period a new version of HARM (v12) has been released and comparisons between exceedances calculated using the old and new versions are given in Section 5.4. More recently Defra decided that the latest version of FRAME (v4.17 at the time) should be used for S, NOx and NHx deposition, instead of using data from two separate models. The exceedance results based on FRAME v4.17 deposition only are given in Section 5.4.

In May 2004 CEH Edinburgh moved to using a new version of FRAME (v4.22) and provided a new 2010 deposition data set. The calibration of the FRAME data is now incorporated into the modelling procedure so that the NFC is no longer required to do this. Exceedance results based on these data are given in Section 5.5.

5.2 Calculating critical load exceedances

Critical load exceedances are calculated using two main methods:

(i) Using macros in Arc/Info to create 1km maps of exceedance values for individual habitats or for all habitats combined.

(ii) Using a suite of C programs and Arc/Info macros (collectively called "Exceed") to calculate:

- The area and percentage area of individual habitats exceeded for acidity and nitrogen, summarised by country (England, Wales, Scotland, NI, GB, UK).
- The Accumulated Exceedance (AE) for individual habitats exceeded for acidity and nitrogen, summarised by country.
- The area, percentage area and AE of Special Areas of Conservation (SACs), Specially Protected Areas (SPAs), Sites of Special Scientific Interest (SSSIs) exceeded for acidity and nitrogen, summarised by country. These values are based on the area of designated sites occurring in 1km grid squares where the habitat critical loads are exceeded. It is not currently possible to routinely generate information on the number of designated sites exceeded.
- The total exceeded area, percentage exceeded area and AE values for all habitats combined, summarised by each 5km grid square of the UK. This information is presented in map form only.

The summary statistics by country are subsequently loaded into template Excel spreadsheets for circulation to Defra and other users including the devolved administrations.

The Exceed programs underwent a thorough update and revision following the update to the national critical loads data in February 2003 to:

(i) Utilise the new habitat-specific critical loads data, which includes more habitat categories than the previous six ecosystem types.

(ii) Include the habitat areas for the latest freshwater data set. These habitat areas are based on the catchment area of each site sampled. To utilise these data with the other habitat data in Exceed, the catchment boundaries are converted to 1km resolution gridded data and the appropriate critical loads values and areas assigned to each 1km square containing all or part of a freshwater catchment. This process has been carried out on the February 2003 freshwater data set but is still to be done for the February 2004 data set.

(iii) Include the latest and most up to date areas of SACs, SPAs and SSSIs in the UK. The latest polygon boundary data have been obtained either directly from the conservation agencies or from JNCC. However, analysing polygon boundary data to obtain critical loads and/or exceedances from the national data sets is a time-consuming activity and too slow for carrying out routine deposition scenario analyses. Therefore the boundaries have been converted to 1km gridded data sets giving the total area of SAC, SPA and SSSI in each 1km grid square. These data can then be quickly analysed within Exceed to give statistics on the area of sites within 1km squares containing exceeded habitat critical loads for acidity or nitrogen. The conservation agencies update their site polygon boundary data on a frequent, but irregular, basis. Therefore we have agreed with Defra to update the versions of data used by the NFC on an annual basis; the data were last updated in May 2004 and these will be used in forthcoming critical load exceedance assessments utilising the March 2004 critical loads data.

5.3 Deposition scenarios using February 2001 critical loads

This section summarises the deposition scenarios and exceedance statistics based on the February 2001 critical loads data.

Scaled ammonia scenarios (July 2001)
Four scenarios were run to examine the impacts of reducing ammonia emissions by 10%, 20%, 40% and 50% for the Gothenburg Protocol. All scenarios used calibrated HARM v11.5 sulphur and oxidized nitrogen deposition and FRAME (pre-variable boundary layer version) reduced nitrogen deposition. A summary of the UK exceedance statistics is given in the table below.

Scenario	Acidity		Nutrient nitrogen	
	% habitat exceeded	Accumulated Exceedance ($x10^3$ keq $year^{-1}$)	% habitat exceeded	Accumulated Exceedance ($x10^3$ keq $year^{-1}$)
Baseline GP	47.7	2906	30.7	2078
10%	42.7 (-10%)	2552	27.9 (-2.8%)	1725
20%	41.5 (-13%)	2195	26.4 (-1.5%)	1431
40%	34.1 (-29%)	1358	19.5 (-6.9%)	735
50%	29.3 (-39%)	1007	15.2 (-4.3%)	454

Reducing ammonia emissions decreases the percentage habitat exceedance (figures in brackets) and acuumulated exceedance from the baseline scenario. These reductions are not linear due to the nature of the exceedance calculations.

NECD scenario (August 2001)
This NECD scenario is based on calibrated HARM v11.5 sulphur and oxidised nitrogen deposition and FRAME (variable boundary layer height version) reduced nitrogen deposition. The UK summary statistics are given in the table below.

Scenario	Acidity		Nutrient nitrogen	
	% habitat exceeded	Accumulated Exceedance ($x10^3$ keq $year^{-1}$)	% habitat exceeded	Accumulated Exceedance ($x10^3$ keq $year^{-1}$)
NECD	41.9	2343	27.5	1639

Gothenburg Protocol (November 2001)
This Gothenburg Protocol scenario is based on calibrated HARM v11.5 sulphur and oxidised nitrogen deposition and FRAME (variable boundary layer height version) reduced nitrogen deposition. The UK summary statistics are given in the table below.

Scenario	Acidity		Nutrient nitrogen	
	% habitat exceeded	Accumulated Exceedance ($x10^3$ keq $year^{-1}$)	% habitat exceeded	Accumulated Exceedance ($x10^3$ keq $year^{-1}$)
Gothenburg	47.5	3149	32.3	2240

Post foot and mouth scenarios (April 2002)
Eight scenarios were run to examine abatement of ammonia emissions from cows, pigs, poultry, fertilisers, non-agricultural sources, all sectors, plus a new 2010

Gothenburg Protocol (GP) scenario and a maximum feasible reductions (MFR) scenario. All scenarios used calibrated HARM v11.5 sulphur and oxidised nitrogen deposition and FRAME reduced nitrogen deposition. A summary of the UK exceedance statistics is given in the table below.

Scenario	Acidity		Nutrient nitrogen	
	% habitat exceeded	Accumulated Exceedance ($x10^3$ keq year^{-1})	% habitat exceeded	Accumulated Exceedance ($x10^3$ keq year^{-1})
GP	47.4	2890	30.5	2034
MFR	42.6	2220	26.6	1489
Pigs	45.2	2585	28.8	1754
Poultry	45.1	2552	28.8	1731
Cows	44.0	2408	27.5	1642
Fertiliser	44.1	2464	27.9	1669
Non-agriculture	44.3	2546	28.4	1720
All sectors	44.2	2453	27.9	1668

The results for reducing ammonia emissions from animal farming and non-agricultural sources are all very similar and all fall between the results obtained for the new Gothenburg Protocol scenario and the Maximum Feasible Reductions scenario.

HARM v11.5 1995-97 deposition and DMP 1995-97 deposition (July 2002)
Two scenarios were run to compare the results of using HARM v11.5 direct model output (ie, uncalibrated data) of sulphur and oxidised nitrogen for 1995-97 together with DMP 1995-97 reduced nitrogen deposition versus the results of using sulphur, oxidised and reduced nitrogen DMP deposition for 1995-97. The UK exceedance statistics are summarised in the table below.

Scenario	Acidity		Nutrient nitrogen	
	% habitat exceeded	Accumulated Exceedance ($x10^3$ keq year^{-1})	% habitat exceeded	Accumulated Exceedance ($x10^3$ keq year^{-1})
HARM + DMP	65.7	5203	47.9	262
All DMP	70.9	7061	39.8	3063

In this comparison both scenarios give similar percentage areas of habitats exceeded. However, comparison of the AE values shows that the combination of HARM + DMP deposition produces much lower AE values, especially for nutrient nitrogen. This means the HARM oxidised nitrogen deposition must be substantially lower than the DMP values as the DMP reduced nitrogen is used in both scenarios.

HARM ENTEC scenarios (July 2002)
This consisted of four scenarios based on HARM v11.5 2010 calibrated sulphur and oxidized nitrogen deposition and FRAME (March 02) reduced nitrogen deposition to look at the effects of variations in SO_2 emissions (with very small accompanying changes to NO_2). The scenarios examined were: (i) business as usual; (ii) business as

usual with compliance scenario 9; (iii) business as usual with compliance scenario 11; (iv) national plan compliance scenario 1 for 2008-2015.

Scenario	Acidity		Nutrient nitrogen	
	% habitat exceeded	Accumulated Exceedance (x10^3 keq year^{-1})	% habitat exceeded	Accumulated Exceedance (x10^3 keq year^{-1})
Bau	46.6	2774	29.4	1928
Cs09	44.8	2598	29.4	1924
Cs11	45.2	2643	29.4	1926
Cs1_08	46.3	2735	29.4	1926

As these scenarios were focused on varying the SO_2 emissions, one would only expect differences in the acidity exceedance statistics. The results for all four scenarios are similar but there are also some differences, especially in the acidity AE values, with the compliance scenario 9 giving the lowest exceedances. For nutrient nitrogen the percentage habitat area exceeded is identical for all four scenarios, but there are still some differences in the AE values as a result of small changes in NO_2 emissions due to the way the chemistry is coupled in the models.

5.4 Deposition scenarios using February 2003 critical loads

This section summarises the deposition scenarios and exceedance statistics based on the February 2003 critical loads data.

Addendum: assessment of critical load exceedances for 1995-97 (May 2003)
The 2003 Addendum (Hall *et al.*, 2003d) was prepared to compare the exceedance statistics using February 2001 critical loads and February 2003 critical loads. For the exceedance calculations presented in the Addendum the DMP 1995-97 deposition was used with both sets of critical loads data. The update to critical loads included changes in the habitats mapped and their distributions as well as revisions to the methods and data used in critical load calculations. The impact of these changes is reflected in the exceedance statistics in the table below – the changes are not the result of a change in the pollution climate. A discussion on the specific reasons for the changes observed in the exceedances is included in the Addendum and will not be repeated here.

Critical loads data used	Acidity		Nutrient nitrogen	
	% habitat exceeded	Accumulated Exceedance (x10^3 keq year^{-1})	% habitat exceeded	Accumulated Exceedance (x10^3 keq year^{-1})
Feb 2001	70.9	7061	39.8	3063
Feb 2003	66.5	5266	62.7	4012

Gothenburg Protocol and NECD (April 2003)

The Gothenburg Protocol and NECD scenarios were re-run using the February 2003 critical loads data and calibrated HARM v 11.5 (S and NOx) and FRAME (variable boundary layer height model) (NHx) deposition. The summary exceedance statistics for the UK are presented below; both scenarios give very similar results.

Scenario	Acidity		Nutrient nitrogen	
	% habitat exceeded	Accumulated Exceedance ($x10^3$ keq $year^{-1}$)	% habitat exceeded	Accumulated Exceedance ($x10^3$ keq $year^{-1}$)
Gothenburg	40.6	1883	44.1	2288
NECD	40.2	1849	44.0	2281

<u>HARM v11.5 vs HARM v12 (June 2003)</u>

The version of HARM was updated in May/June 2003 and the impact of the changes in the model on critical loads exceedances examined. HARM v12 has multiple (three) layers, ecosystem specific deposition velocities and incorporates global background concentrations for all key pollutants. Both versions of the model were run for 1999. The results for the UK are summarised in the table below.

