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Critical Loads and Dynamic Modelling

Final Report

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Chris Evans, Jane Hall, Ed Rowe, Julian Aherne, Rachel Helliwell, Alan Jenkins, Mike Hutchins, Jack Cosby, Simon Smart, David Howard, Dave Norris, Malcolm Coull, Allan Lilly, Muriel Bonjean, Richard Broughton, Susannah O'Hanlon, Elizabeth Heywood and Jackie Ullyett

Centre for Ecology and Hydrology/Canolfan Ecoleg a Hydroleg
Environment Centre Wales/Canolfan yr Amgylchedd Cymru
Deiniol Road/Ffordd Deiniol
Bangor, Gwynedd
LL57 2UW
United Kingdom

Tel: (0)1248 374500

EXECUTIVE SUMMARY

- For the first time, this project has produced national-scale dynamic model predictions of the effect of sulphur (S) and nitrogen (N) deposition on the acidification and eutrophication of sensitive terrestrial ecosystems at a 1km resolution (over 230,000 individual model simulations). The model applications build directly on, and augment, current critical loads, permitting scenario analysis of the timescales of damage and recovery, and calculation of target loads for deposition in order to achieve acceptable ecosystem (chemical) status by a given target date
- For acidification, model simulations are shown to reproduce observed recovery trends at monitoring sites, and generally predict continuing recovery of both soils and surface waters through to 2010 under current legislated emissions reductions (CLE). Beyond 2010, less additional recovery is predicted under a CLE scenario, with a substantial proportion of all modelled ecosystems failing to achieve acceptable chemical status by 2030. Greater emissions reductions under a Maximum Feasible Reduction (MFR) scenario would generate significant further recovery, although a proportion of sites may not recover by 2030 even with these stringent emissions controls (most notably for bogs, which are slow to recover, and for forested areas where deposition remains relatively high).
- Target loads for recovery from acidification have been generated for all habitats. These are particularly useful for ecosystems which will not recover sufficiently by a given target under current legislation, but *could* recover by this date given more stringent emissions controls. Target loads provide a tool for optimising the combinations of S and N emissions controls that will lead to the greatest improvement in ecosystem status by a given date.
- For nitrogen, models appear successful in reproducing observed response to ecosystem manipulation experiments, provided that they allow for the effect of N on carbon accumulation. They are less able to reproduce short-term (mainly climate-driven) variability. In many ecosystems, continuing N deposition in excess of the critical load is predicted to lead to long-term increases in N leaching that may be only partially or temporarily offset by (fairly modest) currently legislated decreases in N emissions.
- At the national scale, models predict the greatest present-day N leaching in high-deposition areas of England, the Welsh and Scottish borders, and southeast Northern Ireland. CLE emissions reductions are sufficient to reduce average N leaching by 2030, but leaching rates will remain high in many forested areas, and a significant proportion of heathlands and acid grasslands. More stringent reductions in N emissions under the MFR scenario are predicted to generate dramatic ($\geq$ 50%) further reductions in N leaching across all habitats and regions.
- Site specific model applications have been used to develop and test models; improve parameterisation; assess the extent of spatial heterogeneity as a source of model uncertainty; examine the potential impact of habitat management (for heathlands in particular); and predict the likely impacts of climate change on acidification and eutrophication. Results suggest that appropriate management may slow the rate of eutrophication, but is unlikely to fully offset the detrimental impacts of elevated N deposition. The impacts of climate change are complex and uncertain, but again model simulations suggest that these impacts may be small relative to, and/or interactive with, the effects of anthropogenic S and N deposition.
- A new surface water dataset collected for the North York Moors National Park, and calibrated in MAGIC, demonstrated very severe levels of (mainly sulphate-driven) acidification in this acid-sensitive, previously under-studied region close to major emission sources. Given the severity of acidification, slow rates of recovery, and the additional detrimental effects of afforestation in some areas, it is predicted that much of the National Park may not return to acceptable chemical status under current leglislation

- The quality of model outputs at both site and national scales is critically dependent on the quality and quantity of input data. Long-term monitoring and experimental data provide the basis for improved process understanding and model testing. Continued, and where necessary new, data collection are vital in order to provide a robust basis for large-scale model applications, and to reduce uncertainties in predictions.
- Critical load exceedances for acidification have been calculated for current (2002-2004) deposition, and indicate that 56% of the area of sensitive habitats remains exceeded for acidity, and 60% for nutrient N. FRAME deposition predictions for 2020 reduce these exceeded areas to 41% for acidity and 48% for nutrient N. Deposition time series for 1970- 2020 indicate a 50% fall in the area of sensitive habitats exceeded for acidity over this time period. Predicted reductions in the area exceeded for nutrient N are smaller (21%); ammonia deposition currently makes the greatest contribution to both acid and total N deposition
- Scenario analyses for the Air Quality Strategy show a further decrease in critical load exceedance by 2020; 'Scenario R', based on reductions in NOx from traffic, and SO_2 and NOx from shipping, would reduce the area exceeded by a further 3.3% for acidity and 4.8% for nutrient N relative to the baseline 2020 scenario. Scenario analyses for the RIA Marine Fuels Directive, focused on reductions in S deposition of (4.6% - 7.8%) indicated that the most stringent scenario would result in a 1% (824 km^2) decrease in the habitat area exceeded for acidity compared to the baseline dataset.
- Air quality objectives for SO_2 and NO_x and the WHO limit for NH_3 concentrations were examined for the Air Quality Strategy in relation to designated areas. A proposed lower limit for SO_2 (10µg m^{-3}) resulted in <1% of the area of designated sites outside the exclusion zone being exceeded. The NH_3 limit was exceeded in <0.1% of the area of designated sites even when using modelled concentration data for 2020.
- The project has continued to provide UK representation to activities under the Convention on Long-Range Transboundary Air Pollution as follows:
    - Chairing and organising annual meetings of the Joint Expert Group on Dynamic Modelling, including organisation of a one-off workshop on modelling nitrogen and its impact on biodiversity
    - Acting as National Focal Centre for the ICP on Mapping and Modelling, attending annual meetings and participating at workshops of the Coordination Centre for Effects (CCE). Critical load and dynamic model outputs have been submitted in response to CCE calls for data in 2004/05 (updated critical loads and dynamic model target loads for freshwaters); 2006/07 (terrestrial and freshwater dynamic model scenario assessments, empirical nitrogen critical loads for UK Special Areas of Conservation, sites which form part of the European Natura 2000 network of designated sites to be protected by the EU Habitats Directive)
    - Acting as National Focal Centre for the ICP on Integrated Monitoring, attending annual meetings and contributing to dynamic model assessments of the impact of climate change on surface water recovery from acidification and target loads.

Work Package 1: Dynamic modelling of UK soils

PI: Chris Evans. Contributors: Ed Rowe, Jane Hall, Rachel Helliwell, Simon Smart, Dave Norris, David Howard and Malcolm Coull

1.1 Summary

- A dataset of 53 MAGIC-calibrated terrestrial sites has now been compiled, providing a vital resource for model testing and development, in support of national modelling.
- MAGIC has generally proven effective at reproducing observed acidity changes at acid-sensitive long-term monitoring sites, and observed C and N responses at N addition experiments. Successful N simulations require incorporation of N-induced vegetation and soil C accumulation at most sites. MAGIC is less successful in predicting trends at acid-insensitive sites, where (unlike at acid-sensitive sites) changes in S and N deposition may not be the main factors determining acidity.
- Climatic variations, including variations in temperature, water flux, drought occurrence, and seasalt deposition, all influence short-term variations in acidity and/or N leaching. Some of these effects can be effectively modelled, but challenges remain in modelling short-term variability in N leaching, and in predicting the longer-term impacts of climate change.
- Site management has the potential to reduce the impacts of N deposition on terrestrial ecosystems, but heathland model simulations suggest that above-ground biomass removal (burning or mowing) only partly offsets N accumulation due to deposition, and the more intensive practice of turf stripping may have detrimental impacts (increased future N leaching) as well as the intended benefits (removal of soil N)
- Site-specific model applications have demonstrated significant small-scale heterogeneity in ecosystem sensitivity to eutrophication and acidification, within both an upland montane transect (Allt a'Mharcaidh) and a single soil/vegetation class (CEH oak wood survey). National-scale modelling cannot be expected to reproduce this local heterogeneity based on default sets of input parameters, and therefore national model outputs (like critical loads) must be viewed as an indication of average ecosystem response, rather than specific predictions for individual locations. Higher-resolution input data (e.g. for soils) would however be expected to improve the local predictive power of national models.
- The VSD model has, for the first time, been applied at UK-wide scale, based on the 1km critical loads dataset, with additional model input data collected during the project. The model has been used for target load calculation and scenario assessments, with outputs submitted to the 2006/07 CCE call for data.
- Model outputs reproduce observed regional patterns of terrestrial acidification and eutrophication across the UK, with near-pristine conditions in Northern Scotland and severe acidification and eutrophication of sensitive ecosystems in high deposition areas such as Central and Northern England. Acidity target load assessments demonstrate that it may be difficult, and in some cases impossible, to achieve recovery to acceptable chemical status on a timescale of decades, particularly in poorly buffered ecosystems such as bogs, where replenishment of soil base status is likely to be very slow.
- A comparison of VSD simulated and Countryside Survey measured pH and C/N ratio showed generally weak positive correlations, with no clear deviation between simulated and observed values. This, and the consistency of national-scale outputs with general observations of the spatial distribution of acidification and N enrichment, provide some encouragement with regard to model performance. However, the VSD simulations generally did not reproduce the range of variability observed in the CS dataset, which may be attributable to the issues of local heterogeneity noted above.

- For the first time, VSD outputs of soil acidity and nitrogen content have been used to generate national-scale predictions of changes in habitat suitability for a number of Common Standards Indicator species using GBMOVE. This approach has great potential for forecasting the effects of deposition change on terrestrial biodiversity, both separately and in combination with changes in land management and climate.

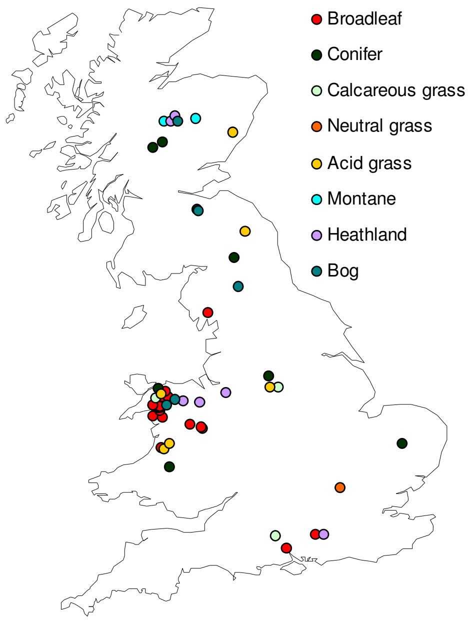
1.2 Description of Work

1.2.1 Site-based model application and testing

Sites with high quality measurements provide an important basis for model development and testing, particularly where either long-term monitoring or experimental data are available to assess the capability of the models to reproduce observed changes. In total, MAGIC has now been calibrated to 53 terrestrial sites, including all sensitive critical load habitat classes (Figure 1.1).

At a number of sites, it has additionally been possible to investigate the impacts of climatic factors, and different management strategies, on recovery from acidification and N soil enrichment. Together, the site-based model applications form an important dataset for national-scale model parameterisation and testing. The following summarises results for the main new applications; due to space limitations this summary focuses on key scientific and policy-related conclusions from each study.

Figure 1.1 Terrestrial MAGIC site applications

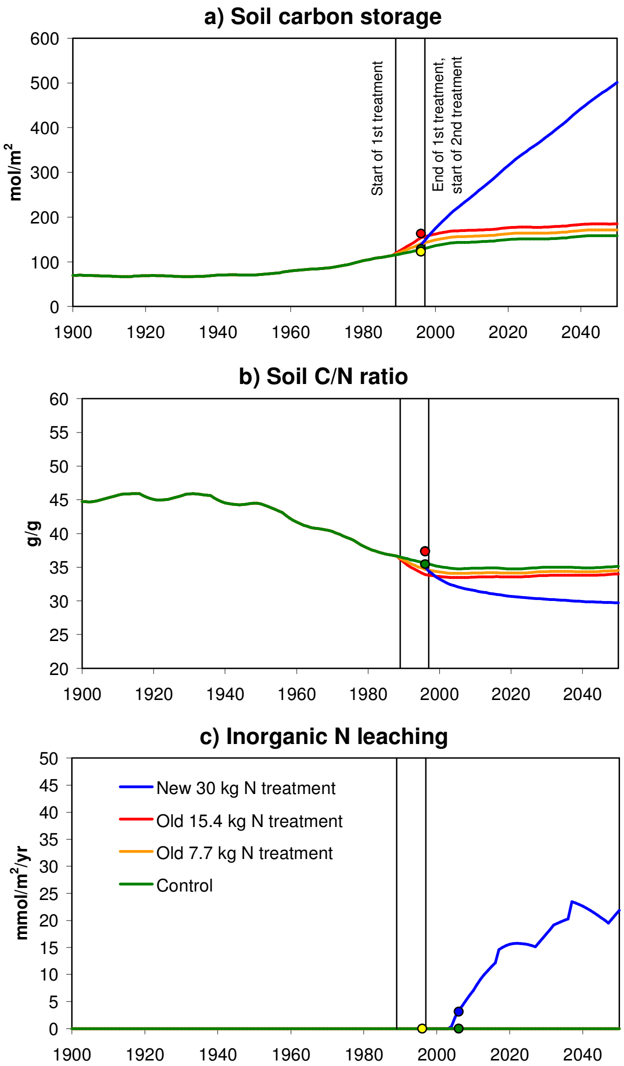


1.2.1.1 MAGIC application to Thursley Common N addition experiment

Previous MAGIC model applications to the Ruabon and Budworth N addition experiments showed that soil and plant C accumulation had slowed rates of ecosystem C/N decline and the onset of N leaching (Evans et al., 2006a). New soil solution data and detailed measurements of soil and biomass C and N stocks for the Thursley N addition experiment, have now permitted a similar model application to be undertaken for this site. The model was applied to a) control plots; b) ‘low’ 7.4 kg N/ha/yr addition plots, to which $(NH_4)_2SO_4$ was added from 1989 to 1996, with no additions thereafter; c) ‘high’ 15.4 kg N/ha/yr addition plots, which operated over the same period; and d) ‘new’ N addition plots, which have been subject to 30 kg N/ha/yr from 1998 to the present day (for the model, these additions were assumed to continue into the future). Applications assumed complete removal of above-ground biomass on a 20-year cycle (equivalent to the ‘low intensity mow’ carried out in the experiment). Two developments on earlier versions of the model were that the (measured) increase in biomass growth under N addition was incorporated in the model, and C and N losses via dissolved organic matter were also incorporated.