Scenario	Acidity		Nutrient nitrogen	
	% habitat exceeded	Accumulated Exceedance ($x10^3$ keq $year^{-1}$)	% habitat exceeded	Accumulated Exceedance ($x10^3$ keq $year^{-1}$)
HARM v11.5	39.0	1480	8.4	166
HARM v12	45.9	2027	13.1	295

The deposition values for HARM v12 are higher than those for HARM v11.5 and hence give higher exceedances.

<u>HARM v12 and FRAME v4.17 calibrated and uncalibrated scenarios (June 2003)</u>

Exceedances were calculated for 1990, 1995-97 and 2010 (NECD) using both uncalibrated and calibrated modelled deposition from HARM v12 and from FRAME v4.17. The results for the UK are compared, including DMP 1995-97 results, in the table below. This table shows that if DMP 1995-97 data are taken as the best available estimate of current deposition, then both HARM v12 and FRAME v4.17 are underestimating deposition and hence exceedance, though the uncalibrated FRAME data give a higher AE value than the DMP.

Scenario	1990		1995-97		2010 (NECD)	
	% area exceeded	AE ($x10^3$ keq $year^{-1}$)	% area exceeded	AE ($x10^3$ keq $year^{-1}$)	% area exceeded	AE ($x10^3$ keq $year^{-1}$)
Acidity						
DMP	-	-	66.5	5266	-	-
HARMu	70.4	3924	44.3	1617	14.5	236
HARMc	84.1	9530	na	na	42.0	1914
FRAMEu	64.9	8579	57.1	5782	31.6	1563
FRAMEc	80.6	20345	na	na	35.8	1573

Nutrient nitrogen						
DMP	-	-	62.8	4009	-	-
HARMu	40.4	974	26.6	445	6.0	52
HARMc	72.9	5664	na	na	45.8	2206
FRAMEu	59.5	4586	57.3	3934	40.9	2000
FRAMEc	65.1	4489	na	na	46	2328

Key:
u refers to uncalibrated deposition (ie, direct model output)
c refers to deposition calibrated with DMP 1995-97 data

Closer inspection of the exceedance statistics by habitat highlights the following:

Acidity exceedances

- FRAME 1995-97 by comparison with DMP 1995-97 appears to overestimate acid deposition for non-woodland habitats and underestimate acid deposition for woodland habitats. (Figure 5.1)
- Calibrating FRAME acid deposition for 1990 increases exceedances for woodland habitats and decreases exceedance for non-woodland habitats, compared to uncalibrated FRAME results. (Figure 5.2)
- Calibrating FRAME acid deposition for 2010 decreases the exceedances for all habitats, compared to uncalibrated FRAME results. (Figure 5.3)
- HARM 1995-97 acid deposition gives lower exceedances than both DMP 1995-97 and FRAME 1995-97 for all habitats. (Figure 5.1)
- Calibrating HARM 1990 data gives higher exceedances than calibrated FRAME 1990 data for non-woodland habitats. (Figure 5.2)
- Calibrating HARM 2010 data gives higher exceedances than calibrated FRAME 2010 data for all habitats. (Figure 5.3)

Nutrient nitrogen exceedances

- FRAME 1995-97 by comparison with DMP 1995-97 appears to overestimate nitrogen deposition for non-woodland habitats and underestimate nitrogen deposition for woodland habitats. (Figure 5.4)
- Calibrating FRAME nitrogen deposition for 1990 decreases the exceedances for all habitats, compared to uncalibrated FRAME results. (Figure 5.5)
- Calibrating FRAME nitrogen deposition for 2010 results in similar exceedances for non-woodland habitats and increased exceedances for woodland habitats, compared to uncalibrated FRAME results. (Figure 5.6)
- HARM 1995-97 nitrogen deposition gives lower exceedances than both DMP 1995-97 and FRAME 1995-97 for all habitats. (Figure 5.4)
- Calibrating HARM 1990 data gives higher exceedances than calibrated FRAME 1990 data for all habitats. (Figure 5.5)
- Calibrating HARM 2010 data gives similar exceedances as FRAME calibrated 2010 data for non-woodland habitats, and similar or smaller exceedances for woodland habitats. (Figure 5.6)

FRAME deposition status report (July 2003)

The above exceedance statistics for DMP 1995-97, FRAME 1995-97, FRAME calibrated 1990 and FRAME calibrated and uncalibrated 2010 (NECD) are included in the FRAME deposition status report to Defra (Dore *et al.*, 2003).

ENTEC scenarios for sulphur in shipping fuels directive (August 2003)
This consisted of four scenarios that were all variants on the NECD with increasingly stringent emission reductions applied to the shipping sector across the EMEP domain. Only sulphur was varied, but because of the coupled chemistry operating in HARM, its possible there was a slight effect on the oxidised nitrogen values.

Scenario	Acidity		Nutrient nitrogen	
	% habitat exceeded	Accumulated Exceedance ($x10^3$ keq $year^{-1}$)	% habitat exceeded	Accumulated Exceedance ($x10^3$ keq $year^{-1}$)
2873.4 kT SO2	36.9	1642	48.9	2517
2501.0 kT SO2	36.3	1610	48.9	2516
2185.8 kT SO2	36.2	1600	48.9	2516
487.6 kT SO2	35.3	1534	48.9	2514

The results for the first three ENTEC scenarios are very similar. The acidity results for the fourth scenario give the lowest exceedances as the SO2 emissions reductions were much greater for this scenario.

5.5 Deposition scenarios using February 2004 critical loads

To date exceedances based on the February 2004 critical loads have been calculated using deposition data for 1995-97 (previous and March 2004 versions), 1998-2000, 1999-2001 and 2010. The 2004 Addendum (Hall *et al.*, 2004c) compares the exceedance statistics and maps for February 2003 critical loads and 1995-97 (previous version) deposition with those for February 2004 critical loads and the March 2004 version of the 1995-97 deposition data. In addition, Annexes to the Addendum include the exceedance statistics based on February 2004 critical loads and March 2004 deposition data for 1998-2000 and 1999-2001. A “Trends” report is currently being prepared that will compare and contrast the exceedance statistics and maps for the different deposition years, and will additionally include the results based on the latest FRAME 2010 scenario.

The table below summarises the exceedance statistics for the UK for acidity and for nutrient nitrogen for 1995-97, 1998-2000, 1999-2001 and 2010.

Deposition data used	Acidity		Nutrient nitrogen	
	% habitat exceeded	Accumulated Exceedance ($x10^3$ keq $year^{-1}$)	% habitat exceeded	Accumulated Exceedance ($x10^3$ keq $year^{-1}$)
1995-1997	72.6%	6028	65.5%	4346
1998-2000	60.8%	3974	57.6%	3332
1999-2001	60.2%	3898	58.7%	3502
2010	47.3%	2375	49.2%	2474

Results based on February 2004 critical loads and March 2004 deposition data for 1995-97, 1998-2000, 1999-2001 and FRAME deposition for 2010 (May 2004 version).

6 FORMAL ASSESSMENT OF UNCERTAINTIES

Critical loads and their exceedances were used as the basis for the negotiation of the Gothenburg Protocol and the National Emissions Ceilings Directive to reduce emissions of sulphur and nitrogen by 2010. Future deposition scenarios show that following implementation of these emission reductions there will still be exceeded areas within the UK and Europe. Because of the associated cost in further emission reductions the policy maker needs to know and understand the uncertainties in critical loads and their exceedances, upon which abatement policy would be based. Therefore under this contract the NFC have carried out a formal analysis of the uncertainties in critical loads and their exceedances, consisting of the activities listed and described below:

- Section 6.1 contains the results of the sensitivity analyses carried out to identify the key parameters driving the critical load calculations.
- Section 6.2 provides a short summary of the literature review carried out to identify and derive the uncertainties in the input parameters to the critical load calculations.
- Section 6.3 refers to the submission of uncertainty information to the CCE in March 2003.
- Section 6.4 examines the range of critical load values that can occur for different soil types within each 1km square of England and Wales and compares these with the critical load for the dominant soil as used in the national empirical soil map.
- Section 6.5 presents the results of the uncertainty analysis of the calculation of critical loads (acidity and nitrogen) for acid grassland and coniferous woodland. It draws upon the literature review described in section 6.2.
- Section 6.6 reports on the effect of uncertainties in deposition (current and future) on critical load exceedance.
- Section 6.7 introduces methods of visually presenting uncertainties in critical load exceedance.
- Section 6.8 provides an assessment of the overall uncertainty in the prediction of critical load exceedance using the best estimates of uncertainty in measured deposition and critical loads for two ecosystems.
- Section 6.9 looks at the impacts of data scale on the calculations of critical load exceedances.
- Section 6.10 draws together the key conclusions from Sections 6.1 to 6.9.

6.1 Sensitivity analyses

This section summarises the results of the sensitivity analyses carried out on the inputs to the calculations of critical loads. It should be noted that in each case the analyses are based on the critical loads data as of February 2001, as this work was carried out prior to the February 2003 update. Sensitivity analyses look at the sensitivity of the output variable (eg acidity critical load) to changes in one input variable (eg, base cation weathering), usually with the others held constant. These analyses therefore provide an objective basis for ranking the parameters of the critical load equations according to their effects on the calculated critical load.

Many of the sensitivity analyses presented below have been performed at two levels:

- Non-spatial analysis – where the mean input parameter values for the UK were perturbed one at a time in steps of ±10% up to ±50%.
- Spatial – where the model was run for all 1km squares containing the ecosystem in the UK; hence it is based on perturbing the actual data for each UK ecosystem rather than perturbing the single mean value for each parameter. For each model run a single parameter was varied by $\pm$ 20 %.

The non-spatial analysis gives an indication of the predicted effect of individual parameters on the critical load calculations, whereas the spatial analysis reflects the real effect based on the full UK data.

6.1.1 Simple Mass Balance (SMB) equation (acidity)

The SMB equation is currently applied to the following woodland habitats: managed conifers, managed broadleaves and unmanaged conifer and broadleaf. Prior to the February 2003 update, the SMB equation was applied to coniferous and deciduous woodland ecosystems and the sensitivity analyses below are based on the coniferous woodland ecosystem and the February 2001 data. The results should hold generally for the 2003 and subsequent critical loads data; however runs should be performed to test the effect of changing the initial conditions on parameter sensitivity. The study relates only to woodland occurring on mineral or organic (non-peat) soils, since the current formulations of the SMB are considered inappropriate for peat soils and in such areas the empirical critical loads of acidity are applied. The sensitivity analyses were carried out separately for two formulations of the SMB in use at that time:

(i) using the critical molar ratio of Ca:Al=1 in soil solution aimed at protecting coniferous woodland on mineral soils.

(ii) using the critical soil solution pH of 4.0 (ie, critical hydrogen ion concentration) aimed at protecting coniferous woodland on organic soils.

It should be noted that for the February 2004 update the methods for calculating critical loads for woodlands occurring on different soil types were reviewed (Section 3.3) and the critical molar ratio of Ca:Al=1 in soil solution was subsequently applied to both mineral and organo-mineral soils. The results of the non-spatial and spatial sensitivity analyses are summarised in tables 6.1 and 6.2 below.

In the SMB equation for woodland on mineral soils (Table 6.1) the molar calcium to aluminium ratio has the largest effect on the critical load, followed by base cation and calcium weathering rates. Whilst the non-spatial and spatial results are generally comparable, the effect of altering the calcium weathering rate was smaller when using the spatial data than the mean values with the non-spatial approach. This could be due to the spatial distribution of the calcium weathering values in relation to the locations of the coniferous woodland. Because of the formulation of the SMB equations changing the value of some parameters increases the critical loads while others decrease the critical loads for the same perturbation.

Table 6.1. The effect of perturbing input values to the SMB equation for coniferous woodland on mineral soils: non-spatial and spatial sensitivity analysis

Parameter	**Percentage effect on critical load**			
	Non-spatial		**Spatial**	
	-20%	**+20%**	**-20%**	**+20%**
Base cation weathering (ANC_w)	-8.2%	+8.1%	-8.4	+8.3
Calcium weathering (Ca_w)	-7.6%	+7.6%	-4.8	+4.8
Runoff (Q)	-1.6%	+1.5%	-1.3	+1.2
Calcium deposition (Ca_{dep})	-4.0%	+3.9%	-4.8	+4.7
Calcium uptake (Ca_u)	+1.3%	-1.3%	+1.6	-1.6
Limiting calcium concentration	+0.1%	-0.1%	Not done	Not done
Gibbsite equilibrium constant (kgibb)	+1.0%	-0.7%	+0.8	-0.6
Critical Ca:Al ratio	+12.6%	-8.5%	+12.8	-8.6
All parameters	-9.0%	+8.9%	Not done	Not done

The results for woodland on organic soils (Table 6.2) are very similar for both the non-spatial and spatial analyses; both show that base cation weathering has the greatest effect on the critical load, followed by the critical hydrogen ion concentration and runoff.

Table 6.2. The effect of perturbing input values to the SMB equation for coniferous woodland on organic soils: non-spatial and spatial analysis

Parameter	**Percentage effect on critical load**			
	Non-spatial		**Spatial**	
	-20%	**+20%**	**-20%**	**+20%**
Base cation weathering (ANC_w)	-13.0%	+13.0%	-13.0	+12.9
Runoff (Q)	-7.0%	+7.0%	-7.1	+7.2
Critical hydrogen ion concentration	-7.9%	+8.6%	-8.0	+8.7
Gibbsite equilibrium constant (kgibb)	-0.6%	+0.6%	-0.6	+0.7
All parameters	-26.5%	+31.6%	Not done	Not done

These analyses highlight the parameters that have the most influence on the critical load values and the importance of these inputs being based on the best available data. The sensitivity results are linear for all parameters except the critical chemical criteria (molar Ca:Al ratio, critical hydrogen ion concentration). The SMB is very sensitive to the values of the critical chemical criteria and it is therefore important that the correct values for protecting the ecosystem are applied. Secondly good estimates of both base cation and calcium weathering rates are required as these also have a large effect on the critical load calculations. Currently the weathering rate data are based on 1km resolution national soil databases.

6.1.2 Maximum critical load of sulphur ($CL_{max}S$)

For terrestrial habitats $CL_{max}S$ is based on the acidity critical load values but also takes into account the net base cation deposition to the soil system and base cation removal from the system:

$$CL_{\max}S = CLA + BC_{dep} - BC_u$$

where CLA = acidity critical load (empirical or SMB)
BC_{dep} = non-marine base cation deposition less non-marine chloride deposition
BC_u = base cation uptake by vegetation

Once again, both non-spatial and spatial uncertainty analyses were carried out and the results for both are given in Table 6.3. The analyses show that the parameter that has the most influence on the calculation of $CL_{max}S$ is the acidity critical load (CLA), regardless of whether empirical or mass balance critical loads are used. This is due to the key role base cation (and calcium) weathering plays in the calculation of the critical loads. The effects of BC_{dep} and BC_u on the calculations are an order of magnitude lower. The value of Cl_{dep} in the non-spatial analysis has the least effect on the critical load calculations, which is not surprising given that the mean values are very small, (ie, 0.014 keq ha^{-1} $year^{-1}$ for non-woodland habitats and 0.016 keq ha^{-1} $year^{-1}$ for woodland habitats). For the spatial analysis Cl_{dep} was not considered separately, but as part of the expression of BC_{dep} as BC_{dep} - Cl_{dep}.

Table 6.3. The effect of perturbing the input parameters to the calculation of $CL_{max}S$: non-spatial and spatial sensitivity analyses.

Habitat	**Parameter**	**Percentage effect on CLmaxS of varying inputs by:**			
		Non-spatial		**Spatial**	
		-20%	**+20%**	**-20%**	**+20%**
Acid grassland (empirical CLA)	CLA	-17.7	+17.7	-16.5	+16.6
	BC_{dep}	-2.5	+2.5	-3.3	+3.4
	Cl_{dep}	+0.1	-0.2		
	BC_u = zero	-	-	-	-
Calcareous grassland (empirical CLA)	CLA	-20.9	+20.8	-20.1	+20.1
	BC_{dep}	-3.0	+2.9	-1.5	+1.6
	Cl_{dep}	+0.2	-0.2		
	BC_u	+3.6	-3.6	+1.6	-1.6
Heathland (empirical CLA)	CLA	-17.7	+17.7	-16.4	+16.4
	BC_{dep}	-2.5	+2.5	-3.7	+3.6
	Cl_{dep}	+0.1	-0.2		
	BC_u = zero	-	-	-	-
Coniferous woodland*	CLA	-20 (-20)	+20 (+20)	-20.2	+20.2
	BC_{dep}	-1.7 (-2.8)	+1.7 (+2.7)	-2.5	+2.5
	Cl_{dep}	+0.1 (+0.2)	-0.1 (-0.2)		
	BC_u	+1.6 (+2.6)	-1.6 (-2.6)	+3.2	-2.7
Deciduous woodland	CLA	Not done		-22.1	+22.0
	BC_{dep}			-2.8	+2.6
	Cl_{dep}				
	BC_u			+4.6	-4.8

* The non-spatial analysis for coniferous woodland was carried out separately for the SMB equations for mineral and organic soils. The results are given for mineral soils and the values in brackets for organic soils. For the spatial analysis the data were not disaggregated for different soil types.

For coniferous woodlands on mineral soils the spatial sensitivity analysis for $CL_{max}S$ also considered each of the parameters assessed for the simple mass balance acidity critical loads (CLA). As for CLA, $CL_{max}S$ is largely influenced by the critical Ca:Al ratio, base cation and calcium weathering and calcium deposition.

6.1.3 Minimum critical load of nitrogen ($CL_{min}N$)

$CL_{min}N$ represents the nitrogen removal processes in the soil that are independent of deposition. For terrestrial ecosystems $CL_{min}N$ is calculated as:

$$CL_{\min} N = N_u + N_i + N_{de}$$

where N_u = nitrogen uptake
N_i = nitrogen immobilisation
N_{de} = denitrification

The results of the non-spatial and spatial sensitivity analyses are shown in Table 6.4. All habitats except acid grassland were most sensitive to nitrogen uptake. The values of N_u are generally greater than the other components of $CL_{min}N$ and hence as the equation is simply the summation of these three parameters, N_u has the greatest effect on the calculation. However, for acid grassland the N_u value is much smaller and so has a lesser effect on $CL_{min}N$.

The percentage effects of varying the input parameters by -20% are similar for both the non-spatial and the spatial analysis. However, increasing the values by +20% for the non-woodland habitats shows some marked differences between the non-spatial and spatial approaches, especially for acid grassland. In some cases the spatial analysis shows $CL_{min}N$ is less sensitive to variations in the input parameter than predicted by the non-spatial analysis.

Table 6.4. The effect of perturbing the input values to the calculation of $CL_{min}N$: non-spatial and spatial sensitivity analysis

Habitat	**Parameter**	**Percentage effect on CLminN of varying inputs by:**			
		Non-spatial		**Spatial**	
		-20%	**+20%**	**-20%**	**+20%**
Acid grassland	N_i	-8.3	+8.3	-8.5	+3.8
	N_{de}	-7.7	+7.7	-7.7	+3.3
	N_u	-4.0	+4.0	-4.0	+12.8
Calcareous grassland	N_i	-1.6	+1.6	-1.6	+3.8
	N_{de}	-2.9	+2.9	-2.9	+3.3
	N_u	-15.6	+15.6	-15.6	+12.8
Heathland	N_i	-5.7	+5.7	-5.2	+3.8
	N_{de}	-4.3	+4.3	-3.4	+3.3
	N_u	-10	+10	-9.3	+12.8
Coniferous woodland	N_i	-3.9	+3.9	-3.8	+3.8
	N_{de}	-3.4	+3.4	-3.3	+3.3
	N_u	-12.8	+12.8	-12.8	+12.8
Deciduous woodland	N_i	-2.9	+2.9	-2.9	+2.9
	N_{de}	-3.7	+3.7	-3.8	-3.7
	N_u	-13.4	+13.4	-13.4	+13.4

6.1.4 Maximum critical load of nitrogen ($CL_{max}N$)

For terrestrial ecosystems the maximum critical load of nitrogen is defined as:

$$CL_{\max} N = CL_{\min} N + CL_{\max} S$$

A spatial sensitivity analysis for coniferous woodland on mineral soils has been carried out incorporating all the inputs to $CL_{min}N$ and $CL_{max}S$ and the results shown in Table 6.5.

Table 6.5. The effect of perturbing the input values to the calculation of $CL_{max}N$: spatial sensitivity analysis for coniferous woodland

Parameter	**Percentage effect on $CL_{max}N$ of varying inputs by:**	
	-20%	**+20%**
Calcium deposition (Ca_{dep})	-3.4 %	+3.3 %
Calcium uptake (Ca_u)	+1.1 %	-1.1 %
Calcium weathering (Ca_w)	-3.4 %	+3.3 %
Runoff (Q)	-2.8 %	+2.7 %
Gibbsite equilibrium constant (K_{gibb})	+0.6 %	-0.3 %
Critical Ca:Al ratio (Ca:Al)	+6.7 %	-4.6 %
Base cation weathering ($ANC_{w)}$	-5.7%	+5.7%
Base cation deposition (BC_{dep})	-1.7%	+1.7%
Base cation uptake (BC_u)	+1.9%	-1.9%
Nitrogen immobilization (N_i)	-1.1%	+1.1%
Nitrogen uptake (N_u)	-3.8%	+3.8%
Denitrification (N_{de})	-1.0%	+1.0%

Not surprisingly Table 6.5 shows that $CL_{max}N$ is influenced by the same parameters identified as having the greatest effect on $CL_{max}S$, (ie, critical Ca:Al ratio, base cation weathering, calcium deposition) and $CL_{min}N$ (ie, nitrogen uptake).

6.1.5 Critical loads of nutrient nitrogen ($CL_{nut}N$)

The mass balance approach is used for calculating nutrient nitrogen critical loads for woodland ecosystems. The mass balance equation for $CL_{nut}N$ is:

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

where N_u = uptake and removal of nitrogen by harvesting of trees
N_i = nitrogen immobilisation
N_{de} = denitrification
$N_{le(acc)}$ = acceptable nitrogen leaching

The outcome of the sensitivity analyses are shown in table 6.6. Virtually identical results were obtained for both the non-spatial and the spatial analyses. The equation is most sensitive to nitrogen uptake and nitrogen leaching as the initial values for these parameters are greater than those for nitrogen immobilisation and denitrification.

Table 6.6. The effect of perturbing the input values to the calculation of $CL_{nut}N$: non-spatial and spatial sensitivity analysis.

Habitat	Parameter	Percentage effect on CLminN of varying inputs by:			
		Non-spatial		Spatial	
		-20%	+20%	-20%	+20%
Coniferous woodland	N_u	-8.3	+8.3	-8.3	+8.3
	N_i	-2.6	+2.5	-2.5	+2.5
	N_{de}	-2.2	+2.1	-2.1	+2.1
	N_{le}	-7.1	+7.0	-7.1	+7.1
Deciduous woodland	N_u	Not done	Not done	-8.5	+8.5
	N_i			-1.8	+1.9
	N_{de}			-2.4	+2.4
	N_{le}			-7.2	+7.2

6.1.6 Critical load exceedances

A sensitivity analysis to examine the impacts of perturbing the inputs to critical load exceedance calculations has also been carried out. For eutrophication, the exceedance is calculated using total nitrogen deposition (derived from nitrogen oxides and ammonia). For acidification, the contributions of both sulphur and nitrogen compounds must be taken into account, and this is done using the Critical Loads Function (CLF, See Section 3.4) which uses the three critical load parameters $CL_{max}S$, $CL_{min}N$ and $CL_{max}N$ in its calculation of exceedance. This example is based on using the pre-March 2004 version of the 1995-97 deposition data and the February 2001 critical loads data. Table 6.7 shows the results of perturbing total nitrogen deposition, sulphur deposition and critical loads on acidity critical load exceedances.