Results (Figure 1.2) suggest that Thursley was in approximate N balance under pre-1950 deposition levels, that soil C/N declined thereafter. The (relatively small) amount of N added by the 1989-1996 treatments essentially accelerated this process, but did not trigger N leaching. The model effectively reproduces the observed increase in soil C storage in the high plots, with a calibrated ratio of C accumulation per unit N addition (C/N_{SEQ}) similar to Ruabon. The model was unable to reproduce the apparent *increase* in C/N measured in both 'low' and 'high' N treatments. This increase is surprising, and the result of apparently higher mineral soil C/N beneath the N treatments. Litter C/N, in on the other hand, did decrease in response to treatment, consistent with predictions. Plans to resample Thursley soils in order to check the validity of earlier soil C/N measurements were hindered by the unplanned burn that affected the site during 2006. Future model predictions suggest no further deterioration of either N leaching or C/N at the 'old' plots, but illustrate the legacy effect of previous N additions on C/N. Applying the calibrated parameters to the ongoing 30 kg N addition suggested that this highly level of treatment may cause more severe N enrichment and trigger N leaching, with a breakthrough C/N leaching threshold of 32.5 g/g.

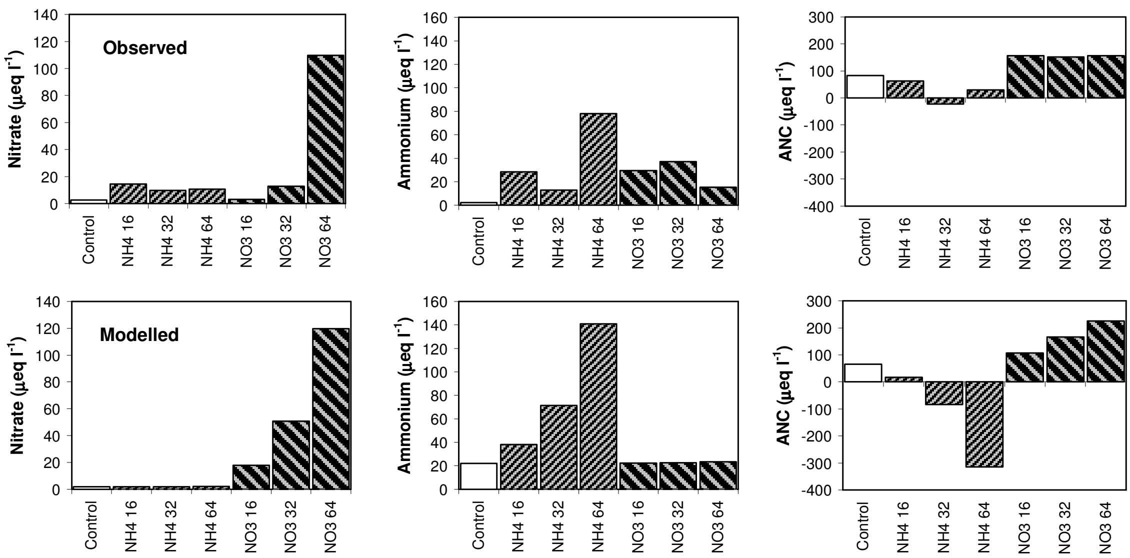
Figure 1.2. MAGIC simulations, Thursley N experiment



1.2.1.2 MAGIC application to Whim Bog N addition experiment

MAGIC has been calibrated to a one-year set of ambient soil solution from an area of peat adjacent to the Whim N addition experiment. The calibrated model was then run for the range of different wet N treatments in the experiment (three levels of NH_4Cl and three levels of $NaNO_3$ addition). Full measured soil solution data from the treatment plots are currently only available for May 2005, so the comparison with model outputs must be considered preliminary. However the results (Figure 1.3) suggest that MAGIC reproduced the direction of NO_3, NH_4 and ANC change well, the magnitude of response to $NaNO_3$ additions reasonably well, and the magnitude of response to NH_4Cl less well (responses were generally over-predicted). The model correctly predicts that the $NaNO_3$ treatment reduces plot acidity, which occurs because much of the NO_3 is retained, leaving an excess of Na which, as a base cation, increases ANC. The NH_4Cl addition has the opposite effect, because NH_4 is retained (or nitrified), leaving an excess of the acid anions Cl and NO_3 which suppress ANC. This acidity change in response to experimental N addition is an essentially inevitable consequence of adding separate N forms, and is important to take into account when assessing the impact of reduced versus oxidised N forms on vegetation based on experimental data. In terms of the sensitivity of bog habitats to N enrichment, the Whim results suggest a surprisingly large leaching response, since organic matter rich ecosystems typically leach low levels of NO_3 (Evans et al., 2006b). The exception to this general pattern occurs in the South Pennines, where bogs appear to be highly N-saturated, but both model simulations and observations suggest that experimentally-enhanced N additions at Whim have quite rapidly triggered enhanced N leaching from the peat.

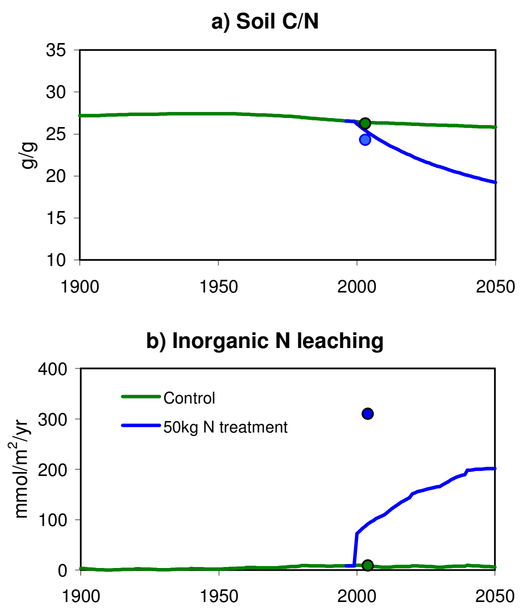
Figure 1.3. Observed and modelled soil solution response to N addition, Whim



1.2.1.3 MAGIC application to Culardoch N addition experiment

The Culardoch experimental site is the first N addition experiment located in a montane ecosystem at which it has been possible to calibrate MAGIC. It is located on an area of prostrate *Calluna-Cladonia* heath (NVC H13) on sub-alpine podzol at 750m asl in the eastern Cairngorm mountains. The experimental set up comprises factorial combinations of N addition, burning and grazing. In 2000 the control plots and those receiving a high N treatment (50 kg N ha^{-1} yr^{-1}) were instrumented with tensionless lysimeters. Data from 2004-2005 were used to calibrate the model. Under ambient N deposition, the model suggests that C/N has decreased slightly since about 1960 (the C pool was modelled as constant through the period). Maximum inorganic N leaching (10 mmol/m^2/yr) was simulated in 2000, following this decline in C/N ratio, and relatively high N deposition in the 1990s.

Figure 1.4 MAGIC simulations, Culardoch N experiment



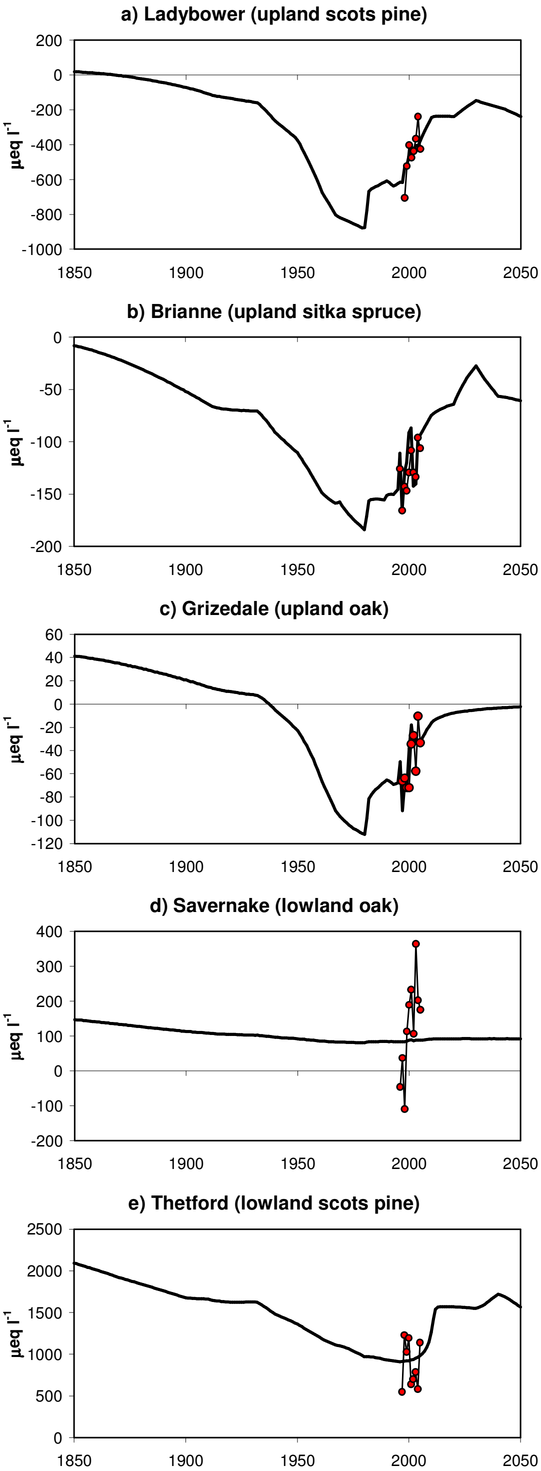
The montane Culardoch site has, in the past, received less N deposition than most other sites in the UK. The 50 kg N ha^{-1} yr^{-1} addition is therefore very large, and both soil C/N and soilwater leaching showed a remarkable and immediate response to N addition. In 2000, soil C/N ratio was measured at 26.5 g/g, but it had declined significantly, to 24.4 g/g, following 3 years of the high N treatment. This sharp decline was simulated with some success by the model (Figure 1.4). The projection to 2050 shows a further dramatic decline in the C:N ratio under continued treatment. The model was unable, however, to reproduce the extreme N leaching response to the 50 kg N addition. As formulated, the model assumes a uniform (annual) input of N, all of which is available to be immobilised. However, it is probable that very large, discrete N applications to this fragile ecosystem could either have a toxic impact on soil microbes, overwhelm the rates at which the microbial population can immobilise N in the short term, or simply bypass the soil (and hence immobilisation) in water transported via soil cracks or macropores. It is likely that some of these issues (which are to some extent experimental artefacts) would be less pronounced at lower (more realistic) N doses, so following this initial model application it was decided to install lysimeters at the lowest N addition level of 10 kg N ha^{-1} yr^{-1}. Lysimeters were installed in October 2006 and sampling began in April 2007. It is anticipated that the response of the soil to this lower N addition will result in a more gradual N enrichment of the soil and a slower release of N to soil water. In summary, the Culardoch site should ultimately provide a valuable addition to the current suite of modelled N addition experiments (the first for a montane ecosystem). Results are quantitatively consistent with the model, but further experimental data are required to produce a more reliable model simulation.

1.2.1.4 MAGIC recalibration to Forest Level II sites

MAGIC was calibrated to 9 Forest Level II sites in the previous TU. For this project, 5 sites with sufficiently long datasets for model testing were recalibrated with the updated version of the model, and incorporating year-to-year fluctuations in seasalt deposition, which are an important cause of inter-annual acidity variability. This recalibration exercise was described in detail in the 2006 Annual Report; plots of modelled and observed ANC are shown in Figure 1.5. In summary, MAGIC ANC predictions were very close to observed annual means at the three acid upland sites (Grizedale, Ladybower and Brianne) over a period of major chemical change, providing some confidence in long-term hindcasts and forecasts. Future predictions show sustained recovery at the Grizedale oak site, albeit to still-negative ANC levels, and some re-acidification at the two conifer sites, associated with predicted increases in (already high) NO_3 leaching at Ladybower, and base cation depletion (due to forest uptake) at Brianne.

The model did not reproduce observed ANC variability at the alkaline, lowland Savernake and Thetford sites. These data suggest that changes in acid deposition are not the major cause of ANC variation at these acid-insensitive sites. At these sites, major controls on ANC variability are more likely climate-related variations in base cation supply from weathering, and hydrological fluctuations which control solute concentrationsin soil water. These factors were not incorporated in the model simulations, but since they appear to be far less important at acid sites (i.e. those at which acidity predictions are relevant) this is not considered a high priority. At both acid and alkaline sites, few trends in soil solution nitrogen were observed, and again these appeared (on the 10-year timescale of the monitoring data) to be largely associated with climatic variability rather than N deposition (which was relatively constant during this period).

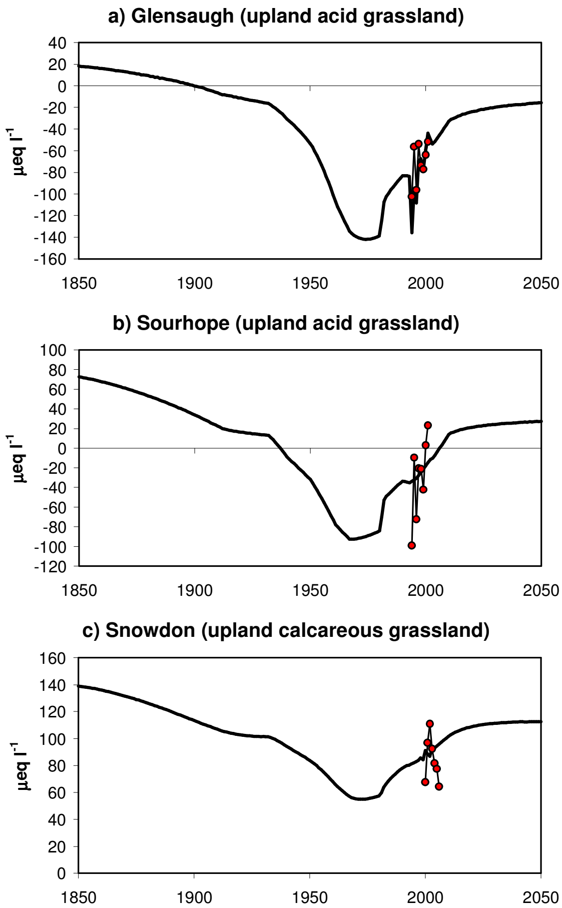
Figure 1.5. MAGIC ANC simulations, Forest Level II sites



1.2.1.5 MAGIC application to ECN sites

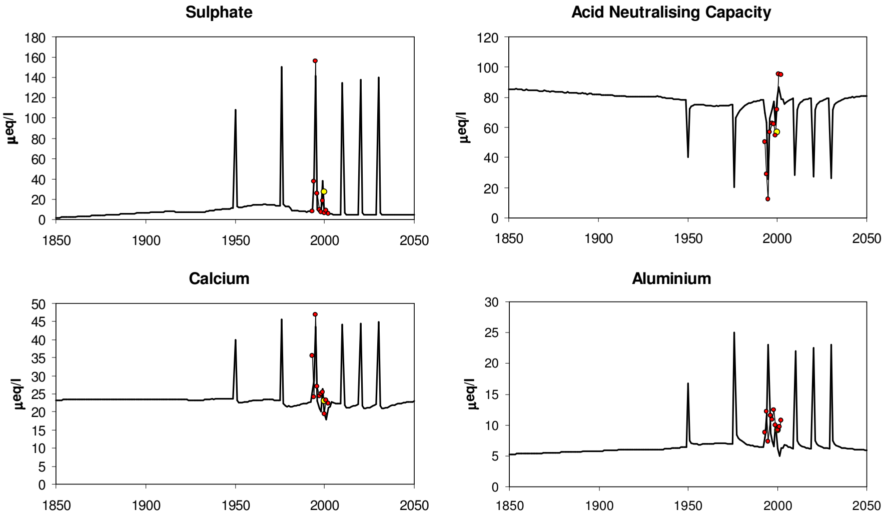
In addition to the Forest Level II sites, long soil solution monitoring data now exist for a number of ECN sites. Those in deposition-sensitive ecosystems are Moor House (blanket bog), Sourhope and Glensaugh (both upland acid grassland) and Snowdon (upland calcareous grassland). New MAGIC calibrations were undertaken for these sites, following the same procedures applied to the Forest Level II sites. Summary ANC simulations for Glensaugh, Sourhope and Snowdon (deeper soil solution samplers) are shown in Figure 1.6. Overall, a good model simulation of all ions was observed for Glensaugh, reproducing the expected acidification recovery trends. Simulation of ion changes at the less acidic Sourhope was generally poorer, but investigation suggests that was a consequence of remarkably large observed decreases in almost all major ions, including SO_4 (to a greater extent than would be expected from decreases in S deposition) and Cl (which cannot be explained in terms of variations in sea-salt deposition). Discrepancies between modelled and observed chemistry at Sourhope therefore appear to be associated with the model inputs (i.e. S deposition trends) rather than the internal model processes, and suggests that further investigation of the observed data is required. At the calcareous Snowdon site, temporal trends in ANC (and other ions) do not correspond particularly well to deposition trends, suggesting that climatic variability may be more important here, as at the alkaline Forest Level II sites.

Figure 1.6. MAGIC ANC simulations, ECN sites



For the Moorhouse peat site, a simple calibration of MAGIC did not provide an acceptable fit to observations. Again, this was associated with climate-related factors, in this case to the influence of periodic droughts on SO_4 leaching. In peats (unlike UK mineral soils, where S is close to conservative in most catchments), large quantities of S can be accumulated in reduced form within organic matter, buffering the peats against acidification. However, this store can be remobilised by oxidation if the peat becomes dry, and acid flushes after droughts have been shown to counteract recovery from acidification in Canadian wetland catchments. At Moor House, SO_4 concentrations are usually near-zero, but severe acid SO_4 pulses have been noted after droughts, most notably in 1995 (Adamson et al., 2001). Wetland S dynamics can be optionally simulated in MAGIC, and application to Moor House (Figure 1.7) successfully reproduced SO_4 peaks during the 1994, 1995 and 1999 droughts, and clearly captured much of the variation in other ions that occurred in response. For illustrative (rather than strictly predictive) purposes, severe '1995-like' droughts were simulated in 1950, 1976, 2010, 2020 and 2030.

Figure 1.7. MAGIC simulation for Moor House ECN site (upland blanket bog), incorporating sulphate storage and remobilisation during droughts.



These results have some significant implications for modelling acidification and recovery in peatlands. In an average year, because most sulphate is retained, the acidity of soil solution at Moor House may be close to natural background levels. However gradual S accumulation in the peat has made the system sensitive to increasingly large (e.g. 1995 vs. 1950) acidic pulses in response to droughts. Because the stores of S are large, this risk is likely to persist into the future despite reduced sulphur deposition, and to be sensitive to climate change: increased drought severity and frequency may be expected to lead to more frequency and damaging acid SO_4 pulses.

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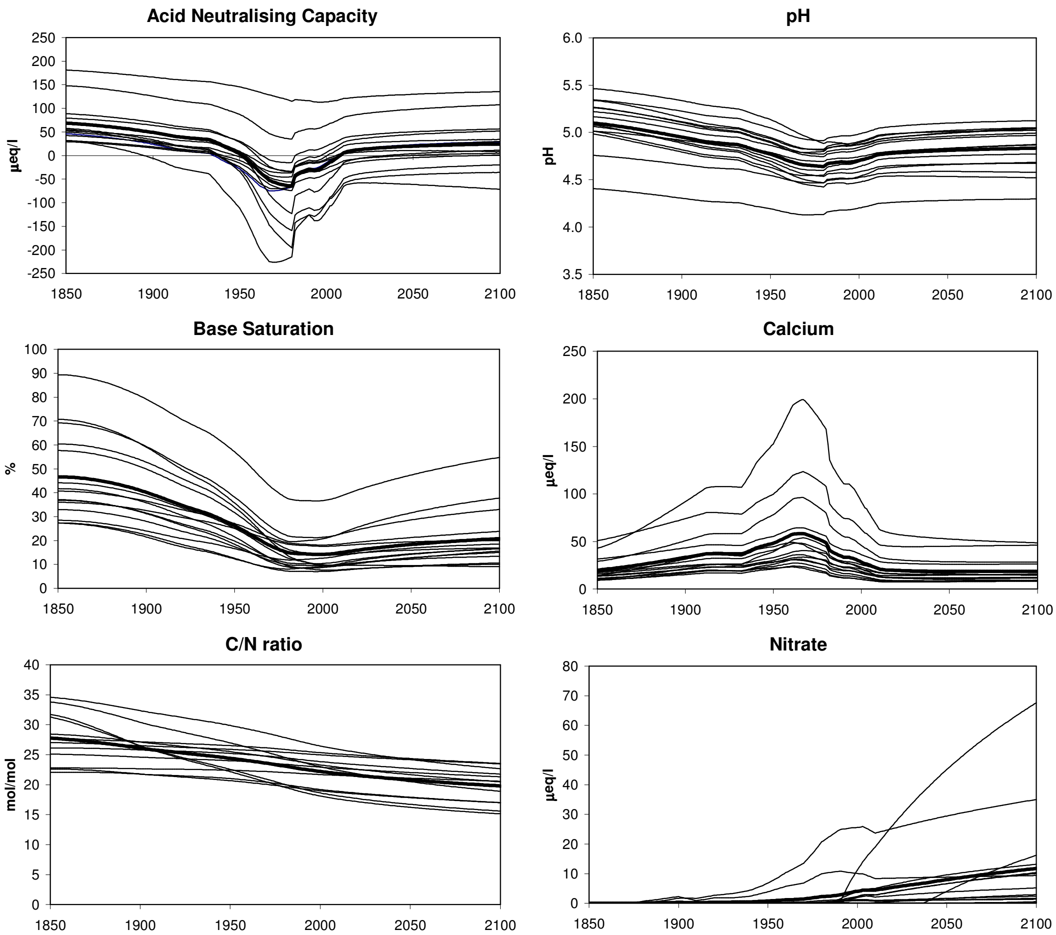
1.2.1.6 MAGIC application to CEH Oak Wood sites

A survey of 19 Welsh oakwoods was undertaken by CEH Bangor during 1998 (Williams et al., 2000) The dataset is unique within the UK, in that MAGIC can be calibrated to detailed and consistent measurements at multiple locations within a single acidification- and eutrophication-sensitive habitat (Atlantic oak woodland) and soil type (brown podzol). While the single year of data do not permit model testing against long-term trends, comparison of calibrated model parameters (such as weathering rates) and future model predictions at individual sites is informative with regard to the likely accuracy of predictions made when scaling up from sites to regional and national scales. All sites were calibrated using an identical procedure, against measured soil and mean soil water chemistry for that site. Of the 19 sites, 4 were influenced by historical land management, so that soil chemistry did not reflect current deposition inputs. While these sites nevertheless follow the expected trajectory of N leaching versus C/N ratio (and other expected ecosystem responses to elevated N such as plant species change), modelling these sites is problematic without more information on historic management and associated N inputs, and these sites were therefore excluded from subsequent assessment.

The MAGIC simulations for the 15 remaining sites, and the mean of these simulations, is shown in Figure 1.8. Overall, ANC and pH simulations for the majority of sites fall within a fairly narrow range. The most acid sites are characterised by higher present-day acid anion concentrations, whereas the less acid sites are those with above-average base cation buffering, as is evident from the Ca simulations shown. A few sites already leach some NO_3, but most had low observed concentrations (< 5 µeq l^{-1}) and at these sites future increases are predicted to be small and gradual. Nevertheless, according to the model, median soil C/N among the 15 sites fell from 23.8 g/g in 1850 to 19.8 in 1998, and will continue to decline to 17.0 by 2100; these changes would be potentially sufficient to cause significant changes in ground flora.

Figure 1.8 MAGIC simulations for CEH oak wood survey sites



The multiple calibrations to a single soil and vegetation type allow an assessment of MAGIC-calibrated model parameters with the default values being used in the national VSD application, described below. A key parameter is the base cation weathering rate, for which the critical load default for this soil type is 20-50 meq m^{-2} yr^{-1}. Five of the calibrated oak sites fall into this range, with the remainder having higher MAGIC-calibrated estimates (median of all 55 sites 69 meq m^{-2} yr^{-1}). Some hetereogeneity is inevitable given variability in geology, land-use history, and potentially also buffering by flow from upslope (Atlantic oak woods typically occur on steep valley sides). The comparison suggests that critical load default values provide a reasonable precautionary estimate of weathering for this soil type, i.e. will be effective in protecting the more acid sensitive areas of this soil within a grid square. Clearly, it would be beneficial to undertake a similar analysis for other major habitat/soil types, but as yet sufficient data to calibrate multiple sites in any one category are not available. The model-calibrated median threshold C/N at which NO_3 leaching is initiated was 23 g/g, with most sites falling within a fairly narrow range around this value (50% of sites had a calibrated threshold between 21 and 25.5 g/g). A relationship between C/N ratio and both NO_3 leaching and N mineralisation has previously been noted for the oak wood dataset (Williams et al., 2000). Although these sites form a part of the analysis of N leaching versus C/N ratio by Rowe et al. (2006), the C/N breakthrough threshold for all broadleaf sites in this study was lower (18 g/g). This suggests that upland oak woods may be susceptible to N leaching at a higher C/N than the other (mostly lowland) broadleaf sites included in this analysis. More species- or soil-type specific default parameters would therefore be desirable. In general, this may be difficult to implement given that critical loads vegetation classes do not distinguish this level of detail. However, Atlantic oakwoods *are* treated separately in terms of critical loads for nutrient N, and it may therefore be both feasible and beneficial to derive a specific set of default parameters from MAGIC calibrations for use in future VSD applications to this particular habitat type.

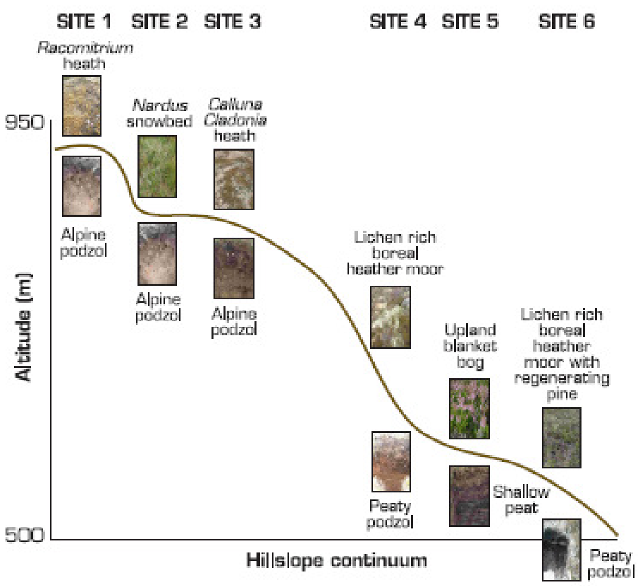
1.2.1.7 MAGIC application to Allt a'Mharcaidh transect study

At the Allt a'Mharcaidh in the Cairngorms, five sites have been studied along a hillslope continuum, allowing spatial controls on nutrient cycling and N leaching to be analysed within the model. The starting hypothesis is that N leaching in a montane environment increases with altitude, as i) N deposition is higher, and ii) harsher conditions in the alpine zone suppress plant growth and soil development, providing a smaller organic matter pool for N immobilisation. Downslope, larger carbon pools, higher C/N ratios and lower levels of deposition are expected to result in less N leaching. The location of the sites is shown as an idealised cross-section in Figure 1.9, and characteristics summarised in Table 1.1.

Table 1.1. Environmental data for the five Allt a'Mharcaidh transect sites

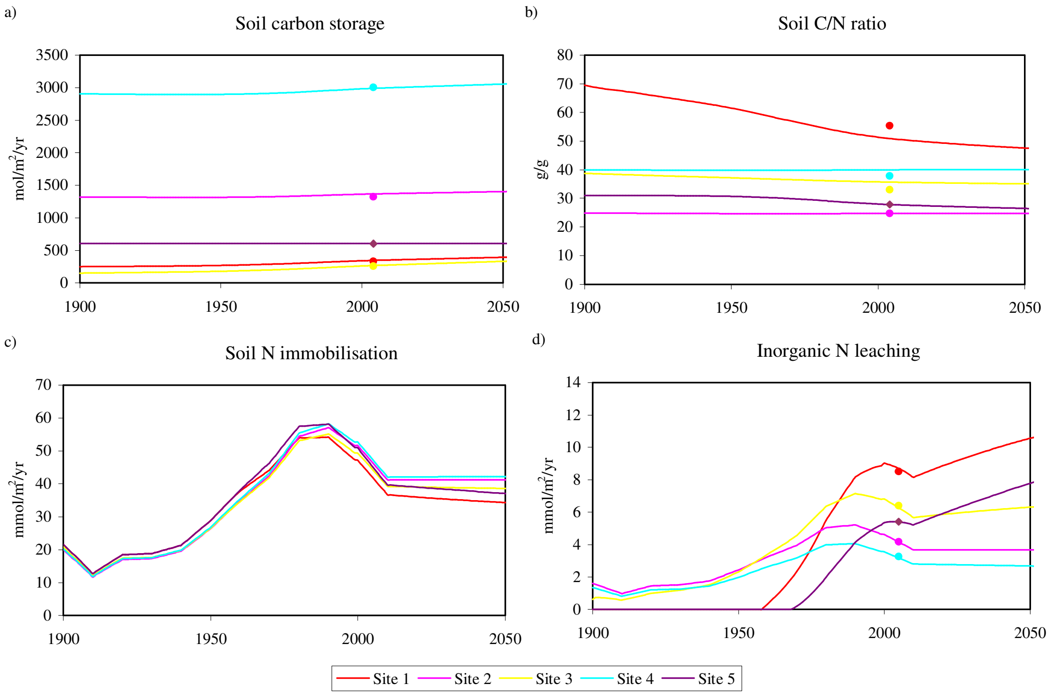
	Site 1	Site 2	Site 3	Site 4	Site 5
Soil Type	Alpine podzol	Alpine podzol	Alpine podzol	Peaty podzol	Shallow peat
Vegetation	*Racomitrium* heath	Snowbed (*Nardus strictus*)	*Calluna Cladonia* heath	Lichen rich boreal heather moor	Upland blanket bog
Altitude (m)	908	882	794	640	621
Soil C (mol/m^2)	334	1319	260	3005	606
Soil C/N (g/g)	55.3	24.7	33.0	37.8	27.9
NO_3 (µmol/l)	2.8	2.1	3.3	1.9	2.0
NH_4 (µmol/l)	5.7	2.1	3.1	1.4	3.4
DON (µmol/l)	20.7	21.4	15.0	20.7	22.9

Figure 1.9. Idealised cross-section of the Mharcaidh hillslope showing soils and vegetation change with altitude *(Site 6 is new, and not included in this study)*



MAGIC simulations (calibrated to 2005 data, Figure 1.10) reflect the highly heterogeneous nature of mountain environments in terms of N deposition, soil C stocks, and the effect of these on the timing and magnitude of N leaching. The model simulates significant N-induced increases in C stocks at sites 1 (45%) and 3 (64%) from 1900 to 2050. Sites with smaller C pools are more responsive to changes in N deposition, and soil C/N ratios decline more rapidly at these sites. Sites 2, 3 and 4 have above-zero modelled soil water N concentrations in 1900, but appear less responsive to change due to greater N immobilisation capacity so that future soil water N concentrations at these sites are forecast to remain stable. Although site 5 has the greatest total C pool in this study (4287 mol/m^2), the reactive pool that is responsible for the immobilisation of N is small (606 mol/m^2) reflecting the very low bulk density of the biologically active upper horizons (64 kg/m^3 to a depth of 23cm). At this site, a modelled decrease in C/N ratio triggered the onset of N leaching during the 1950s. A similar situation is simulated at site 1, except that the N leaching is occurring at this site despite a very high present-day C/N ratio of 55 g/g, indicating a very high susceptibility of these thin alpine soils to N deposition. Soil C/N is actually simulated to have been considerably higher in the past, and although the model suggests some C accumulation due to N deposition this has not been sufficient to buffer the site against N accumulation. Future model predictions at sites 1 and 5 suggest that N leaching will increase further as a result of the continued decline in the soil C/N ratio.