Table 6.7. The effect of perturbing the input values to the calculation of acidity exceedances.

Habitat	Parameter	Percentage effect on exceedance of varying inputs by:	
		-20%	+20%
Acid grassland	S_{dep}	-21	+21
	N_{dep}	-35	+35
	$CL_{max}S$	+10	-9
	$CL_{min}N$	+5	-6
	$CL_{max}N$	+15	-17
Coniferous woodland	S_{dep}	-17	+16
	N_{dep}	-43	+42
	$CL_{max}S$	+6	-6
	$CL_{min}N$	+2	-3
	$CL_{max}N$	+25	-25

Increasing or decreasing the inputs leads to approximately linear increases and decreases in the critical load exceedance values. Overall, perturbing nitrogen deposition has the largest effect on the exceedance values; this is most probably because in many areas of the country these will be the largest values in the equation. Changing $CL_{max}N$ also has a large effect on the resulting exceedance values, because

$CL_{max}N$ is the sum of $CL_{min}N$ and $CL_{max}S$. As expected, increasing deposition increases the exceedance values, and increasing the critical loads decreases the exceedance values.

Exceedance of nutrient nitrogen critical loads is a simpler calculation: total nitrogen deposition minus the nutrient nitrogen critical load. Table 6.8 shows the results of varying these two inputs on the nutrient nitrogen exceedance values.

Table 6.8. The effect of perturbing the input values to the calculation of nutrient nitrogen exceedances.

Habitat	Parameter	Percentage effect on exceedance of varying inputs by:	
		-20%	+20%
Acid grassland	N_{dep}	-118	+118
	$CL_{nut}N$	+98	-98
Coniferous woodland	N_{dep}	-32	+32
	$CL_{nut}N$	+12	-11

Once again because of the simple calculations increases or decreases in deposition or critical loads lead to linear increases or decreases in exceedances. Perturbing nitrogen deposition also has the largest effect on the results.

For both acidity and nutrient nitrogen the calculation of exceedance is most sensitive to the deposition data, rather than the critical loads. However, it should be noted that the results of this analysis are based on deposition data for 1995-97. As deposition decreases in the future (eg, 2010) following implementation of further emission reductions, we would expect the significance of the deposition parameters to decrease.

6.2 Literature Review

A literature review of the uncertainties in the inputs to critical load calculations has been prepared for publication (Appendix 1). The calculations of critical loads of acidity and nutrient nitrogen use data from many different sources and uncertainty estimates need to be derived for each parameter. This review has two objectives:

(i) To summarise current knowledge about the uncertainties entailed in estimating critical loads. There have been a number of attempts to establish the range of uncertainty in critical loads in recent years by scientists across Europe. There is now a wide body of literature on the uncertainties in the input variables to the critical load models available.

(ii) To derive uncertainty ranges, distributions and correlations for inputs to the UK critical load calculations. This was accomplished by using professional judgement based on the extensive review of available literature, collected data, and interviews with experts on the parameter of interest. The probability distribution assigned to each of the parameters was occasionally obtained from experimental data, but usually subjective judgement was used to reflect the degree of belief that the value lies within a specified range. A summary of the preliminary results can be found in Hall *et al.* (2003b).

This review highlighted the wide range of estimates of uncertainties derived for some parameters. For example, uncertainties in weathering rates have been one of the most difficult parameters to quantify and yet our sensitivity analysis (Sections 6.1.1) and that of Hodson & Langan (1999) has demonstrated that it is of paramount importance when attempting to calculate critical loads nationally. Table 6.9 shows the range of uncertainty values defined by different countries and authors.

Table 6.9. Ranges of uncertainty in base cation weathering rates

Country and/or author	Uncertainty range for base cation weathering rates
German NFC	± 20%
Austrian NFC	± 40%
Netherlands NFC	± 50%
Barkman *et al.* (1999)	± 20 to 30%
Hodson *et al.* (1997)	± 250%

Some of the differences between the estimates of uncertainty may be due to the methods used by different countries to calculate base cation weathering.

The uncertainty analyses in Sections 6.5, 6.6 and 6.8 below utilise Monte Carlo analysis which depends critically on the means, ranges, distribution types and correlations chosen for the input parameters. The results of the literature review were used to objectively derive uncertainty ranges in the input variables for the Monte Carlo analysis. Additionally where data were lacking and assumptions had to be made in respect of ranges, distributions etc, this was stated explicitly.

6.3 Submission of uncertainty information to the CCE

The above Section describes the derivation of uncertainties in the input parameters to the UK critical load calculations. The preliminary results of this study were carried out on the February 2003 data and submitted in the report accompanying the data submission to the CCE in March 2003. The work is described briefly in the CCE 2003 Status Report (Hall *et al.*, 2003b) and more fully in Appendix 1 of this report. Where values were taken from default ranges given in the literature, these ranges have been used to calculate the percentage uncertainty around the default parameter. Where experimental data was used to calculate input parameters these have been analysed to give a coefficient of variation (CV). In a few cases uncertainty ranges were taken directly from the literature or expert judgement has been used.

6.4 Empirical acidity critical loads

This section briefly describes (i) the basis of setting the empirical critical loads of acidity for soils in the UK and (ii) the results of an analysis of the soils database to examine the range of critical load values within each 1km grid square within England and Wales and the effects this could have on the national critical loads map.

The empirical critical loads of acidity for soils are based on the mineralogy and weathering rate of the dominant soil in each 1 km grid square of the UK. Soil materials were divided into five classes on the basis of their dominant weatherable minerals (Hornung *et al.*, 1995). Critical load ranges were then assigned to these classes, according to the amount of acidity that could be neutralised by base cations produced by the weathering of these minerals (Table 6.10). This provided a method of assigning ranges of critical load values to a soil (Hornung *et al.*, 1995). However, as a single value is usually required for each grid square (eg, for exceedance calculations), the mid-range value has been used, with the exception of class one where the value is set to the top of the range. This approach is consistent with studies by Langan *et al.* (1995) and Sverdrup *et al.* (1990). These empirical acidity critical loads are applied to non-woodland terrestrial ecosystems in the UK (Hall *et al.*, 2003c).

Table 6.10. Critical load classes

Critical loads class	Critical loads range (keq H^+ ha^{-1} $year^{-1}$)	Mid-range value used (keq H^+ ha^{-1} $year^{-1}$)
1	> 2.0 <= 4.0	4.0 (upper limit used)
2	>1.0 <= 2.0	1.5
3	> 0.5 <= 1.0	0.75
4	> 0.2 <= 0.5	0.35
5	<= 0.2	0.1

It should be noted that this approach is inappropriate for classifying peat soils and a separate method is used to assign critical loads to 1km grid squares dominated by peat soils (Hall *et al.*, 2003c; Hall *et al.*, 2004b).

Originally the soil surveys (Soil Survey and Land Research Centre, Macaulay Land Use Research Institute and Department of Agriculture in Northern Ireland) provided CEH with the critical loads class for each 1km grid square based on the dominant soil. Additionally for England and Wales we held data on all soil associations and their percentage cover in each 1km grid square. As empirical critical load values have been assigned to all soil associations in England and Wales (Loveland, 1991) it was possible to derive 1km maps to compare critical loads based on:

- The dominant soil association
- The most sensitive soil (ie, that with the lowest critical load)
- The least sensitive soil (ie, that with the highest critical load)

Peat soils were not included in the analysis. The three maps are shown in Figure 6.1. However, it should be noted that this work was carried out prior to the February 2003 update to the national critical loads map which made use of new revised national soil databases. These revised data led to changes in the percentage areas of soils in some 1km squares, which could have an impact on the results presented in this section.

An analysis of the three mapped data sets (Figure 6.1) highlighted:

- The critical load values for 20% of the 1km grid squares did not change, either because the grid square contains only one soil type or all soil types in a square have the same critical load.
- The critical load values for 35% of the 1km grid squares could be lower because one or more of the sub-dominant soil types present have lower critical loads.
- The critical load values for 29% of the 1km grid squares could be higher because one or more of the sub-dominant soil types present have higher critical loads.

- The critical load values for 16% of the 1km grid squares could be either lower or higher because they contain sub-dominant soils with both higher and lower critical load values than the dominant soil.

Whilst for mapping at the national scale, use of the critical load for the dominant soil is likely to provide the best national picture, when considering critical loads at the local or site-specific scale, or even at the habitat level, it is important to recognise that the critical load for the dominant soil may differ from that for the soil (or the soil associated with a particular habitat) at a specific location. The empirical acidity critical loads map for soils is used to set the acidity critical loads for non-woodland terrestrial habitats and provides the weathering rate input to the SMB acidity critical loads for woodland habitats. These acidity critical loads are also used in the derivation of $CL_{max}S$ and $CL_{max}N$, so uncertainties identified in the empirical soil acidity map may also have an impact on other critical loads derived from these data.

6.5 Assessing uncertainties in the calculation of UK critical loads

This section provides a summary of the uncertainty analysis of the calculations of critical loads for acid grassland and managed coniferous woodland. A paper detailing this work is currently in preparation.

Since 2003 UK critical loads have been calculated for 9 broad habitats for acidity and 10 for nutrient nitrogen. Because of the amount of data analysis involved it was not practical to estimate uncertainty in all these habitats, therefore two habitats were selected: (i) acid grassland, representing critical loads (acidity and nitrogen) based on empirical methods; and (ii) managed coniferous woodland representing critical loads based on mass balance methods. The uncertainty in the estimation of these critical loads was investigated by means of Monte Carlo analysis.

Uncertainties in $CL_{min}N$, $CL_{max}N$, $CL_{max}S$ and $CL_{nut}N$ for the two habitats were assessed. Monte Carlo analysis requires the input values to the calculations to be selected at random from their distributions. These inputs were taken from the distributions and ranges identified by the literature review (Section 6.2 above) and critical loads calculated for every 1km grid square mapped for the two habitats in the UK. The calculations for each were repeated a sufficient number of times (approximately 1000 repetitions) to achieve a stable output.

The Monte Carlo simulations generate a range of possible critical load values which can then be presented using graphs (eg, frequency or cumulative frequency distributions) or statistical measures (eg, mean and median values that give a typical value about which the distribution is clustered). The median is defined as the 'middle' value of a set of numbers arranged in size order. When applied to a frequency distribution we can think of the median as splitting the area under a frequency curve into two equal portions. This curve can then be divided into 100 equal portions, known as percentiles. "Measures of dispersion" show how spread out a distribution is; the simplest of these are the range and percentile range. The standard deviation is the measure used most widely and can be used in conjunction with the mean to give a coefficient of variance.

The critical load distributions have been calculated for every 1km habitat grid square, however, due to the large amounts of data produced, it is not possible to present the output from each square. Therefore a distribution based on the mean critical load values of all the Monte Carlo runs is used to define the median and percentile critical load values, which can be compared with the deterministic critical load value, ie, the value normally calculated.