Figure 1.10 MAGIC simulations, Allt a'Mharcaidh catchment



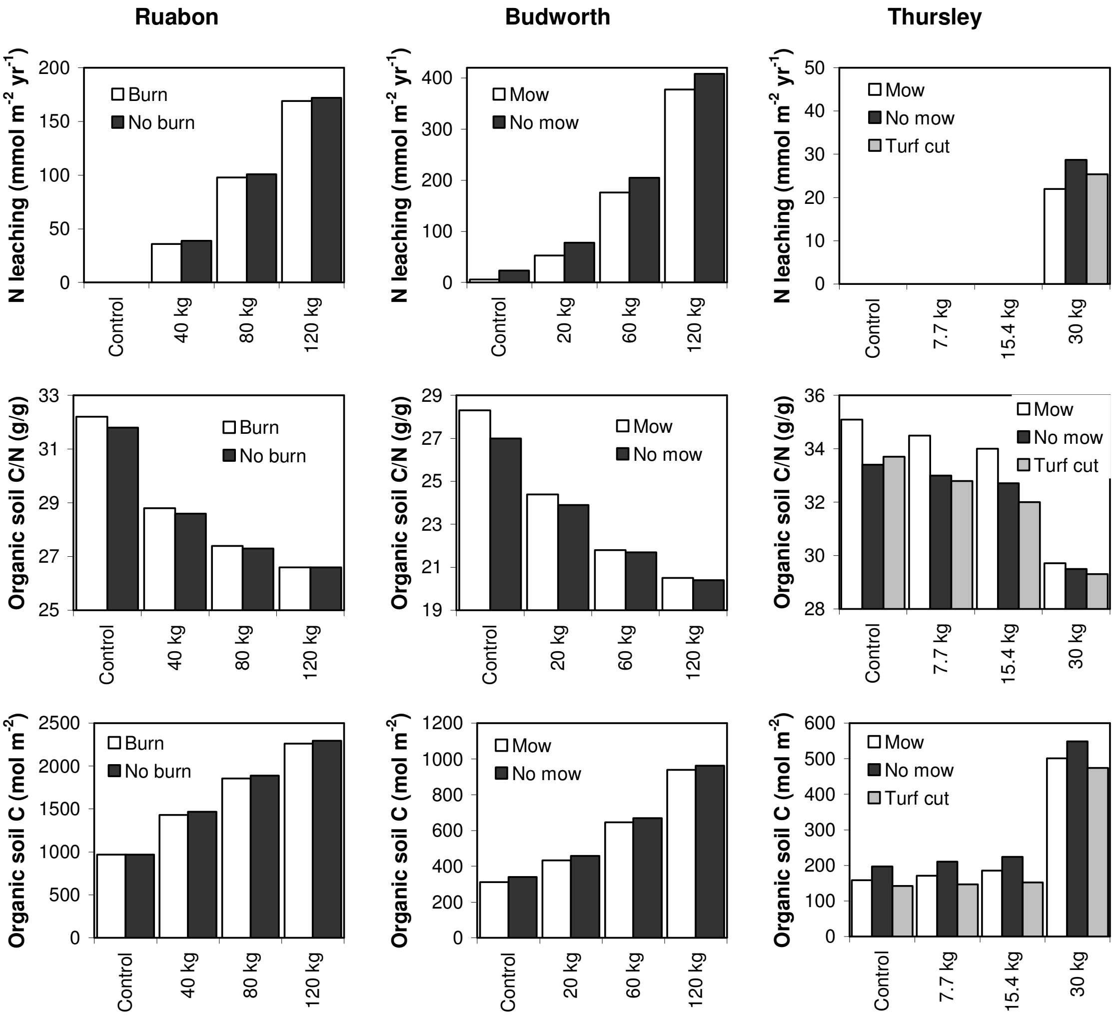
The Allt a'Mharcaidh transect study demonstrates the importance of small-scale heterogeneity in mountain environments. Altitude, slope position, local topography and exposure all influence soil development and vegetation development, such that the five locations studied vary in their susceptibility to N saturation, and also in their characteristic plant communities. The mountaintop *racomitrium* heath is highly sensitive to N deposition, whereas the snowbed *nardus stricta* site (only 26m lower) is relatively productive, due to the shelter afforded by the concave topography and snowpack insulation during winter, and therefore both more productive and more buffered against N deposition. Site 3 is again more exposed, subject to frost heave during winter, and has lower productivity and higher N leaching. The lower altitude sites (4&5) are less exposed and 2-3° warmer on average, leading to a longer growing season and greater biomass development, and again favouring greater soil formation and N retention. The accurate prediction of N deposition impacts on sensitive plant species in each of these habitats may therefore ultimately require a finer-scale approach (in terms of spatial scale or habitat type definition) than can currently be achieved at a national scale.

1.2.1.8 Modelled effects of management on nitrogen dynamics

Three heathland experimental sites, Ruabon, Budworth and Thursley, have been subjected to management practices as well as N addition. To assess the possible impact of management in alleviating (or exacerbating) N enrichment, calibrated models for these sites were applied with alternative management strategies into the future. At each site, the base scenario was the continuation of existing practices, i.e. periodic burning at Ruabon, and low-intensity mowing at Budworth and Thursley. For all three sites, a scenario of discontinued biomass removal (i.e. cessation of either burning or mowing) was applied in a forecast simulation run to 2050, in combination with each of the N addition levels. For Thursley, a one-off turf-stripping event (equivalent to that which took place at Budworth in 1993, and similar in impact to a high-intensity management burn) was also applied to all treatments in 1997.

The results of the different managements, by site and N addition rate, are shown in Figure 1.11. At Ruabon, the discontinuation of periodic burning is predicted to impact only slightly on the rate of N saturation (in terms of N leaching and soil C/N); the impact in terms of possible vegetation change due to lack of management would likely be more significant. At the lowland Thursley and Budworth sites, subject to more intensive biomass removal through mowing and with smaller soil organic matter pools, management has substantially more effect on soil C/N ratio and N leaching, particularly at the N-saturated Budworth site, where cessation of biomass removal on the control plots leads to a 1.3 unit decrease in soil C/N and a four-fold relative increase in 2050 N leaching. Turf stripping at Thursley also has a detrimental predicted impact on C/N and N leaching, because the litter removed has a higher C/N than the underlying mineral soil, and the stock of organic matter available to immobilise future N inputs is depleted. A pulse of N leaching is predicted immediately after turf stripping; this is consistent with observed responses to similar management on a German heathland (Härdtle et al., 2006).

Figure 1.11. Effect of heathland management on N leaching, soil C and C/N, 2050



Thursley 7.7 and 15.4 kg N additions from 1989 to 1996 only. All other treatments continued to 2050.

1.2.2 National-scale model application

1.2.2.1 Introduction and methodology

The objective of this component of WP1, and the ultimate aim of the model development and site-application work described above, has been to generate the first national-scale dynamic model outputs for deposition-sensitive UK terrestrial ecosystems. The approach builds on existing methodology and datasets used for critical load calculation, and thereby ensures that dynamic model outputs and target loads are consistent with critical loads for acidity, and (for target loads) use the same critical acidity thresholds. Consistency with empirical critical loads for N as a nutrient is not yet possible, since these are defined in terms of an acceptable deposition flux, rather than a critical threshold for a particular abiotic variable. Following the procedure used for critical loads, dynamic models have been applied to all 1km grid squares across Great Britain in which the dominant soil type is acid sensitive (Skokloster weathering classes 3-6). In each 1km square, the model has been applied to all acid-sensitive habitat types (i.e. bog, acid grassland, heathland, montane, broadleaf and coniferous woodland) occupying more than one hectare within that square. Calcareous grasslands, which are sensitive to N but not to acidification, have not yet been modelled. This methodology generates a very large number of individual model applications (over 200,000) and as a result the Very Simple Dynamic (VSD) model, developed by the CCE (Posch et al., 2003) was used in preference to MAGIC. If configured appropriately, the VSD is structurally very similar to MAGIC and provides very similar results (Evans and Reynolds, 2003), but has the advantages that it can be run directly from an Access database, and that it has a simpler calibration routine which enables such large numbers of model runs to be carried out relatively quickly.

The input data used, and their sources, are summarised in Appendix 2. In addition to the parameters used to calculate critical loads (e.g. soil weathering rates, water fluxes, plant base cation and N uptake in managed forests, long-term N losses through soil formation and denitrification), a large number of additional parameters are required to apply the VSD model. Wherever possible, additional data were obtained from existing datasets (such as NSRI soils data, EMEP gridded historic and forecast deposition sequences), or from appropriate defaults described in the CCE Dynamic Modelling Manual (Posch et al., 2003). However some additional data collection and derivation was required to provide suitable parameter estimates for UK application. In particular, a large (133 sample) survey of representative sensitive soil types was undertaken in order to obtain data on soil cation exchange capacity, base saturation and C/N ratio (Evans et al., 2004), augmented by additional sampling during by the Macaulay Institute during the project; and available soil and soil solution measurements from 80 locations were used to derive vegetation-specific default relationships between soil C/N ratio and %N immobilisation (Rowe et al., 2006) and default estimates of organic acid concentrations by soil type. The VSD is calibrated against present-day base saturation, and can be used to calculate target loads and to undertake scenario assessments. The model was initially tested for the whole of Wales (rather than for 20km x 20km test 'boxes' as originally planned), and subsequently applied to the whole of the UK. The model has been used to calculate target loads (Section 1.3.2.1), to undertake scenario assessments (results described under WP5), and outputs have been tested against soil core data from the 1998 Countryside Survey (Section 1.3.2.2). Further details of the methodology and data used for VSD application are given in report accompanying the data submission to the CCE (Appendix 2).

1.2.2.2 VSD application and target load calculations

A total of 238,888 VSD applications were undertaken, ranging from 3018 to 67,323 simulations per habitat type (Table 1.2). This large model dataset has provided the basis for generating estimates of target loads for acidity for each habitat class across the UK as a whole, and also for a set of scenario assessments for the 2006/07 CCE call for data, which are described under WP5. Complete target load functions (combinations of S and N deposition that will achieve recovery to the relevant critical chemical threshold for that habitat) have been calculated for target years of 2030, 2050 and 2100. For simplicity, data are presented here for 2030 only, and for values of TLmaxS (the maximum acceptable S deposition in the absence of any N deposition, i.e. one end of the target load function).

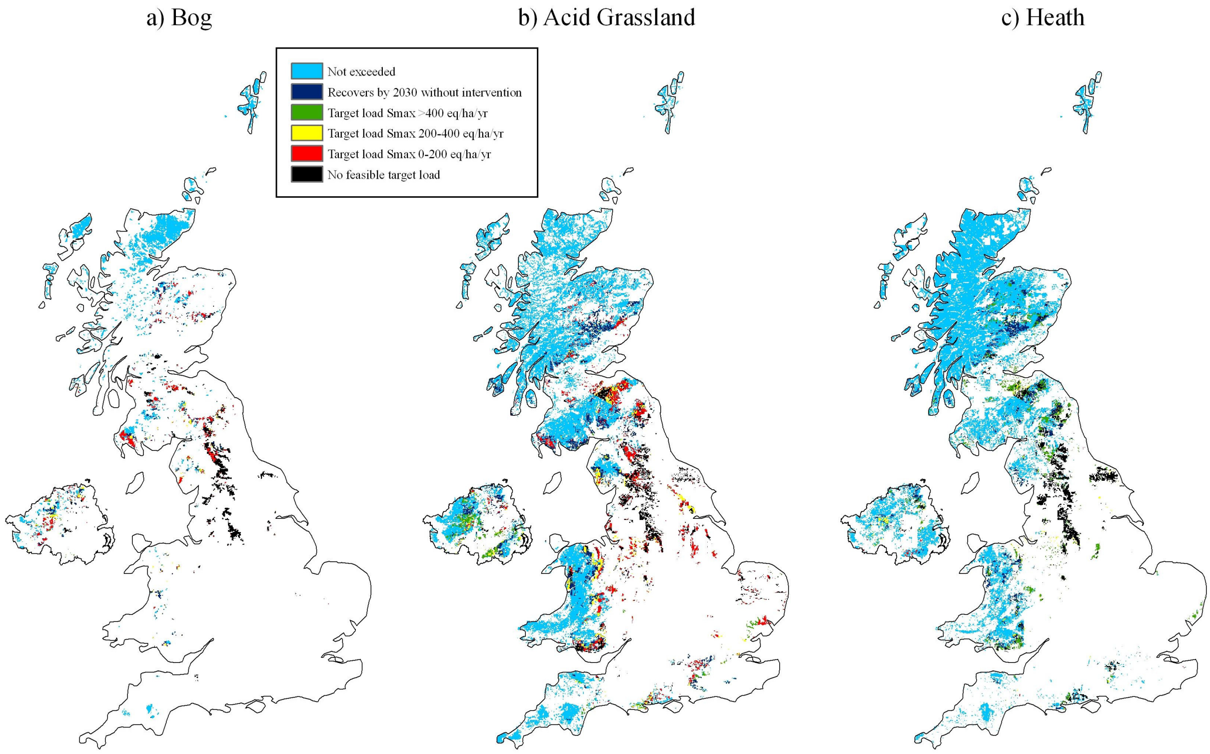
Table 1.2. VSD applications to terrestrial ecosystems

Habitat	EUNIS Code	VSD runs
Bog	D	16423
Acid Grass	E1.7/E3.5	66573
Montane	E4.2	3018
Heath	F	67323
Managed broadleaf	G1	26545
Managed conifer	G3	38475
Unmanaged woodland	G1/G3	20531
Total		**238888**

Table 1.3. Percentage of 1km VSD applications in each acidity target load class, by habitat

Habitat	Acceptable chemistry in 2010	Will recover under CLE	TL Smax > 400 eq/ha/yr	TL Smax 200-400 eq/ha/yr	TL Smax < 200 eq/ha/yr	No feasible target load
Bog	62.7%	3.3%	0.7%	2.9%	6.7%	23.6%
Acid Grass	78.4%	2.3%	2.2%	2.9%	7.5%	6.8%
Montane	10.0%	8.3%	1.5%	7.7%	28.5%	44.0%
Heath	85.7%	1.8%	0.1%	0.8%	5.0%	6.6%
Managed broadleaf	66.6%	1.5%	5.7%	4.1%	15.5%	6.6%
Managed conifer	53.2%	3.2%	7.3%	7.6%	16.5%	12.2%
Total	71.5%	2.3%	3.1%	3.4%	10.5%	9.3%

Figure 1.12. Modelled target loads for acidity (TLmaxS) for a target date of 2030, for three sensitive habitat types.



Predicted 2030 target loads show a broadly expected geographical distribution (e.g. Figure 1.12). According to the model, although many areas of the UK experienced severe critical load exceedance previously, soil buffering has so far been sufficient to maintain soil chemistry above the relevant critical threshold (pH = 4.4 for bogs, molar Ca/Al ratio = 1 for forests, ANC = 0 for other habitats). In a substantial additional area, currently legislated emissions reductions are projected to lead to recovery to acceptable chemical status by 2030. However, for a significant proportion (26%) of the sensitive terrestrial ecosystems modelled, these emissions reductions are *not* expected to be sufficient to permit chemical recovery by 2030. For 64% of these, additional emissions reductions would be expected to lead to recovery by 2030, but for the remaining 36% (i.e. 9.3% of all modelled grid squares), chemical recovery may not be possible by this date even with complete cessation of acidifying emissions. This conclusion, although problematic for setting emissions targets, is not unexpected; ecosystems that have been subjected to severe critical load exceedance for many decades have been very severely acidified, and will be slow to recover. This is particularly the case for ecosystems with very low weathering rates, such as blanket peats (affecting both bog and heathland habitat types, Figure 1.12 b,c), where the replenishment of depleted base cation pools is likely to take decades or even centuries. Later target dates for achievement of acceptable chemical status (e.g. for 2050 or 2100) increase the proportion of grid squares which will either recover under current emissions legislation, and the proportion of the remaining land area for which achievable target loads can be defined.

1.2.2.3 Model testing against Countryside Survey data

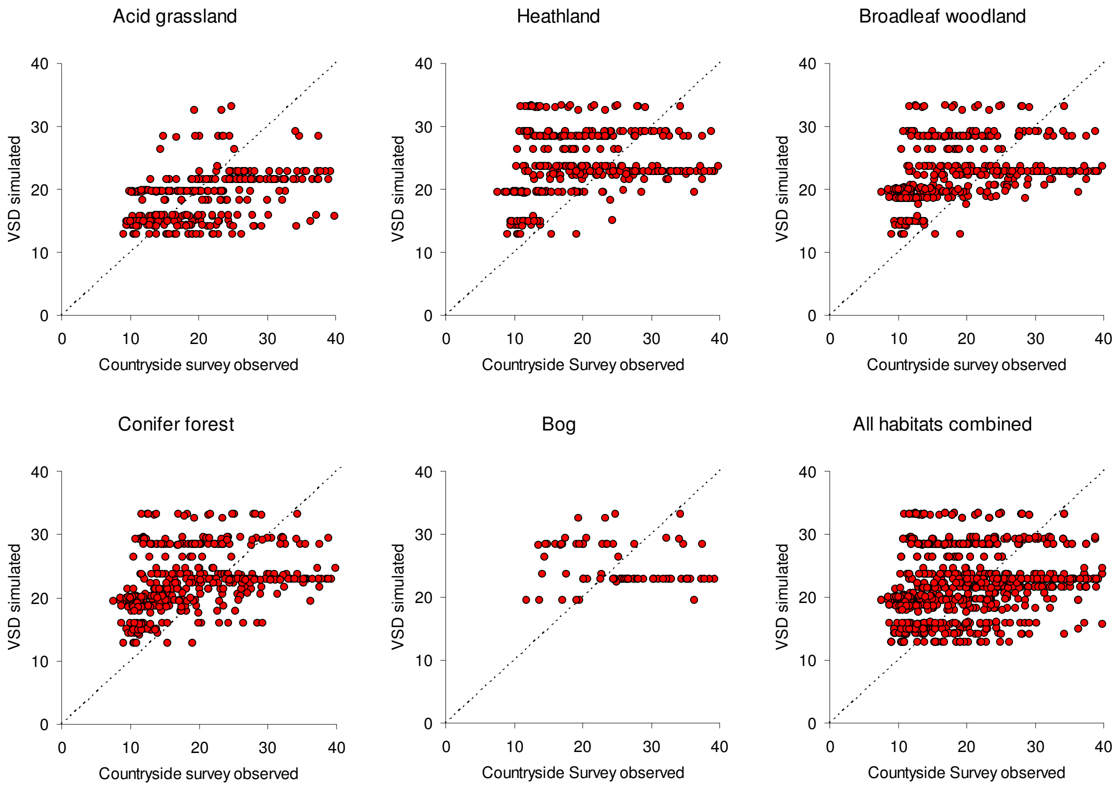
As a first test of model performance, VSD outputs for organic C/N and soil solution pH were compared to independent measurements of top 15cm soil pH and C/N ratio from the Countryside Survey of England, Wales and Scotland (CS), and provide useful comparisons with the national-scale scenario analyses. The CS used a stratified random grid-based design to sample biogeographic zones throughout England, Wales and Scotland. In CS2000, a total of 244 1 km^2 gridsquares were sampled. Within each gridsquare, up to five plots ('X-plots') were sampled at random locations. Many X-plots from the original CS1978 were not sampled in CS2000, due to access restrictions or urbanisation, and in CS2000 the average number of X-plots sampled per gridsquare was 2.99. For each CS X-plot, soil and habitat classes have been assigned. Soil Major Groups were defined according to profile descriptions obtained in CS1978. Habitat class definitions used in CS differ from the EUNIS categories used by the NFC. The correspondences used for comparisons are shown in Table 1.4. Samples taken under aggregate CS classes (such as 'heath and bog') were compared with VSD data from all corresponding EUNIS classes. Comparisons were made between individual X-plot pH and C/N measurements, and the VSD application for that the appropriate (CS mapped) soil type and habitat class.

Table 1.4. Correspondence of CS aggregate habitat classes with EUNIS habitat classes. Aggregate CS classes (e.g. 'Heath and bog' were compared with all corresponding EUNIS classes.

EUNIS habitat class	CS aggregate habitat class(es)
D1 bog	VIII Heath and bog
E acid grassland	IV Infertile grassland; VII Moorland grass mosaics
E42 montane	(none)
F heath	VII Moorland grass mosaics; VIII Heath and bog
G1 managed deciduous woodland	V Lowland wooded; VI Upland wooded
G3 managed coniferous woodland	V Lowland wooded; VI Upland wooded
G1 & G3 unmanaged woodland	(none)
(not assigned)	I Crops and weeds; II Tall grass and herb; III Fertile grassland

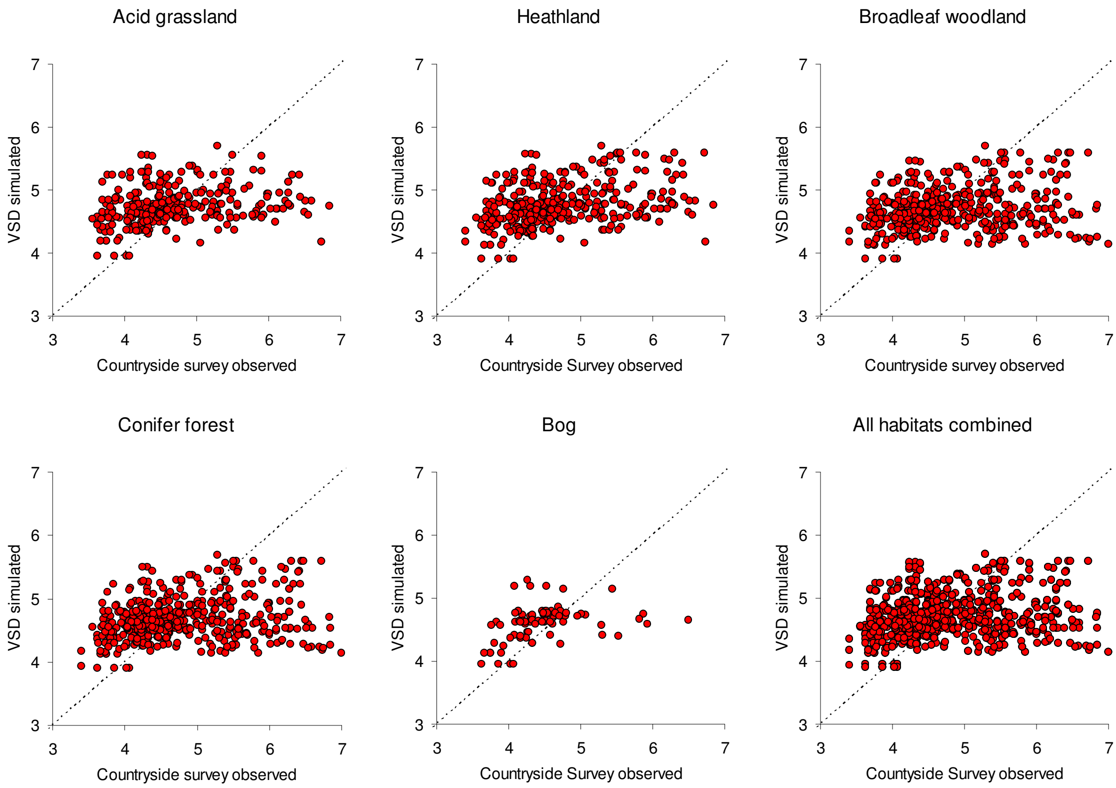
Results (Figures 1.13 and 1.14) show a generally rather weak relationship between modelled and observed C/N and pH data. A statistical analysis by Simon Smart (Terrestrial Umbrella report, Task 17), did not find significant relationships between modelled and observed pH or C/N when applying a General Linear Mixed Model to the combined dataset of VSD model outputs for CS squares, with habitat type proving to be the dominant explanatory factor. However, correlations between simulated and observed pH and C/N within individual habitat classes, and for the combined dataset, are significant ($p < 0.01$) in all cases except C/N in bogs (R^2 values for individual habitats 1.4-12% for pH, 3.3- 21% for C/N). There are a number of possible reasons why the correspondence is not stronger. First, the CS measurements do not correspond entirely to what the VSD is simulating, particularly for pH, which for CS was measured in the laboratory in a soil-water slurry, whereas the VSD simulates in-situ soil solution pH (more directly comparable to measurements from soil solution samplers, as used for model calibrations in Section 1.3.1). Second, VSD simulations were parameterised on a rather constrained set of input data, which cannot be expected to capture the full range of real-world variability. For example, only four weathering rates were possible, based on the Skokloster class of that soil type, and this and many other parameters were assumed constant for each soil (or soil-vegetation combination) across the whole UK. This can be compared, for example, to the much wider range of weathering rates and other parameters calibrated by MAGIC to sites in the CEH oak wood dataset (Section 1.3.1.6). Under these circumstances, it is inevitable that VSD outputs will have a restricted distribution relative to the observed distribution from the CS. In light of this, the lack of any clear bias above or below a 1:1 line for most habitats is encouraging, as it suggests that average predictions for each habitat class are approximately correct, as are the weak positive correlations for most habitats, which suggest that some of the within-class variability (that part associated with variations in atmospheric deposition) is also being captured. Finally, as noted elsewhere, the geographical pattern of VSD predictions appears reasonable in terms of the expected effects of atmospheric deposition on soil chemistry, and consistent with soil and surface water data showing the greatest extent of acidification and nitrogen saturation in polluted areas such as the Pennines, and least impacted conditions in NW Scotland.

Figure 1.13. VSD modelled soil C/N (g/g) compared to Countryside Survey 1998 measurements on the same soil and EUNIS habitat class in that 1km square



Nevertheless, there appears to be much scope to improve the accuracy of VSD simulations at a fine spatial scale. One area of concern appears to be the lack of dynamic variation in modelled C/N ratio (evident in the horizontal 'stripes' in Figure 1.13), which appears to be the result of using rather large estimates of the biologically active C pool, based on NSRI estimates of the C content of the top 20cm of soil. In mineral soils, a substantial part of this C may be inactive, resulting in an over-estimate of the capacity of the soil to immobilise N. Refinement of this and other measurable model input and calibration parameters (e.g. cation exchange capacity and base saturation) could be achieved by further sampling, with less reliance on national default datasets, less necessity for aggregation of heterogeneous soil types into single lumped classes, and more allowance for regional-scale variations as a consequence of factors such as climate (and in the case of base saturation, deposition history). Input parameters that cannot be easily measured, notably weathering rates, could in principle be defined for each major soil type by calibrating MAGIC to a representative set of sites, but this requires measured soil solution from a sufficient number of locations for each soil type (which, to date, has only been possible for oak woodland on podzolic soils). It is worth noting that, were such refinements to be made, it would also be necessary to recalculate critical loads with the revised weathering rates.

Figure 1.14. VSD modelled soil pH compared to Countryside Survey 1998 measurements on the same soil and EUNIS habitat class in that 1km square



1.2.3 *Model development, and vegetation model application*

1.2.3.1 Model development

An upgraded version of the MAGIC model (version 777ext) has been developed over the course of the project. Changes include:

- Non constant soil C pools, so that nitrogen-induced C accumulation can be simulated, affecting rates of N saturation and providing improved fits to experimental data (now used in all MAGIC applications)
- A flexible 3-box structure, permitting for example the simulation of climate-driven wetland sulphur reduction and oxidation dynamics (see Moor House application)
- More flexible input files, permitting effects of climatic variation on all input parameters to be specified as required (see e.g. WP7)
- Greatly improved bulk data handling capabilities for large-scale model application and multiple scenario assessments (e.g. for the 2006/07 call for data, see WP5)
- Option to pre-specific variables which are normally calibrated, such as weathering rates. This will permit MAGIC to be applied to large but incomplete datasets, corresponding to the approach which has been used to apply the VSD to terrestrial ecosystems.
- Option to select one of a range of critical chemical criteria for target load calculation (ANC, pH, base saturation or NO_3 leaching in either soil solution or surface water, soil solution Ca/Al ratio, soil C/N ratio)

A report documenting changes to the model has been compiled by Jack Cosby, and is available on request.