These results for acid grassland (Table 6.11) show:

- The 95th percentile of predicted $CL_{max}S$ is 1.25 times the mean: the mean is 1.38 times the 5th percentile. The probability distribution is approximately uniform.
- The 95th percentile of predicted $CL_{min}N$ is 1.30 times the mean: the mean is 1.48 times the 5th percentile. The probability distribution is approximately normal.
- The 95th percentile of predicted $CL_{max}N$ is 1.2 times the mean: the mean is 1.26 times the 5th percentile. The probability distribution is approximately normal.
- The 95th percentile of predicted $CL_{nut}N$ is 1.4 times the mean: the mean is 1.83 times the 5th percentile. The probability distribution is approximately normal.

The resultant coefficient of variation (CV) for $CL_{max}N$ is the smallest of the acidity critical load components, even though $CL_{max}N = CL_{max}S + CL_{min}N$. This appears to be a compensation of errors mechanism, a phenomenon also noted by Suutari *et al.* (2001) and Abbott *et al.* (2003). This occurs when it is assumed that the input parameters are uncorrelated (as they were in this case apart from base cation and nitrogen uptake). A negative effect on $CL_{max}S$ is compensated by a positive effect on $CL_{min}N$.

The larger CV for $CL_{nut}N$ is a result of there being no compensation mechanism, as $CL_{nut}N$ is based on a single empirical value with an uncertainty range of $\pm$ 66% around the nominal value.

Table 6.11. The deterministic, median, 5th and 95th percentile values for $CL_{max}S$, $CL_{min}N$, $CL_{max}N$, $CL_{nut}N$ and their coefficients of variation for acid grassland.

Critical load	Critical load values (keq ha^{-1} year^{-1})*					Coefficient of variation (%)
	Deterministic	Median*	5th percentile	95th percentile	Standard deviation	
$CL_{max}S$	0.82	0.83	0.60	1.04	0.14	17
$CL_{min}N$	0.37	0.37	0.25	0.48	0.07	19
$CL_{max}N$	1.19	1.20	0.95	1.44	0.15	13
$CL_{nut}N$	1.07	1.08	0.59	1.55	0.29	27

- Similar results are obtained for the median and the deterministic because the inputs to the uncertainty analysis are centred around the default values used for the deterministic estimations. Therefore, when a stable output is reached using the Monte Carlo analysis, the median results are similar to the deterministic.

The results for managed coniferous woodland (Table 6.12) show:

- The 95th percentile of predicted $CL_{max}S$ is 1.49 times the mean: the mean is 1.76 times the 5th percentile. The probability distribution is approximately log-normal.
- The 95th percentile of predicted $CL_{min}N$ nationally is 1.25 times the mean: the mean is 1.92 times the 5th percentile. The probability distribution is approximately normal.

- The 95th percentile of predicted $CL_{max}N$ is 1.35 times the mean: the mean is 1.47 times the 5th percentile. The probability distribution is approximately log-normal.
- The 95th percentile of predicted $CL_{nut}N$ is 1.2 times the mean: the mean is 1.3 times the 5th percentile. The probability distribution is approximately normal.

The uncertainty in $CL_{max}S$ (29%) corresponds to that found by Abbott *et al.* (2003) when calculating $CL_{max}S$ for a coniferous forested site. The smaller uncertainty in $CL_{min}N$ is due to the compensation of error mechanism described above.

The uncertainty in $CL_{nut}N$ is small when compared to the acid grassland result. This is due to the different method used for calculating CLnutN for managed coniferous woodland. A mass balance equation is applied to woodland habitats and is the sum of four parameters (Section 6.1.5). As all of the input parameters are assumed to be uncorrelated the compensation of error mechanism is seen.

Table 6.12. The deterministic, median, 5th and 95th percentile critical loads ($CL_{max}S$, $CL_{min}N$, $CL_{max}N$, $CL_{nut}N$) and coefficients of variation for managed coniferous woodland.

Critical load	Critical load values (keq ha^{-1} $year^{-1}$)*					Coefficient of variation (%)
	Deterministic	Median*	5th percentile	95th percentile	Standard deviation	
$CL_{max}S$	1.97	1.94	1.10	2.90	0.56	29
$CL_{min}N$	0.48	0.48	0.25	0.60	0.08	17
$CL_{max}N$	2.44	2.47	1.68	3.33	0.53	21
$CL_{nut}N$	0.76	0.73	0.56	0.88	0.10	14

* Similar results are obtained for the median and the deterministic because the inputs to the uncertainty analysis are centred around the default values used for the deterministic estimations. Therefore, when a stable output is reached using the Monte Carlo analysis, the median results are similar to the deterministic.

6.6 Effects of uncertainties in deposition on critical load exceedances

This section provides a summary of the uncertainty analysis to examine the effects of uncertainties in deposition data on critical load exceedances. This work has been published by Heywood *et al.* (2002). The analysis was carried out using the 2001 acidity critical loads (6 ecosystems) data and varying the deposition only. Two methods of uncertainty analysis were applied: a fixed value analysis and a Monte Carlo analysis and the methods and results are summarised below.

6.6.1 Fixed value analysis

The fixed value analysis provided best and worst case estimates of the habitat area exceeded and accumulated exceedance. This was used as a simple bounding calculation to determine the size of the effect we may expect. The analysis was performed using the measured 1995-97 (pre-March 2004 version) and modelled 2010 deposition scenarios. The deposition values were varied by $\pm 40\%$ over the entire country; this was considered to be a suitable range based on an assessment of uncertainty in UK deposition available at the time of the analysis (Smith *et al.*, 1995).

For both the fixed value and Monte Carlo analysis the following equation was used to determine the deposition values:

$$D_F = D_P \cdot (1 + F \cdot U) \qquad \text{Equation 6.6.1}$$

D_F is the value of the deposition value (either nitrogen or sulphur)
D_P is the original value of the deposition value (either nitrogen or sulphur)
F is a factor between -1 and 1
U is the uncertainty range (in this case 40%)

For the fixed value analysis the factor F was set to either -1 to give a best-case scenario (ie, deposition -40%), or 1 to give a worst-case scenario (ie, deposition + 40%). Exceedances were calculated and results for total area exceeded and accumulated exceedance (all 6 ecosystems combined) examined and compared with the deterministic exceedance values (Table 6.13).

Table 6.13. The exceedance results for the fixed value analysis, comparing the deterministic with the best and worse case scenarios.

Exceedance output	Scenario	Deposition Year	
		1995-97	2010
Area exceeded (km^2)	Deterministic	68 000	29 000
	Best Case	39 000	10 000
	Worst case	81 000	40 000
Accumulated Exceedance ($x10^3$ keq $year^{-1}$)	Deterministic	7 236	1 436
	Best Case	2 034	300
	Worst Case	13 288	3 500

The fixed value analysis showed that across the range of deposition uncertainty there was a considerable, non-linear relationship between the deposition and area exceeded and accumulated exceedance for both the 1995-97 and 2010 deposition scenarios. The results showed that the area exceeded in the year 1995-97 varied from +19% to -43% of the deterministic value. Accumulated exceedance varied within wider limits between +84% and -72%. Similar percentage changes are found for the 2010 deposition data. It should also be noted that the best case prediction for 1995-97 is similar to the worst case prediction in 2010 hence obscuring any improvements in ecosystem protection due to implementation of the Gothenburg Protocol. The wide bounds for area exceeded and accumulated exceedance predicted by the fixed value analysis suggested that further investigation was warranted, hence the Monte Carlo approach was also explored (Section 6.6.2 below).

The reasons behind the non-linearity in the fixed-value analysis are:
(i) Magnitude of exceedance and area exceeded. With the worst-case scenario where deposition inputs are increased by 40%, the magnitude of exceedance for habitat squares already exceeded will increase, but this will not increase the exceeded area of habitat. Hence the exceedance magnitude increases but not the area. The critical loads for additional habitat squares may become exceeded (by a small or large amount) and add to the exceeded habitat area. Conversely for the best case scenario, where deposition inputs are reduced by 40%, the magnitude of exceedance for exceeded habitat squares will reduce, but there will be no change in the exceeded

area. For some habitat squares the critical loads may no longer be exceeded and there will be a decrease in the total area exceeded.
(ii) Integration of magnitude of exceedance with exceeded area in the calculation of AE. To understand the non-linearity in AE values it should be remembered that AE is a product of both the exceeded area and *positive* values of exceedance. This is the reason that we see larger increases in AE than decreases. Table 6.14 below provides an example of the calculation of AE values for two illustrative grid squares and shows the effect of applying a best (deposition -40%) and worst (deposition +40%) deposition scenario on the calculation of AE. However, despite this non-linearity, because AE integrates both the magnitude of exceedance and the exceeded area it is a useful term for comparing the results of different scenarios.

Table 6.14. An example of calculating AE for a deterministic, best and worst case scenarios.

<table>
<tr><th>Method</th><th>Ecosystem area</th><th>Critical load</th><th>Deposition</th><th>Exceedance</th><th>AE
(area x exc)</th></tr>
<tr><td rowspan="2">Deterministic</td><td>3</td><td>1</td><td>1.5</td><td>0.5</td><td rowspan="2">1.5 + 0
= 1.5</td></tr>
<tr><td>3</td><td>2</td><td>1.5</td><td>None</td></tr>
<tr><td rowspan="2">Best case</td><td>3</td><td>1</td><td>0.6</td><td>None</td><td rowspan="2">0</td></tr>
<tr><td>3</td><td>2</td><td>0.6</td><td>None</td></tr>
<tr><td rowspan="2">Worst case</td><td>3</td><td>1</td><td>2.1</td><td>1.1</td><td rowspan="2">3.3 + 0.6
= 3.9</td></tr>
<tr><td>3</td><td>2</td><td>2.1</td><td>0.2</td></tr>
</table>

6.6.2 Monte Carlo analysis

For the Monte Carlo analysis the factor *F* in equation 6.6.1 above is set for each run by a random generator (separately for nitrogen and sulphur) and the deposition values calculated. The random generator was adjusted to give both uniform and triangular distributions. Sufficient repetitions (250) were carried out to achieve a stable output frequency distribution. The output uniform and triangular distributions were compared: the distributions for both were similar but smaller for the triangular distributions. This indicates that the assumptions made on the shapes of the input distributions were not important in this analysis. The results presented in this section are for the uniform distribution.

A cumulative frequency diagram describes the probability that a random variable X has a value less than or equal to a specified value x. An inverse cumulative frequency diagram is 100% minus the cumulative probability and gives the probability that the random variable X has a value greater than x. Inverse cumulative frequency diagrams were derived from the Monte Carlo results for area exceeded and accumulated exceedance. These are referred to as “Probability of Exceedance” curves and are shown in Figure 6.2(a) for the area exceeded and Figure 6.2(b) for accumulated exceedance. These curves allow us to read off how certain or confident we are that the value is exceeded, i.e., the probability of exceeding x.

The position of the top of the curve (Figures 6.2(a) and (b)) indicates the probability that the area exceeded or accumulated exceedance will exceed the amount shown on the x-axis is very close to 100%. This makes sense, because this value is the smallest of the Monte Carlo results – a minimum amount that we can be sure we will obtain.

As the area exceeded or AE is increased (ie, from left to right on graph), the probability of this value being exceeded begins to decrease. The horizontal hashed lines on the plot indicate the median (ie, 50%), 5% and 95% probabilities of exceedance. As the curve continues to decline and approaches 0% on the y-axis, the values on the x-axis become so large as to be highly unlikely to be exceeded.