1.2.3.2 Vegetation model application

Development of the vegetation model, GBMOVE, has been led by Simon Smart, and undertaken primarily as part of the Terrestrial Umbrella. A full report on the model development is provided in the Terrestrial Umbrella report. The CLDM project has contributed to GBMOVE development throughout, notably through the organisation by the JEG of a workshop on nitrogen and biodiversity modelling (see WP6); publication of two reports on modelling biodiversity change (Rowe et al., 2005; de Vries et al., 2007); and ongoing comparative studies of UK, Dutch and Swedish biogeochemical-biodiversity model chains.

The following section describes set of test applications of using output from national VSD applications as input to GBMOVE, in order to predict change in the favourability of soil conditions for selected indicator species. This work was undertaken by Simon Smart and David Howard. Maps show predicted change in habitat suitability (Hs) between 2007 and 2020 for selected Common Standards Monitoring (CSM) indicator species for semi-natural habitats in Britain (www.jncc.gov.uk/page-2199). Indicators can be positive; desirable species, characteristic of stands in favourable condition, or negative; undesirable or at least species that ought not to dominate stands of the habitat and whose increase could lead to unfavourable condition.

Change in Hs was predicted by linking the output of the soil model VSD to the plant species niche model GBMOVE. Thus, simulated time series of soil C/N and pH were used to generate abiotic indices (mean Ellenberg values) for 1km squares recorded by the Countryside Survey. These indices were in turn used to solve empirical regression models indicating the favourability of different combinations of abiotic conditions for a large number of British lower and higher plants. Simulations of soil variables were targeted on CS squares in order to establish when sensitive soils were present with a high degree of realism. VSD was in turn driven by modelled atmospheric N and S inputs based on the FRAME model.

The maps were created in two stages:

a) Mean estimates of change in Hs for each species were generated for each of the 40 ITE land classes in Britain.
b) The region in which predictions from the land class map could apply was constrained, and therefore made realistic, by overlaying the remotely sensed Land Cover Map 2000 to show the coincidence between the predictions of change and areas of land where the habitat concerned was actually estimated to occur.

All maps were created using the Countryside Information System. Geostatistical smoothing techniques were not used because the sampling intensity and design of the Countryside Survey is not optimal for such methods (S.Wright & D.Howard pers.comm.).

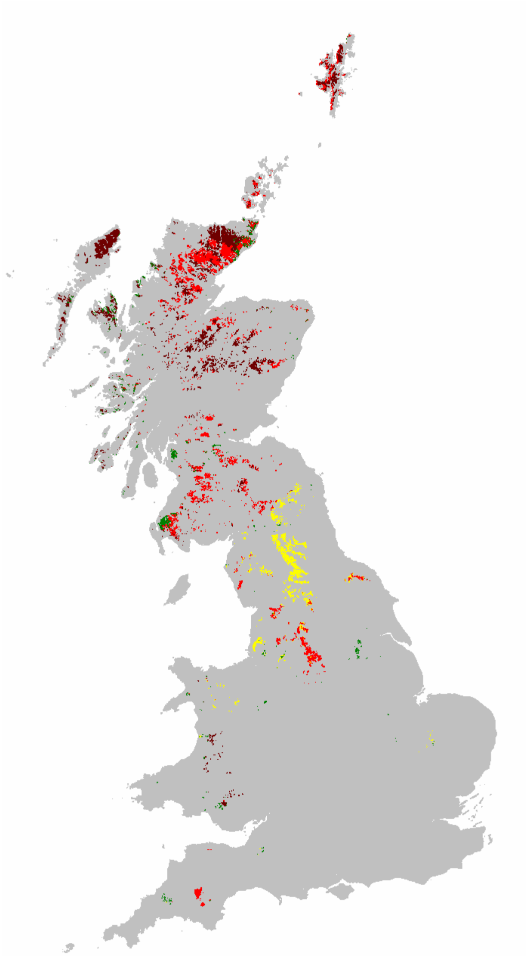
At this stage, these examples are intended to be illustrative, providing some demonstration of the potential application of the linked VSD-GBMOVE (or MAGIC-MOVE) models in predicting large-scale changes in habitat suitability for individual species. The magnitude of predicted changes on the short (13 year) forecast timescale is generally small, but provides some indication of the longer-term changes that may be expected in response to deposition-induced changes in soil acidity and nitrogen enrichment. Future work will aim to compare the modelled trajectory of habitat suitability changes with observed trends in species occurrence from the Countryside Survey, and to simulate the combined impacts of deposition, land-management and climate change.

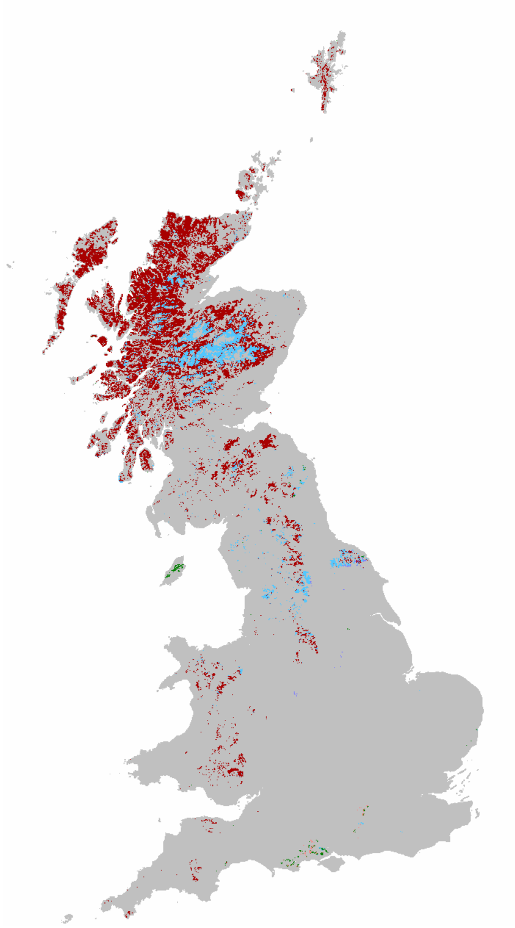
Example 1. *Narthecium ossifragum*, a positive CSM indicator for blanket bog.

KEY (%change where 100% = shift from optimum to zero suitability)

- -0.1-0
- 0-1.5
- 1.5-3.6
- 1 km squares with <5 ha Bog but with *N.ossifragum* recorded in survey squares.
- No *N.ossifragum* recorded in survey squares in land-class and with <5 ha Bog

VSD-GBMOVE outputs for *Nathecium ossifragum* (bog asphodel) suggest little change in habitat suitability in Northern Scotland, but generally positive changes further south. The most salient feature is a 1.5-3.6% increase in suitability in the Pennines.





Example

2. *Erica tetralix*, a positive CSM indicator for dwarf shrub heath.

KEY (%change where 100% = shift from optimum to zero suitability)

- -2 to -1
- -1 to 0
- 0 to 1
- 1 to 2
- 1 km squares with <5 ha Heath but with *E.tetralix* recorded in survey squares.
- No *E.tetralix* recorded in survey squares in land-class and with <5 ha Heath

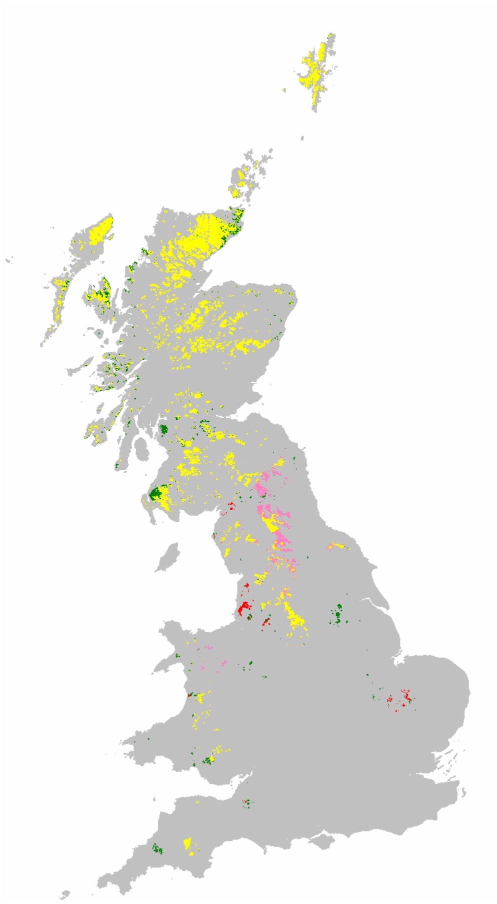
Stability prevails overall with highly localised and largest declines (-2 to -1% reduction in Hs) predicted for *E. tetralix* in dwarf shrub heath in the New Forest and Hampshire heaths.

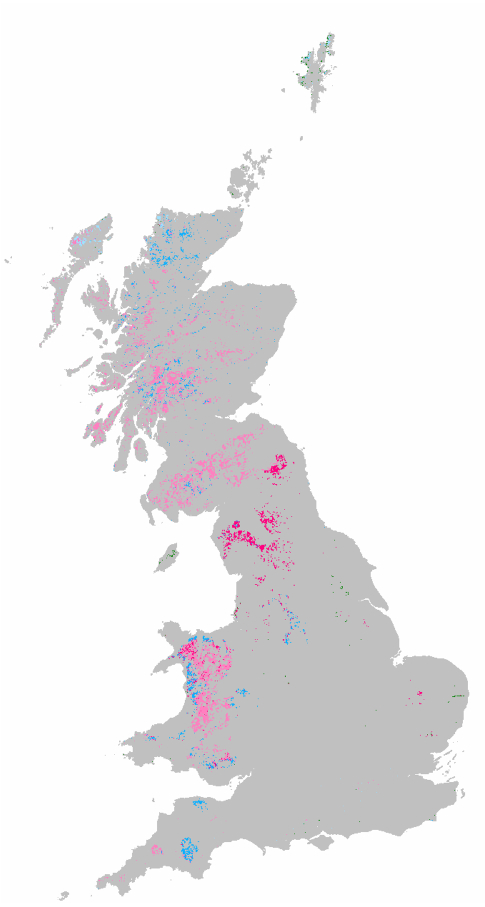
Example 3. *Sphagnum capillifolium*, a positive CSM indicator for bog.

KEY (%change where 100% = shift from optimum to zero suitability)

- -2 to -1
- -1 to 0
- 0 to 1
- 1 km squares with <5 ha Bog but with *S. capillifolium* recorded in survey squares.
- No *S. capillifolium* recorded in survey squares in land-class and with <5 ha Bog per 1km square.

Stability prevails overall with highly localised and largest declines (-2 to -1% reduction in Hs) in lowland SE England, the Solway plain and Cheshire, much more modest reductions or stability in the Pennines and stability throughout the rest of the Welsh and Scottish uplands.





Example 4. *Nardus stricta*, a negative CSM indicator for heath, also widespread in upland acid grasslands.

KEY (%change where 100% = shift from optimum to zero suitability)

- -0.2 to -0.1
- -0.1 to -0.001
- -0.001 to 0.1
- 0.1 to 1.6
- 1 km squares with <5 ha Heath but with *Nardus stricta* recorded in survey squares.
- No *Nardus stricta* recorded in survey squares in land-class and with <5 ha Heath

Stability prevails overall with localised but small magnitude increases in habitat suitability in the Lake District, North Pennines, and Northwest Snowdonia.

1.3 Milestones and Deliverables

D1.1	*Report describing analysis of UK soil survey data* *Completed (see Evans et al., 2004)*	*Dec 2004*
M1.1	*Testing of model outputs against monitoring data* *Completed*	*Mar 2005*
D1.2	*Adapted version of MAGIC to include new C-N dynamics* *Completed*	*Mar 2005*
M1.2	*Completion of dataset for new site-specific model applications* *Completed (but will continue to be added to whenever possible)*	*Oct 2005*
M1.3	*Creation of database for national-scale modelling* *Completed*	*Oct 2005*
M1.4	*Trial 'regional' soils model applications and testing* *Completed (VSD application to Wales)*	*Mar 2006*
M1.5	*Model analysis of land-management impacts* *Completed*	*Mar 2006*
M1.6	*Model analysis of climate change impacts* *Completed (see also WP7)*	*Oct 2006*
M1.7	*Testing of vegetation model with site-specific model outputs* *Completed (undertaken for VSD outputs and Countryside Survey data)*	*Oct 2006*
M1.8	*Initial national soils model application and testing* *Completed*	*Oct 2006*
D1.3	*Final site-specific model outputs* *Completed*	*Mar 2007*
D1.4	*Provision of model output data for vegetation predictions* *Completed*	*Mar 2007*
D1.5	*Final national Target Load Functions* *Completed*	*June 2007*

Work Package 2: Dynamic Modelling of UK Freshwaters

PI: Chris Evans. Contributors: Julian Aherne, Rachel Helliwell, Ed Rowe, Mike Hutchins, Dave Norris, Malcolm Coull and Allan Lilly

2.1 Summary

- MAGIC has been calibrated according to a consistent methodology to sampled lakes and streams from seven UK acid-sensitive regions, totalling 320 sites. This database has provided the basis for target load and scenario assessments submitted to the CCE in response to two calls for data during the project.
- As in terrestrial habitats, a substantial proportion of modelled surface waters are currently highly acidified, and although currently legislated emissions reductions will lead to chemical recovery (above critical ANC) at many sites, a substantial proportion will require greater emissions reductions to attain critical ANC within the next few decades, and at the most acid sites this target may be difficult or even impossible to attain within the next 20-90 years.
- A new surface water dataset has been collected for the North York Moors, showing this area to be heavily impacted by soil and water acidification, primarily due to persistent high concentrations of sulphate, with only a minor contribution from nitrate leaching. MAGIC application suggests that the region will exhibit slow and incomplete recovery under current emissions legislation, but additional measurement data are required to increase confidence in these predictions.
- Input datasets and methodology for MAGIC application to surface waters have been substantially improved. Model validations for UK Acid Waters Monitoring Network sites show good correspondence between simulated and observed recovery from acidification at acidified sites. At present, the model does not simulate short-term (climate-related) variability in NO_3 leaching, and monitoring datasets are not yet long enough to validate predicted long-term N saturation.
- Development and application of a 'two box' version of MAGIC permits more accurate prediction of soil chemical change in individual soil horizons, and simulation of change in the severity of acid episodes in response to reduced deposition and/or climate change.
- Static empirical models have been used to predict biological responses to changes in surface water acidity at site and regional scales.