Table 6.15. Area exceeded and accumulated exceedance values for the 5%, 50% and 95% probabilities of exceedance

Exceedance output	Probability of exceedance	Deposition Year	
		1995-97	2010
Habitat area exceeded ($km^{2)}$	5%	79 000	39 000
	50%	68 000	27 000
	95%	48 000	14 000
Accumulated exceedance ($x10^3$ keq $year^{-1}$)	5%	11 597	3 034
	50%	7 236	1 223
	95%	3 363	368

Table 6.15 shows that if we are willing to accept a low probability of exceedance (ie, 5%) for the 1995-97 scenario we would have to protect 16% more habitat area than with the median (50% exceedance probability); this means protecting 16% more than with our deterministic estimates, since the median from the Monte Carlo analysis gives similar results to the deterministic. The table also shows that, for the same probability of exceedance, the area exceeded for 2010 drops to between 30% and 50% of the 1995-97 values.

The results for the 5% probability of exceedance are similar to the worst case scenario of the fixed value analysis. However, there are larger differences between the results for 95% probability of exceedance and the best case scenario of the fixed value analysis; the best case gave consistently lower results than the 95% probability.

6.7 Methods for the visual presentation of uncertainties in critical load exceedances

This section summarises the methods developed to visually present uncertainties in critical loads exceedances and identify areas subject to different levels of risk. A draft manuscript of this work is provided in Appendix 2.

Various methods for visually presenting the uncertainty in exceedance were investigated using the February 2003 acidity critical loads data and HARM modelled deposition data (see Section 5.1.2). HARM models deposition data at 10km resolution and includes deposition estimates of wet and dry sulphur, oxidised and reduced nitrogen. Uncertainty information for HARM deposition data has been developed at Lancaster University using the Generalised Likelihood Uncertainty Estimation methodology (GLUE) and Wales as the case study area. A full description of the deposition uncertainty analysis can be found in Page *et al.* (2003) and a summary in Appendix 2 of this report. The results of this GLUE analysis currently provide the best estimate of deposition uncertainty. Over two thousand (2101) different estimates of wet and dry sulphur, nitrogen and ammonia deposition were supplied for each 10 km grid square in Wales as well as the interpolated 5^{th}, median and 95^{th} percentiles of the deposition distributions. The critical loads data (February 2003 version) were not varied in this uncertainty analysis as, at the time, the necessary information was not available. Four separate methods of representing the data were developed and are presented below.

6.7.1 Mapping exceedances for given levels of probability

The 5th, median and 95th percentiles of the distribution of deposition estimates were used to calculate and map critical load exceedances. The maps based on the 5th percentile (ie, low) deposition scenario (Figures 6.3a and 6.4a) represent the area exceeded and accumulated exceedance (AE) where we are 95% certain critical loads are exceeded. Conversely the maps based on the 95th percentile (ie, high) deposition scenario (Figures 6.3c and 6.4c) represent the area exceeded and AE where we are only 5% certain critical loads are exceeded. Therefore, the higher the percentile deposition used, the higher the area exceeded, but the less certain we are that the critical loads are actually exceeded; hence, we may say the probability of exceedance in these areas is low. Conversely, lower deposition results in smaller areas exceeded but a higher probability that the critical loads are exceeded. These points are clearly illustrated by the maps in Figure 6.3 and 6.4 where the exceeded area and AE increase from left to right (a-c) as the higher percentile deposition is applied. It should be noted that the maps presented in Figures 6.3 and 6.4 are not true "probability" maps, but rather the area exceeded or AE for a given level of probability as defined from the percentiles of deposition data used.

The maps in Figures 6.3 and 6.4 quantify the exceedance in terms of exceeded habitat area and AE. An alternative way of presenting these results is to generate semi-quantitative maps of the same data, to show three classes of exceedance risk:

- Not exceeded: grid squares that are **not** exceeded using 95th percentile deposition
- Exceeded: grid squares exceeded using 5th percentile deposition
- Uncertain: grid squares not exceeded using 5th percentile deposition but exceeded using 95th percentile deposition

An example three-class "exceedance risk" map is shown in Figure 6.5. Nearly 80% of the grid squares are classed as being exceeded. However, two points should be remembered when interpreting this map:

(i) The underlying critical loads data are at 1km resolution and each grid square can contain up to nine sensitive habitats. This means that if a single critical load for a single habitat within a 10km square is exceeded, the whole square is shown as exceeded, i.e. only one out of a possible 900 habitat critical loads within a grid square may be exceeded.

(ii) The magnitude of the exceedance or exceeded area is not taken into account using this method to map the data.

To investigate further the effect of point (i) above, a similar map was reproduced for a single habitat: managed coniferous woodland (Figure 6.6). The proportion of grid squares now classed as exceeded dropped to 58%, but in each square there may still only be one out of a possible 100 managed coniferous woodland critical loads exceeded.

The HARM deposition data used in these analyses were at 10km resolution. However, to explore the effect of using higher resolution deposition data, so the resolution of the exceedance risk map could be increased, a 5km version of the deposition data were generated by simply assigning the same deposition values to all four 5km squares in each 10km square, and re-calculating the exceedances. This reduced the number of possible managed coniferous woodland critical load values that could be exceeded to 25 in any one grid square. In this example (Figure 6.7) the percentage of exceeded squares was reduced to 37%.

These results clearly demonstrate the effects of (a) mapping exceedance information for single or aggregated habitats, and (b) resolution chosen to present the results.

The methods in Sections 6.7.2, 6.7.3 and 6.7.4 below address point (ii) above by utilising the 1km critical loads data for a single habitat (managed coniferous woodland) and individual exceedance values calculated using all percentiles of deposition (ie, all 2101 deposition estimates).

6.7.2 Cumulative distribution functions (CDFs) to communicate uncertainty

Figure 6.8 shows the CDFs of exceedance values obtained for a single 1km grid square of managed coniferous woodland. The red line shows the Monte Carlo exceedance predictions and the blue line the fitted normal distribution. The plot also shows the 5^{th} and 95^{th} percentiles of the distribution and the mean and standard deviation, and the line representing zero exceedance. The CDF is a common way of communicating the range of uncertainty for a single grid square. However, it would be a time consuming task to generate a CDF for each 1km grid square of the UK and such information is too complex to represent on a map. Kämäri *et al.* (1993) have aggregated uncertainty data to map CDFs for each EMEP 150 km square, but even at this scale, the maps are not easy to interpret visually.

6.7.3 Using standard deviation classification

For this approach the exceedance data were classified by calculating the range for two standard deviations above and below the mean value for each 1km grid square. If this lower end of the range was greater than zero the grid square was classed as exceeded, if the higher end of the range was less than zero the grid square was classed as not exceeded, and all other grid squares were classed as uncertain (Figure 6.9). In this example most of the grid squares in Wales fall in the uncertain category. Further map categories could be defined by using intervals at other (eg, 1, 0.5 or 0.25) standard deviations.

6.7.4 Mapping the probability of exceedance

The method presented in Section 6.6.1 mapped exceedances for given levels of probability. The method presented below uses the distributions of exceedance values based on all the different percentiles of deposition, to determine and map the probability of exceedance.

An example for a single grid square can be given by referring to Figure 6.8. The probability of exceedance can be calculated as 100% minus the cumulative percentage of the exceedance distribution that is above zero (ie, exceeded), which in this case equals 97.5%, so the probability of exceedance equals 2.5% (100 – 97.5).

To apply this methodology at the UK scale, CDFs would need to be calculated for every 1km grid square, which would be computationally demanding. Instead the mean and standard deviation of the exceedance distribution for each grid square were used to create a standard normal distribution. From this the probability of exceedance was calculated and mapped for each 1km managed coniferous woodland square in Wales (Figure 6.10). This map shows that less than 9% of the coniferous woodland area in Wales exhibits a more than 95% probability of being exceeded and that nearly 80% of the forest has a probability of between 5 and 95% of being exceeded.

6.8 Effects of uncertainties in critical loads and deposition data on critical load exceedances

This section summarises the uncertainty analysis that incorporates estimates of uncertainties in both critical loads (February 2003 version) and deposition (1995-97, pre-March 2004 version) in the calculation of critical load exceedances. A paper on this work is currently in preparation.

The assessment of uncertainty in deposition estimates is a continuing task. Although a complete assessment of the uncertainty in measured deposition has not been carried out, scientists who produce the data have recently given their expert judgement as to the range the uncertainty should take. A subjective assessment suggests that a 95% confidence band around the deposition estimate for given 5 km square of ±30% is probably over optimistic, ±50% is optimistic and ±100% is quite likely. A normal distribution has been assumed. The uncertainty analysis presented in this Section has used the optimistic estimate (ie, ±50%) of uncertainty for every 5 km grid square of the UK for sulphur and nitrogen deposition. Smith *et al.* (1995) report that there is spatial auto-correlation in the national deposition data sets, with larger uncertainties expected in upland regions. However, spatial auto-correlation is not included in the analysis carried out here, as it is yet to be quantified. The Pearson product moment correlation coefficient (r) between each pair of nitrogen and sulphur estimates for each 5km grid square was 0.6 and a correlation coefficient of 0.6 was used in the analysis.

Monte Carlo analysis was carried out using the uncertainty ranges, distributions and correlations for critical loads ($CL_{max}S$, $CL_{min}N$, $CL_{max}N$ and $CL_{nut}N$) for acid grassland and managed coniferous woodland as previously calculated and discussed (Section 6.5) and the deposition data as described above.

Output distributions of exceedances were generated for every 1km grid square which contained either acid grassland or managed coniferous woodland. The probability of exceedance was calculated from the exceedance distributions for each grid square using the mean and standard deviation for each grid square and assuming the exceedance data to be normally distributed. The results of these analyses are presented in Figures 6.11 to 6.14, using the same exceedance probability mapping method described in Section 6.7.4.

The acid grassland map (Figure 6.11) shows that for acidity 75% of the habitat has a very high probability (>95%) of exceedance and only 5% of the habitat has a very low probability (<5%) of exceedance. For nutrient nitrogen (Figure 6.12) only 22% of the acid grassland habitat has more than 95% probability of exceedance; these areas are mainly confined to Cumbria, the Pennines, north and south Wales, the moorland areas of Devon and Cornwall and some areas in eastern Northern Ireland. Very low probabilities (<5%) of exceedance for nutrient nitrogen are observed for 17% of the habitat, mainly in northern Scotland.

The coniferous woodland map (Figure 6.13) shows that for acidity most (61%) of the habitat has a 25-75% probability of exceedance. For nutrient nitrogen (Figure 6.14) the probability of exceedance is above 95% for 82% of the habitat.

The exceedances for acid grassland are generally higher than those for managed coniferous woodland and therefore the probabilities of exceedance are also higher for acid grassland.

The exceedance statistics for the deterministic, <5% and >95% probabilities are presented in Table 6.16 below.

Table 6.16. Acidity and nutrient nitrogen exceedance statistics for the UK for deterministic, <5th and >95th probabilities.

Exceedance	Habitat	Habitat area (km^2)	Habitat area (km^2) exceeded		
			Deterministic	<5% probability	>95% probability
Acidity	Acid grassland	15 288	13 203	653	11 450
	Conifer wood	7 972	5 849	887	957
Nutrient nitrogen	Acid grassland	15 236	10 241	1 728	2 205
	Conifer wood	7 970	7 415	31	6 562

6.9 Assessing the impacts of scale on the calculation of critical load exceedances

This section highlights the impacts of scale in critical loads or deposition data on the calculations of critical load exceedances. It should be noted that the analyses presented here are based on various sets of historical critical loads and deposition data, as different parts of this work were carried out at different times during the contract. It should also be noted that the term “percentile”, when used to refer to percentile critical loads, has a different derivation and meaning from the distribution percentiles used in the earlier parts of Section 6 of this report. The definition of percentile critical loads is provided in Section 6.9.1 below.

6.9.1 Effects of scale and statistic of critical loads data

Percentiles are a common statistic used to summarise critical load values for different habitat types, or for aggregating critical loads data to a larger grid size. Percentiles set the critical load to a value to protect a specified percentage of the habitat area represented, for example, a 5^{th}-percentile critical load is the value that will protect 95% of the sensitive habitat area in a given grid square. Percentile critical loads are calculated by generating a cumulative frequency distribution of the habitat areas against critical load values (for a single or multiple habitats) which are ranked from the lowest to highest value. At the point where the required percentage of the total habitat to be protected is reached, the corresponding percentile critical load is set.

For this analysis 1km and 5km resolution 5^{th}-percentile critical loads ($CL_{max}S$, $CL_{max}N$, $CL_{min}N$ and $CL_{nut}N$) for all habitat types combined (except freshwaters) were calculated from the February 2004 1km habitat critical loads data. Figure 6.15 shows the 5^{th}-percentile $CL_{max}S$ maps; both the 1km and 5km maps show the same broad patterns of critical load values, however, aggregating data to 5km resolution tends to increase the area of the country with lower critical load values, due to how the 5^{th}-percentile is calculated (ie, ranking of critical loads from low to high).

Critical load exceedances were calculated using the 1km and 5km 5^{th}-percentile critical loads with the 1995-97 (March 2004 version) 5km deposition data, to examine the impacts of data statistic and scale. For both calculations the average deposition values for all habitat types were applied. The resulting two acidity exceedance maps (Figure 6.16) show the same broad patterns of exceedance. However, the 5km map gives the impression of larger areas of the country being exceeded, for example in central Scotland where many squares are mapped as not exceeded on the 1km map, but exceeded on the 5km map. A simple comparison of the results is given in Table 6.17 below, showing the number of 1km and 5km squares occurring in each exceedance class.

Table 6.17. Comparison of the number and percentage of grid squares in each exceedance class for exceedance maps based on 1km and 5km 5^{th}-percentile critical loads.

Exceedance class (ranges in keq ha^{-1} $year^{-1}$)	Number and percentage of 1km squares exceeded by class		Number and percentage of 5km squares exceeded by class	
	Number	Percentage	Number	Percentage
Not exceeded	72947	39.5%	2465	23.7%
< 0.5	38888	21.0%	2401	23.0%
0.5 – 1.0	30093	16.0%	2462	23.6%
1.0 – 2.0	34534	18.7%	2519	24.0%
> 2.0	8123	4.0%	569	5.0%
Total exceeded	111638	60.5%	7951	76.3%

The differences observed in Table 6.17 are not that large for individual exceedance classes, although the exceedance map based on 5km 5^{th}-percentile critical loads shows 15.8% more squares exceeded. The differences between the two sets of results may be smaller or greater if habitat area exceeded was considered, instead of just the number of grid squares exceeded.

6.9.2 Effects of deposition data scale

The effects of using national and European scale deposition data on the calculations of critical loads exceedances have been investigated using a deposition scenario for 2010. Deposition data covering the European region is mapped by EMEP (European Monitoring and Evaluation Programme) using their long-range transport models. At the time of this analysis the spatial resolution of the EMEP data was 150 km^2. The EMEP deposition values available at the time, and used in the European-scale calculations of critical load exceedances were the means for all vegetation types; data for individual vegetation or habitat types were not available. The national deposition data available at the time were from two UK models:
(i) FRAME provided 5km resolution deposition of sulphur, oxidised and reduced nitrogen for three ecosystems: all vegetation types (average), moorland and woodland.
(ii) HARM provided 10km resolution deposition of sulphur, oxidised and reduced nitrogen as averages for all vegetation types.
It should be noted that as this analysis was carried out early in the contract, the critical loads data used were those for 2001, ie, prior to the move to mapping critical loads for the BAP Broad Habitats.

The percentage area of ecosystems exceeded using the three different deposition data sets were compared with each other and with the results from the UNECE integrated assessment modelling outputs from the RAINS model (Table 6.18)

Table 6.18. Comparison of percentage of ecosystems exceeded for acidity and nitrogen using different deposition data sets

Deposition data (2010) used	% ecosystem area exceeded	
	Acidity	Nutrient Nitrogen
UK FRAME 5km ecosystem-specific	43.8	27.6
UK HARM 10km average	10.4	1.5
EMEP 150 km average	10.2	0.9
RAINS (using 150km EMEP data)	9.2	1.3

These results of this comparison show:

- The percentage areas of critical load exceedance are similar when using EMEP data and HARM modelled deposition and also compare favourably with the output from the RAINS model at the time.
- The use of EMEP deposition underestimates the areas of sensitive ecosystems exceeded in the UK, both for acidity and for nutrient nitrogen, when compared with the FRAME modelled ecosystem-specific deposition. The FRAME deposition gives the best estimate of areas exceeded in the UK, since the data are the highest resolution (5km) and also ecosystem-specific. Average values of deposition may underestimate the deposition to some ecosystems, particularly to woodland.
- The use of EMEP data suggest that acidification and eutrophication will not be a significant problem in the UK by 2010 – a direct contrast to the national scale results based on the best estimates of ecosystem-specific deposition.

It should be noted that since this analysis was carried out in 2002, the EMEP model has been updated from:

- a Lagrangian to a Eulerian model
- 150km resolution to 50km resolution
- average deposition values for all vegetation types to separate deposition fields for woodland and other habitats. This area of work is ongoing within EMEP to make use of consistent land cover data for the whole of the European region in applying the ecosystem-specific parameters to the models.

The latest version (2004) of HARM, at 10km resolution for the UK, also now provides ecosystem-specific deposition values of sulphur, oxidised and reduced nitrogen.

Updates to both EMEP and HARM to include ecosystem-specific deposition estimates are likely to have a significant effect on the exceedance calculations for the UK if the analysis above were repeated. The latest exceedance calculations based on February 2004 critical loads and the latest FRAME modelled 2010 deposition (NECD scenario) result in 47.3% of sensitive BAP Broad Habitats being exceeded for acidity and 49.2% exceeded for nutrient nitrogen (Hall *et al.*, 2004d).

6.10 Conclusions from the assessment of uncertainties

The sections below summarise the key findings from the formal assessment of uncertainties in critical loads and their exceedances.

6.10.1 Sensitivity analyses

The sensitivity analysis of the critical load equations (using the 2001 data sets) led to the following conclusions:

- The simple mass balance (SMB) equation used for the calculation of acidity critical loads for woodland ecosystems was most sensitive to the critical chemical criterion (molar ratio Ca:Al in soil solution) and base cation and calcium weathering rates
- The most influential parameter on the calculation of $CL_{max}S$ was the acidity critical load whether calculated using empirical (eg, for acid grassland) or SMB (eg, for woodlands) methods.
- $CL_{min}N$ was most sensitive to nitrogen uptake for calcareous grassland, heathland, coniferous and deciduous woodland. Acid grassland was less sensitive to nitrogen uptake as the value for this habitat is smaller.
- $CL_{max}N$ was influenced by the same parameters identified as having the greatest effect on $CL_{max}S$ and $CL_{min}N$.
- $CL_{nut}N$ for coniferous and deciduous woodland was most sensitive to the nitrogen uptake and nitrogen leaching terms.
- The deposition data (pre-March 2004 version of 1995-97 data), especially total nitrogen, dominated the variance in critical load exceedances.

6.10.2 Uncertainty ranges

Plausible ranges of input parameters and their uncertainties have been identified based on a literature survey, collected data, and interviews with experts on the parameter of interest. The values applied in the UK uncertainty analysis presented in this report are summarised in Table 6.19 below.

Table 6.19 Summary of the uncertainty estimates and ranges identified in the inputs to UK critical load calculations, together with the reference/source for their justification.

Critical loads parameter	Uncertainty ranges[#]	Distribution	Justification
Base cation and calcium deposition	± 50% (site specific estimate)	Normal	Abbott *et al.* (2003)
Base cation uptake	Managed conifer ± 23% Managed broadleaved ± 14%	Normal	Experimental data; see Appendix 1
Base cation weathering	100 eq ha^{-1} yr^{-1} = ± 100% 350 eq ha^{-1} yr^{-1} = ± 43% 750 eq ha^{-1} yr^{-1} = ± 33% 1500 eq ha^{-1} yr^{-1} = ± 33% 4000 eq ha^{-1} yr^{-1} = ± 50%	Uniform	Langan *et al.* (1995)
Nitrogen uptake	Managed conifer ± 27% Managed broadleaved ±7%	Normal	Experimental data, see Appendix 1
Nitrogen immobilisation	more mineral soils 0.5-1.5 kg N ha^{-1} yr^{-1} more organic soils 1.5-4.5 kg N ha^{-1} yr^{-1}	Uniform	Sverdrup *et al.* (1990) Emmett & Reynolds (1996)
Acceptable nitrogen leaching	Managed conifer: 1-5 kg N ha^{-1} yr^{-1} Managed broadleaved: 1-3 kg N ha^{-1} yr^{-1}	Triangular Mode = 4 kg N ha^{-1} yr^{-1} for conifers Mode = 3 kg N ha^{-1} yr^{-1} for broadleaved	Emmett *et al.* (1993) and Emmett & Reynolds (1996)
Denitrification	0.5 - 1.5 kg N ha^{-1} yr^{-1} for aerated soils 1.5-2.5 kg N ha^{-1} yr^{-1} for sites with waterlogged soils and low deposition 2.5-5.5 kg N ha^{-1} yr^{-1} for sites with waterlogged soils and high deposition.	Uniform	Grennfelt & Thornelof, 1992 (Appendix 1)
Runoff	± 23%	Normal	Arnell *et al.* (1990)

Gibbsite coefficient	± 20%	Uniform	Suutari *et al.* (2001)
Critical BC:Al (Ca:Al) in soil solution	± 50%	Uniform	Cronan & Griegal (1995)

Uncertainty ranges defined as follows:
(i) Where a uniform distribution is assumed the uncertainty range is quoted as ± x %:
Minimum value = mean value - x% * mean value
Maximum value = mean value + x % * mean value
(ii) Where a triangular distribution has been assumed the range is quoted as –x% to + y:
Minimum value = most likely value – x % * most likely value
Maximum value = most likely value + y% * most likely value
(iii) Where a normal distribution has been assumed a coefficient of variation is quoted as x%:
x = (mean value / standard deviation) * 100

The mean and most likely values of the distribution have been assumed to be the default values

6.10.3 Uncertainty in the calculations of critical loads

The empirical estimates of acidity critical loads for soils are based on the dominant soil in each 1km grid square according to the national soil databases. For England and Wales the critical load values for all soil types in each 1km square were examined and this showed that for:

- 20% of squares the critical load remained the same as the dominant soil
- 25% of the squares the critical load could be lower than the dominant soil
- 29% of the squares the critical load could be higher than the dominant soil
- 16% of the squares the critical load could be lower or higher than the dominant soil.

The uncertainties in $CL_{max}S$, $CL_{min}N$, $CL_{max}N$ and $CL_{nut}N$ were investigated for two representative ecosystem types. Statistics calculated for the means of the national data showed:

(i) For acid grassland:

- The 95th percentiles of the predicted critical loads ($CL_{max}S$, $CL_{min}N$, $CL_{max}N$, $CL_{nut}N$) varied between 1.2 to 1.4 times greater than the mean value.
- The 5th percentiles of the predicted critical loads ($CL_{max}S$, $CL_{min}N$, $CL_{max}N$, $CL_{nut}N$) varied from 0.5 to 0.8 of the mean value.
- Coefficients of variation varied between 13 and 27%.
- The probability distributions of the critical loads approximated to uniform and normal distributions.