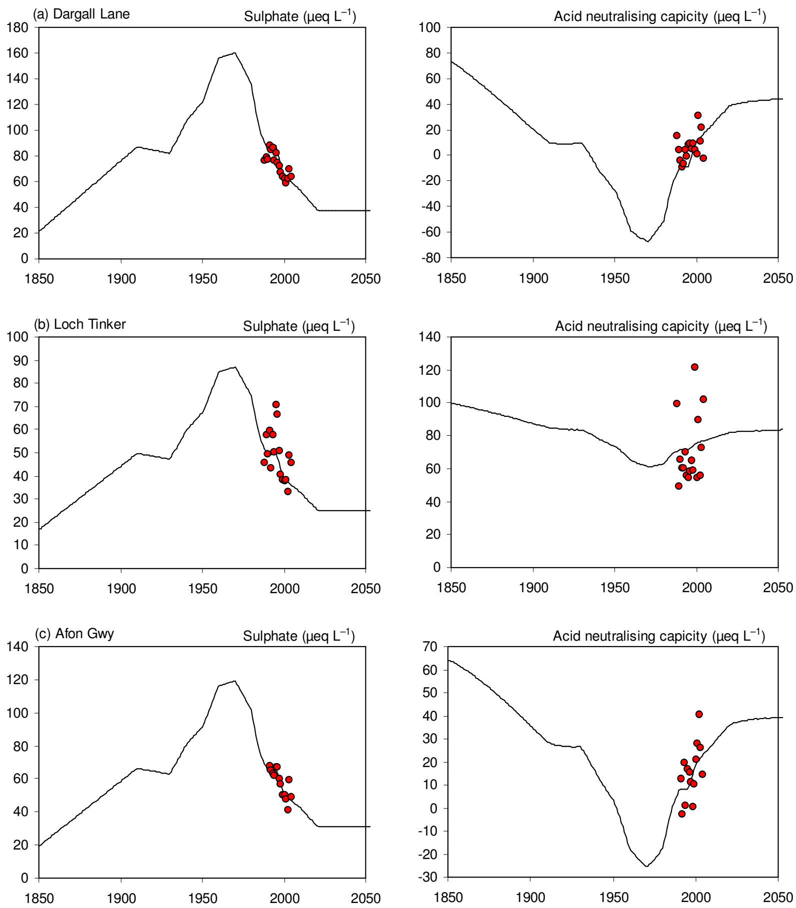
2.2 Description of work

2.2.1 Development and validation of the MAGIC model

Developments in the MAGIC model described in Section 1.2.3 have also been applied to surface waters, with new software developed by Jack Cosby to support rapid multiple-scenario MAGIC assessments (see WP5). MAGIC has been used to model surface waters for more than 20 years and has been applied extensively in North America and Europe. Overall the model has proven to be robust, reliable and useful in a variety of scientific and managerial activities. Nonetheless uncertainty in model prediction may arise from model application methodology and model input data. Developments and validation work for WP2 (led by Julian Aherne and Rachel Helliwell) has focused on several key areas: validation of the regional-scale MAGIC applications, improved model parameterisation and development of a two soil-box modelling approach. Model testing has focused primarily on the data-rich UK Acid Waters Monitoring Network (AWMN) catchments, which now show clear evidence of chemical recovery trends (Davies et al., 2005), and some evidence of associated biological trends (Monteith et al., 2005).

For each of the regional-scale modelling areas (see Section 2.2.2), MAGIC was applied to all within-region UK AWMN sites (work led by Julian Aherne and Rachel Helliwell). The model application followed the standard protocol for regional scale modelling that was developed to meet the requirements of 2004/05 CCE call for target load data. A comparison of modelled and observed long-term chemical trends (observed data: 1988–2004) was carried out for all sites (Figure 2.1). In general, there is good agreement between observed and simulated surface water chemistry indicating that the current regional approach is reliable, and supportive of policy development based on MAGIC simulations. Model predictions indicate that in general surface water acidity will continue to improve in the next decades under current legislated emission reductions (as indicated by the FRAME model).

Figure 2.1. Validation of the regional modelling approach at the UK AWMN catchments: simulated and observed surface water sulphate and ANC shown for 3 sites



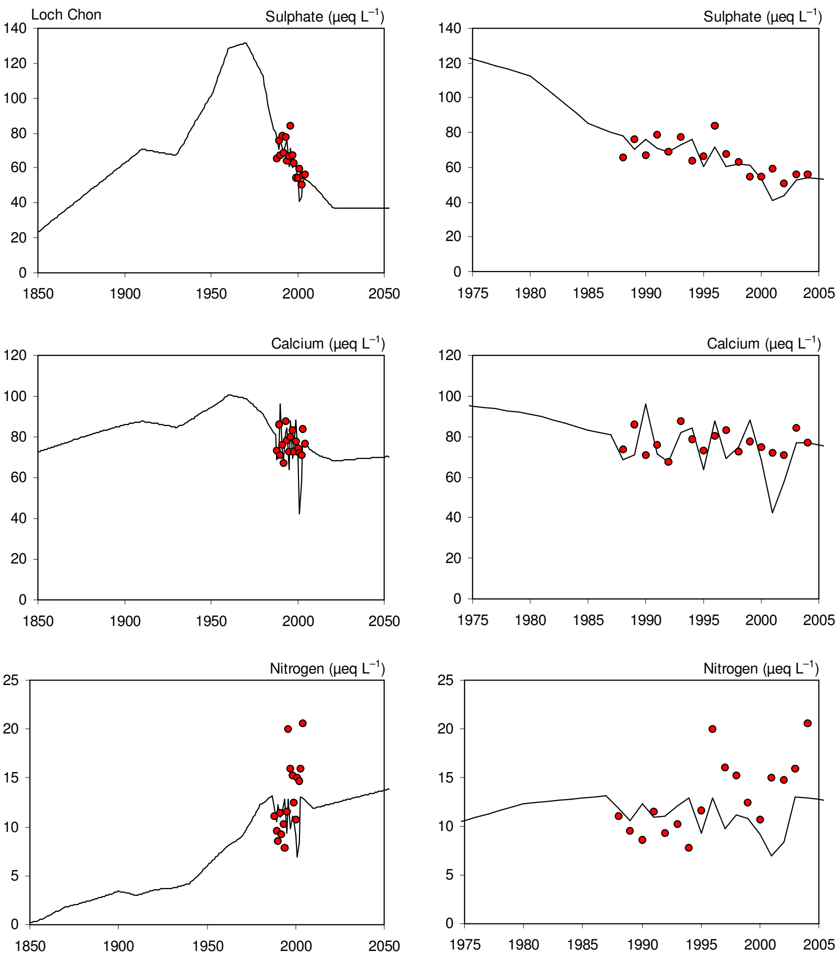
Improvements in model parameterisation have focused on providing consistent inputs for soils and waters for all the UK AWMN catchments. The current database represents somewhat of the 'state-of-the-art' in model parameterisation. The key improvements are as follows:

- Improved soils database: A consistent approach has been used to derive 'new' soils data for all AWMN catchments. The approach has relied on existing derived soil and attribute data held at the Macaulay Institute. Several analogue soils were used to generate consistent data across all sites. The lumped soil physical and chemical data are provided in Appendix 6.

- In catchments, hydrological routing may result in a significant proportion of annual through-flow bypassing a significant portion of the soil. The Hydrology of Soil Types (HOST) classification was used to estimate flow-routing, providing a consistent methodology for all UK AWMN catchments (see Aherne et al. (2007) for further details.

- A method for estimating carbon pools has been developed using topography to derive slope classes, and data from the Scottish National Soils Database held at the Macaulay Institute. Mean data for %C for each soil type is derived for each slope class, and the proportion of each class (derived from a digital terrain model) used to calculated catchment C pool. N pools were estimated from observed catchment C:N ratios and the new C pool estimate.
- The forest uptake database has been revised to include data for five main species of conifers; Sitka Spruce, Norway Spruce, Scots Pine, Corsican Pine and Douglas Fir, as well as several other tree types, at a range of sites and yield classes. These data were extracted from published papers and reports. Uptake data has been included for major cations, N, P and S.
- Following the procedure developed by Cooper (2005), time-series deposition inputs have incorporated into MAGIC calibrations at all AWMN catchments. Site-specific atmospheric inputs allow for a greater correspondence between simulated and observed data and provide robust calibrations, which may reduce uncertainty in model predictions. As for MAGIC applications to soils (WP1), there is good correspondence between simulated and observed time-series data for most ions, but short-term NO_3 fluctuations are not captured (Figure 2.2).

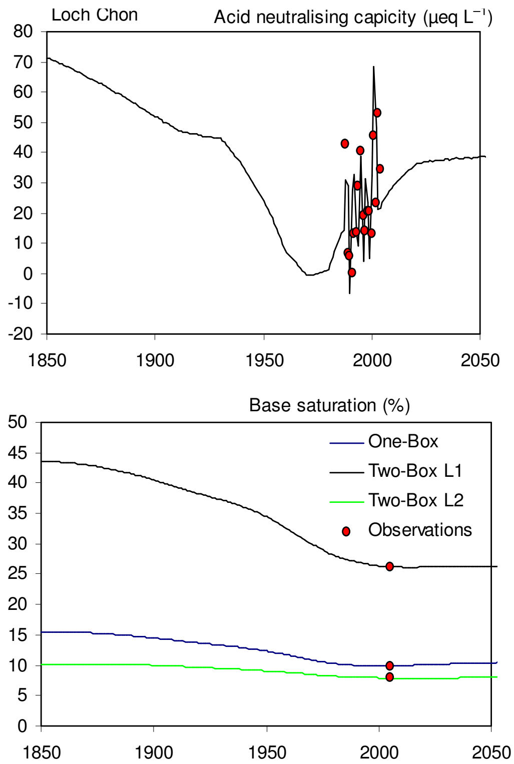
Figure 2.2. Comparison of simulated and observed surface water chemistry, Loch Chon, using observed deposition time series to drive the model



Significant efforts have been directed towards developing a two soil-box modelling approach. Most MAGIC applications aggregate or 'lump' soil physico-chemical properties into one layer integrated over the catchment. Although this approach has been suitable for surface water end-point applications, it does not account for the differences in soil buffering capacity with depth, or the importance of hydrological pathways in determining acid sensitivity. Soil properties for the

AWMN catchments were segregated into two layers using the HOST classification (Aherne et al., 2007). HOST describes the dominant pathways of water movement through UK soils based on 29 classes. In addition, each class has been assigned a standard percentage runoff (SPR) value, which indicates the percentage of rainfall that contributes to short-term increase in flow. Soil properties for the two-box model show considerable divergence between layers (Figure 2.3). The one-box simulation for base saturation lies somewhere between the upper and lower layer for the two-box approach, dependent on the relative segregation of the soil profile into two layers.

Figure 2.3. Simulated and observed ANC and soil base saturation at Loch Chon using 1 and 2 box MAGIC.



The vertical two-box approach provides improved resolution for soils by representing their natural horizonation (acid-sensitive upper layers and higher-weathering lower layers). Model simulations reflect the vertical differentiation in acid sensitivity, with the upper layers showing greater response to changes in acid deposition. The vertical two-box approach provides a more appropriate tool for the integrated assessment of land use and climate impacts on catchments. It can also be used to simulate changes in acidic episodes, where these occur due to increased runoff from more acid surface soils at high flow. A two-box MAGIC application to the Afon Gwy (Evans et al., in press) suggests that ANC minima during episodes will increase more rapidly than mean ANC in response to declining deposition, with clear benefits for aquatic biota. Increased high flow extremes due to climate change may partially offset, but will not negate, the improvements associated with decreasing S and N deposition.

Overall, the site-specific model development and testing described supports the use of MAGIC to predict surface water chemical change at the regional scale, and illustrates the potential for further improvements in predicting soil chemical change from surface water data, and biologically-important chemical extremes. An important conclusion is that the validity of model outputs is strongly dependent on the quality of input data; improving input datasets will reduce the uncertainty associated with model predictions. The model structure itself appears robust with regard to acidity, including simulation of short-term variation, but further work is required to simulate short-term variability in NO_3 leaching. A systematic uncertainty analysis would provide insight into the level of confidence in model estimates. Further, it can lead to the identification of the key sources of uncertainty (such as data gaps) which merit further research, as well as the sources of uncertainty that are not important (sensitivity).

2.2.2 Regional-scale MAGIC applications

2.2.2.1 Introduction and methodology

MAGIC has been applied to a total of 320 lakes and streams, covering seven acid- and N-sensitive regions of the UK (Table 2.1). Work was undertaken early, during Year 1 of the project, in order to meet the requirements of 2004/05 CCE call for target load data. The spatial coverage of sites represents a significant expansion of the previous set of modelled surface waters, incorporating new sites for Wales and the Mourne Mountains, and updated soil and surface water chemistry data for the South Pennines and Galloway, based on the NERC-funded GANE Lakes project. One region modelled under a previous Defra contract (the Trossachs) was omitted from the assessment since all sampled sites were above a critical ANC of 20 μeq l^{-1}, and target loads for these sites were not therefore relevant. In general, sampling was focused on areas of known acid sensitivity, rather than designed to be representative of the wider population as a whole.

For the first time, all surface waters were modelled with a standardised methodology, with N dynamics implemented at all sites. The methodology and input data were as consistent as possible with those used for terrestrial model applications, and for freshwater critical load calculation using the FAB model (the modelled sites comprise a subset of the larger FAB dataset). However, one major difference (versus terrestrial model applications) was that it was possible to calibrate catchment weathering rates and cation exchange constants using observed soil and surface water chemistry, rather than relying on default data based on soil type. This limits the number of model runs to sites with measured data, but increases confidence in individual model applications. Further methodological details are provided in the report accompanying the submission of target loads for the 2004/05 CCE call for data (Appendix 3). Subsequently, all previously calibrated sites were used as the basis of a major scenario assessment in response to the 2006/07 CCE call for data, which is reported under WP5.

Table 2.1. Sites included in MAGIC surface water application, by region

Region	Location	Number of standing waters	Number of streams
Cairngorms	Northeast Scotland	38	0
Galloway	Southwest Scotland	59	0
Mourne Mountains	Northern Ireland	8	0
Lake District	North-west England	52	0
South Pennines	Northern England	62	0
Snowdonia	North Wales	34	27
Cambrian Mountains	South/central Wales	7	37
Totals		260	64

2.2.2.1 Target load estimation

Target loads for acidity were calculated for all sites, with critical ANC values (ANC_{crit}, set to 20 μeq l^{-1} at most sites, zero at naturally more acidic sites) set according to those in the FAB dataset. Emission forecasts were fixed to current legislation with an implementation year of 2010, with deposition from 2020 through to the target year adjusted within the model in order to estimate combinations of S and N deposition that would lead to attainment of the critical ANC by target years of 2030, 2050 and 2100. As for terrestrial model applications, results are presented for TLmaxS, i.e. the maximum deposition of S that would lead to achievement of ANC targets in the absence of any N deposition.