(ii) For coniferous woodland:

- The 95th percentiles of the predicted critical loads ($CL_{max}S$, $CL_{min}N$, $CL_{max}N$, $CL_{nut}N$) varied between 1.2 to 1.5 times greater than the mean value.
- The 5th percentiles of the predicted critical loads ($CL_{max}S$, $CL_{min}N$, $CL_{max}N$, $CL_{nut}N$) varied from 0.5 to 0.8 of the mean value.
- Coefficients of variation varied between 14 and 29%.
- The probability distributions of the critical load approximated to normal and log-normal distributions.

Overall the coefficients of variation were narrower than what might be intuitively assumed. This may be the result of optimistic assumptions about input data. However, considering all input parameters together reduces uncertainty because of a "compensation of errors" mechanism (see Section 6.5).

6.10.4 Effects of uncertainties in deposition on acidity critical load exceedances

The effects of uncertainties in deposition on acidity critical load exceedances were assessed using 1995-97 and 2010 deposition scenarios and two methods, fixed value analysis and Monte Carlo analysis. The key conclusions are:

(i) Fixed value analysis:

- There is a non-linear relationship between deposition and habitat area exceeded or accumulated exceedance.
- The habitat area exceeded varied from +19% (worst case scenario) to -43% (best case scenario).

- The accumulated exceedance varied from +84% (worst case scenario) to -72% (best case scenario).

(ii) Monte Carlo analysis:

- A 5% probability of exceedance requires the protection of 16% more habitat area than the results for 50% probability.
- A 95% probability of exceedance requires the protection of 42% less habitat area than the results for 50% probability.
- The 5% probability results are similar to the worst case scenario of the fixed value analysis.
- The best case scenario of the fixed value analysis gave consistently lower areas exceeded and AE values than the 95% probability results.

6.10.5 Effects of uncertainties in critical loads and deposition data on critical load exceedances

This analysis was carried out for acid grassland and managed coniferous woodland using the February 2003 critical loads data and the pre-March 2004 version of the 1995-97 deposition data. Monte Carlo analysis showed:

(i) For acid grassland:

- For acidity, 75% of the habitat had a very high (>95%) probability of exceedance and 5% of the habitat had a very low (<5%) probability of exceedance.
- For nutrient nitrogen, 22% of the habitat had a very high (>95%) probability of exceedance and 17% of the habitat had a very low (<5%) probability of exceedance.

(ii) For managed coniferous woodland:

- For acidity, 61% of the habitat had a 25-75% probability of exceedance.
- For nutrient nitrogen, 82% of the habitat had a very high (>95%) probability of exceedance.

6.10.6 Effects of data scale on the calculation of critical load exceedances

Two small studies examined the impacts of data scale (critical loads and deposition) on critical load exceedances. The key findings were:

- The acidity exceedance map based on 5km 5th-percentile critical loads showed 15.8% more grid squares to be exceeded than the exceedance map based on 1km 5th-percentile critical loads. For both maps the 1995-97 deposition data (March 2004 version) were used. The differences that would be observed in terms of habitat area exceeded and accumulated exceedance for the two maps were not quantified.
- Using the UK FRAME 5km ecosystem-specific deposition for 2010 increases the habitat area exceeded by ~34% (acidity) and ~28% (nutrient nitrogen) compared to using either national 10km or EMEP 150km average (or non-ecosystem specific) deposition. The EMEP deposition are used in the assessment of critical loads exceedances at the European scale and at the time of the study underestimated the areas exceeded compared to the UK results. Since this work was carried out the EMEP model has been updated to include ecosystem-specific deposition at a finer resolution (50km).

6.10.7 Visual presentation of uncertainties

Critical load exceedances have commonly been mapped to show the magnitude of exceedance, the habitat area exceeded and the accumulated exceedance. Under this contract four methods were explored for the visual presentation of critical load exceedances and the uncertainties associated with them:

- Mapping exceedances for given levels of probability, in terms of habitat area exceeded, accumulated exceedance or three-class exceedance risk maps (eg, Figures 6.3 and 6.4).
- Cumulative distribution functions to communicate uncertainty information for a single grid square (eg, Figure 6.8).
- Classifying and mapping exceedance data from Monte Carlo analysis based on the mean and standard deviation values for each 1km grid square (eg, Figure 6.9).
- Mapping the probability of exceedance (eg, Figure 6.10).

Each method has its advantages and disadvantages and therefore feedback from policy makers will help determine the method(s) of presentation best suited to their needs.

7. RELATED ACTIVITIES

This section documents activities carried out that are related to the National Critical Loads Mapping Programme, but not part of the contract.

7.1 Related projects

7.1.1 Comparison of SEI and CEH national land cover maps

This work was carried out as part of Defra contract EPG 1/3/173 led by the Stockholm Environment Institute at York. A joint meeting was held to discuss the aims of the project and the CEH Land Cover Map 2000 (LCM 2000), to help determine the relationships between the CEH and SEI land cover classes. The NFC then provided the SEI with the percentage area of each of the 27 CEH land cover classes in each EMEP 50 x 50km grid square of the UK. The SEI analysed and compared these data with their own map and reported their findings in a report to Defra (SEI, 2003).

7.1.2 EA Site relevant critical loads

The aim of this EA funded project was to assign site-relevant critical load values to the designated features of Special Areas of Conservation (SACs) and Specially Protected Areas (SPAs). The work was carried out by the UK NFC in collaboration with a number of UK critical load experts. The designated features of SACs and SPAs can be habitats or species and at that time the national critical loads data (February 2001) were only available for six broad ecosystem types. The following approach was agreed with the EA:
(i) Determine whether the designated feature(s) is sensitive to acidification and/or eutrophication.
(ii) Where possible associate the designated features (habitats/species) with one or more of the six ecosystem types.
(iii) Where the features could be associated with critical load ecosystems, assign the national critical loads data to each site polygon. Critical loads values were only assigned where the national ecosystem critical loads data coincided with the site polygons.
(iv) Calculate the minimum, maximum and area-weighted mean acidity (empirical, mass balance, CLmaxS, CLminN, CLmaxN) and nutrient nitrogen (empirical, mass balance) critical loads for each SAC/SPA site polygon. Import data into database.
(v) Provide full database and reports, including caveats on the use of national critical loads data for this work.

The results of this study were reported by Hall *et al.* (2001b, 2001c). In addition to identifying the number of site features and polygons that critical loads could be assigned to, the report highlighted technical and scientific problems encountered in this approach; the key points were:

- The inconsistencies in the format and labelling of the JNCC SAC/SPA boundary data.
- The problems encountered in converting these boundary data from ArcView shapefiles to ArcInfo coverages for automated analyses.

- The lack of spatial information on the location of designated features within SAC/SPA site polygons.
- The implications of using national data for site-scale applications.

7.1.3 Critical Loads Scoping Study

Following on from the requirement by the Environment Agency and JNCC for site relevant critical loads for assessing sites for the Habitats Directive, we have begun work on a CEH funded project to look into potential methods for deriving site-specific critical loads. A total of 18 SACs of different size, location and characteristics have been identified for study. Initially two sets of critical loads data are being compiled for each site polygon:

(i) Minimum, maximum and mean critical loads from the 1km national habitat-masked critical loads data sets.

(ii) Minimum, maximum and mean critical loads from the 1km national critical loads data sets that have no habitat masks applied.

Further work will include making use of high resolution digital land cover and soils information to assign appropriate critical loads across the sites. The critical loads derived from a number of approaches using the data outlined above will be compared and contrasted to help determine the way forward.

In addition, a proposal has been sent to the Environment Agency for consideration for work related to the Habitats Directive. This builds on some preliminary investigations into soil and habitat relationships that suggest a way forward for improving our assignment of critical loads at the habitat level. Added to this are two statistical techniques (empirical Bayesian model, Dempster-Shafer method) that could provide us with appropriate methods to improve our estimates of critical loads at the site level, of use for screening designated sites. Note that this proposed work does not involve developing critical load models for specific application at the site scale.

7.1.4 Developing effects based approaches for heavy metals

The development of effects based approaches including critical loads for heavy metals is carried out under Defra contract EPG 1/3/188 led by Bradford University. The UK NFC is responsible for developing the appropriate national scale databases to implement critical load methods and models for heavy metals within a GIS framework. Preliminary heavy metal critical loads data (cadmium and lead) were submitted to the CCE in March 2002 (Hall *et al.* 2002), though these data are not intended for any policy use. Further developments in the methods have been made since then and these are summarised in the latest contract report to Defra (Ashmore *et al.*, 2003). A call for data from the CCE is expected in the Autumn 2004 and the UK NFC intends to submit data for cadmium and lead based on the most up to date methodologies as in Ashmore *et al.* (2003) and the UNECE Mapping Manual.

7.2 Meetings

The UK NFC has contributed to the activities of APRIL (Air Pollution Research in London) and promoted the work of the NFC at University seminars as described below.

7.2.1 APRIL

Jane Hall has attended a number of the APRIL meetings over the last two years. The work of the NFC has been brought to the attention of APRIL, as well as the use of the European Nature Information System (EUNIS). In addition a presentation was made to them on the UK National Biodiversity Network (NBN), which may provide a mechanism for them to record species data from their projects.

7.2.2 University seminars

The UK NFC was invited to give seminars at Lancaster University and Manchester Metropolitan University (MMU). Liz Heywood presented the work of the NFC at Lancaster (February 2003) and Jane Hall gave the presentation to MMU (March 2003). The presentations included information on the February 2003 update to the national critical loads and following the presentation at MMU, the ARIC group have included a link to the UK NFC web site from their “Atmosphere, Climate & Environment” web site.

8. FUTURE WORK

The following areas of future work have been identified by the UK National Focal Centre (NFC) and proposed to Defra:

- To continue to play a role in the development of critical loads methodologies through the representation of the NFC on the International Cooperative Programme on Modelling and Mapping.
- To continue to maintain and update the national critical load (and dynamic modelling) databases.
- To update the national steady-state critical loads as new data and knowledge become available and to maintain consistency with dynamic modelling activities.
- To provide national critical loads (steady-state and dynamic model outputs) data to the Coordination Centre for Effects as required by the work plan of the UNECE Working Group on Effects, for the further development and implementation of protocols under the LRTAP Convention.
- To maintain and update the NFC web site to provide transparency of the data and methods used in UK critical loads activities and for the dissemination of critical loads and related data.
- To advise Defra and the devolved administrations on the impacts, in terms of exceeded sensitive habitats and designated areas, of current and future emission and deposition scenarios, especially for the review of the National Emissions Ceilings Directive and the Gothenburg Protocol.
- To develop automated methods for the routine generation of probabilistic estimates of critical load exceedance for different emission and deposition scenarios.
- To compare and contrast critical load exceedance statistics based on the national 5km ecosystem-specific deposition with exceedance statistics using the new EMEP ecosystem-specific deposition data.
- To identify the key parameters in the critical loads models likely to be affected by climate change and to quantify the effects through sensitivity analyses and the potential impacts on critical load exceedance estimates.
- To compare the new harmonised land cover map being developed for CLRTAP activities across Europe with the national-scale Broad Habitat maps developed for UK critical loads work.
- To develop habitat maps required for UK critical levels work using methods analogous to those used to develop the Broad Habitat maps for UK critical loads activities.
- To carry out a desk study to determine the requirement to update or extend the UK habitat maps for UK critical loads and levels work to other sensitive ecosystems.
- To propose and carry out a “contribution-in-kind” study, involving the multilateral cooperation of other NFCs, to determine the methods other countries are using or developing to assess the threats from acidification and eutrophication to Natura 2000 sites.

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APPENDIX 1

Draft manuscript:

A Review of Uncertainties in Inputs for UK Acid and Nutrient Nitrogen Critical Loads Calculations

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APPENDIX 2

Draft manuscript:

Visual Presentation of Uncertainty in Critical Load Exceedances Across Wales

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