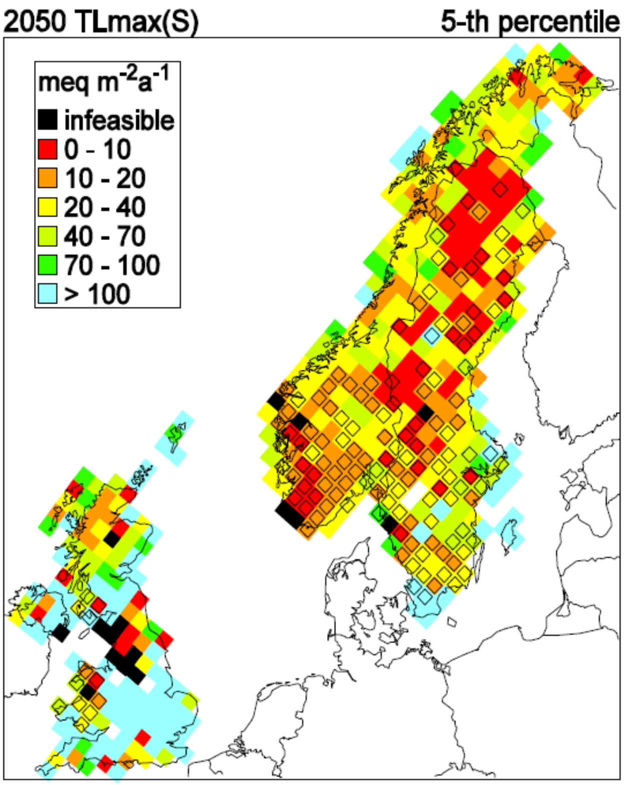
With the exception of the Mourne Mountains, the majority of modelled surface waters are predicted by the model to have an ANC > ANC_{crit} by 2050 (Table 2.2). This includes sites that remain acidified at present, but are predicted to recover to this level in response to currently legislated emissions reductions. For at least half of the remaining (i.e. non-recovering) sites in all regions, additional reductions in S and/or N deposition would be sufficient to achieve ANC > ANC_{crit} at this time. A particularly high degree of additional surface water recovery would be attainable with additional deposition reductions in the Mourne Mountains and in Wales, but clear benefits are predicted for all modelled regions. However, based on the model outputs it is predicted that for a minority of sites in all regions it will not be possible to achieve acceptable chemical status on this timescale, even if emissions are reduced to background levels. The proportion of 'non-recoverable' sites (for a 2050 target date) varies from 2% (Galloway) to 18% (South Pennines).

Table 2.2. 2050 target loads for acidity, surface waters

Region	Site safe in 2050	Target load calculated	ANC_{crit} not attainable by 2050
Cairngorms	74%	16%	11%
Galloway	81%	17%	2%
Mournes	25%	63%	13%
Lake District	69%	15%	15%
South Pennines	63%	19%	18%
North Wales	61%	25%	15%
South Wales	59%	32%	9%
Total	67%	22%	12%

The percentage of non-recoverable sites for the modelled surface water dataset as a whole (12%) is quite similar to the percentage of modelled terrestrial ecosystems predicted to be non-recoverable (Section 1.2.2.2.). The region with the greatest proportion of non-recoverable sites is in both cases predicted to be the South Pennines, where the legacy of very high historic deposition and extensive poorly buffered blanket bogs combine to produce highly acidified and slow to recover ecosystems. These observations suggest a degree of consistency in the conclusions obtained for terrestrial and aquatic ecosystems, although given the differences in site selection and (to a lesser extent) model formulation, some caution is required in this conclusion.

Figure 2.4. 5th percentile target loads for modelled surface waters in the UK, Norway and Sweden, overlaid on the EMEP critical load map



Finally, UK surface water target loads were combined with outputs from similar work in Norway and Sweden as part of a larger-scale assessment (Moldan et al., in prep.). Figure 2.4 shows 5th percentile acidity target loads for all three countries on the EMEP grid, overlaid on existing critical load maps. EMEP grids in which target loads have been calculated are outlined in black. Because of the regional focus of UK model applications, and the 12% of surface waters predicted to be non-recoverable on this timescale, the 5th percentile target load in a number of modelled UK gridsquares is mapped as 'infeasible' (black), as are those in the most acidified and poorly-buffered areas of Southwest Norway. In all, modelled 5th percentile TLmaxS values fall into a lower band than the 5th percentile ClmaxS (calculated from the same dataset) in 13 out of the 22 UK EMEP grids for which dynamic models have been applied. This illustrates the greater emissions reductions that would be required to achieve target ANC_{crit} values by 2050, rather than at long-term steady state.

2.2.2.2 North York Moors survey and model application

A survey of surface waters in the North York Moors was undertaken as an optional work item (Activity B) during year 2 of the project, based on prior evidence that this region was highly deposition-impacted but poorly represented in existing datasets. In March 2005, 51 catchments (47 streams and 4 standing waters) were sampled, along with representative soils. Results are described in detail in the survey report (Evans et al., 2005), and summarised here.

Results (Table 2.3) confirm that surface waters draining the geologically-sensitive sandstone area of the North York Moors have been very severely impacted by acid deposition from nearby (and mostly upwind) emission sources, notably from major coal-fired power stations such as Drax. Levels of ANC, pH and aluminium were all at an almost unprecedented level based on previous surveys of UK waters, the closest comparable region being the South Pennines, an area long considered to be the most deposition-impacted in the UK. Most streams appeared highly unlikely to be able to support viable salmonid fish populations, and local reports suggested that attempts at stocking had resulted in episodic fish deaths. Acidification of the moorland area appears to be driven almost entirely by SO_4, and a set of S isotope analyses undertaken by Tim Heaton (BGS) strongly suggested that most or all of this SO_4 could be attributed to atmospheric deposition. Levels of NO_3 leaching from the peaty moorland soils, however, was very low (this contrasts with the South Pennines, where NO_3 leaching is much higher), indicating that N saturation is not greatly advanced in these managed heathland ecosystems. Streams draining forested areas, however, had very high levels of both NO_3 and SO_4 leaching, and had the lowest ANC of all samples sites.

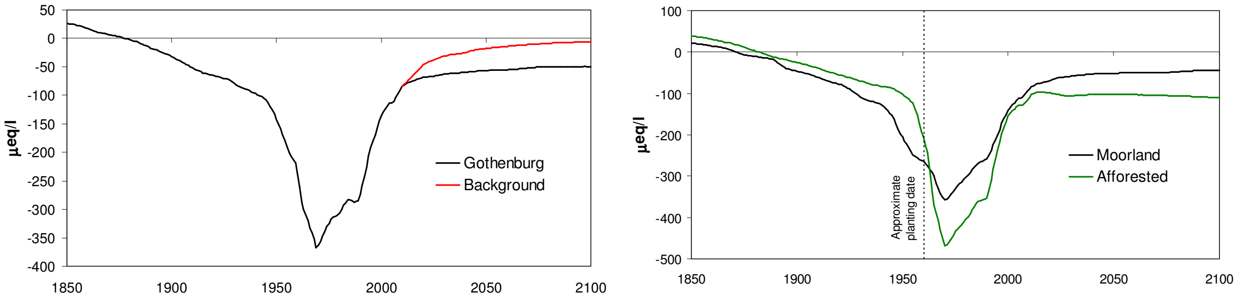
Table 2.3 Summary surface water chemistry data for the North York Moors

	pH	Alkalinity	ANC	Na	K	Ca	Mg	Al	NH4	Cl	NO_3	SO_4	xSO_4	DOC
		μeq/l	μeq/l	μeq/l	μeq/l	μeq/l	μeq/l	μg/l	μeq/l	μeq/l	μeq/l	μeq/l	μeq/l	mg/l
Minimum	3.84	-100	-317	219	10	31	65	30	0	272	0	105	56	0.9
10th percentile	4.06	-85	-151	257	11	40	73	110	0	330	1	145	95	3.3
25th percentile	4.15	-82	-128	276	13	46	87	215	0	382	3	165	114	3.9
Median	4.27	-64	-110	355	19	75	104	380	0	471	8	193	147	4.8
75th percentile	4.60	-20	-79	429	23	124	135	435	1	562	15	224	178	6.6
90th percentile	6.10	69	19	507	28	310	187	510	2	718	31	344	284	8.6
Maximum	7.51	805	667	709	42	1161	356	1880	18	878	95	712	621	27.5

MAGIC was calibrated to all 51 sampled surface waters, following the methodology described in Section 2.2.2.1). Model predictions (Figure 2.5) suggest that surface waters have always been quite acidic, but that high historic S deposition led to very severe acidification, from which recovery will be incomplete (most sites remaining below ANC_{crit}) under the Gothenburg scenario. Conifer afforestation is shown to have exacerbated this acidification, with projected N saturation of these areas leading to some re-acidification in the future. Since even reducing deposition to background levels is not predicted to increase median surface water ANC above zero by 2100 (due to slow recovery of the poorly buffered soils), over half of all modelled sites have no feasible target load for 2100, increasing to over 75% if the target data is brought forward to 2030. Recovery of surface waters in this region is therefore expected to be slow, and difficult to achieve.

While these results are clearly of great concern, and there is little doubt that the acidity levels recorded would have been biologically damaging, model outputs from the North York Moors have to date not been submitted to the CCE. This decision was taken on the basis that the single, March samples (particularly for streams) could not be considered sufficiently representative of annual mean chemistry (a necessary assumption for calibrating MAGIC) to provide reliable outputs for use within the CLRTAP. Subsequent measurements on a subset of streams sampled by Rick Battarbee (UCL) during baseflow conditions in summer 2006 indicated that pH was considerably higher at this time, and it appears that the most acidic conditions in these systems occur seasonally and/or episodically. Further sampling is therefore required in order to provide a robust dataset for MAGIC application to this important, and highly impacted, region.

Figure 2.5. Median MAGIC-modelled ANC for the 51 calibrated surface waters in the North York moors, showing effect of different future deposition scenarios, and differing trajectories of surface waters draining moorland and forest catchments.

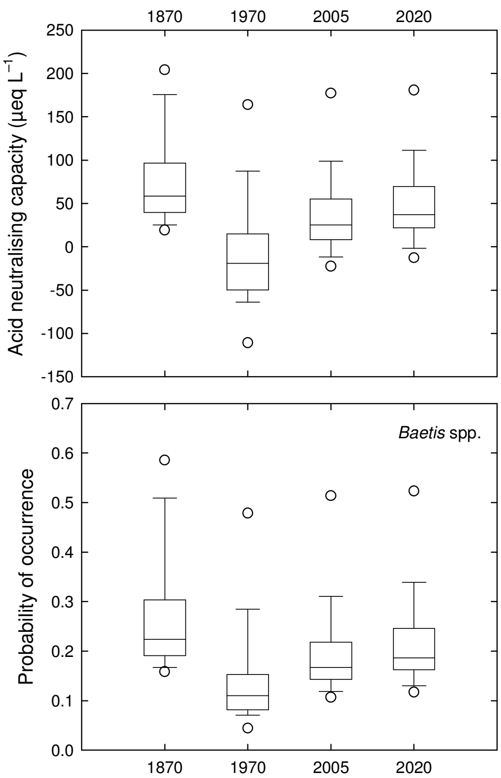


2.2.3 Prediction of biological response to chemical change

MAGIC model outputs have been used to predict changes in freshwater biological status as a function of changing water acidity. Static empirical chemical-biological relationships developed under the previous Freshwater Umbrella contract by Dr Steve Juggins, University of Newcastle, relate ANC to probability of occurrence. This assessment uses simulated ANC from MAGIC to predict changes in probability of occurrence for one widely-used acid-sensitive indicator species, *Baetis rhodani*. All UK AWMN sites show a decrease in species probability of occurrence in concert with the decline in acid neutralising capacity until 1970 (Figure 2.6). By 2005, some improvements in biological status are simulated.

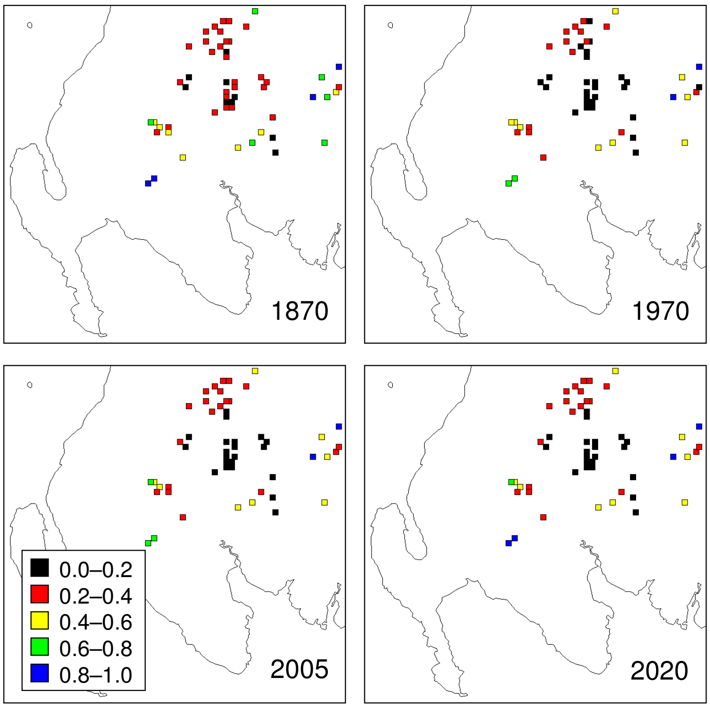
Figure 2.6. Simulated ANC and probability of occurrence for *Baetis* spp. at the AWMN catchments in 1870, 1970, 2005 and 2020.

Boxes span the interquartile range, whiskers are drawn to the most extreme point within 1.5 × the interquartile range, dots show 5th and 95th percentiles



At the regional scale, MAGIC output from regional modelling (Section 2.2.2) was used predict changes in freshwater biological status. The Galloway region (and others) show a decline in occurrence until 1970 and limited recovery thereafter (see Figure 2.6). This approach was also used to predict biological changes within a large catchment (the Conwy) using the combination of MAGIC and the PEARLS mixing model (Evans et al., 2006c). Empirical relationships between probability of occurrence of an acid-sensitive indicator stream invertebrate species and stream chemistry are only based on ANC; greater predictive power might be expected through inclusion of biologically relevant variables such as pH, inorganic Al species and Ca; however, ANC can be viewed as an effective (and directly modelled) proxy for other acidity-related variables. Further improvement in biological predictions may be achieved through utilisation of empirical relationships for a wider range of invertebrate and diatom species, and by utilising relationships that take into account the influence of acidic episodes on the biota (developed by Prof Steve Ormerod and co-workers, University of Cardiff) incorporating the 2-box MAGIC model approach described in Section 2.2.1.

Figure 2.6. Probability of occurrence for *Baetis* spp. at the regional-scale in lakes in Galloway 1870, 1970, 2005 and 2020 (Gothenburg Protocol)



2.3 Milestones and Deliverables

D2.1	*Submission of Target Load functions to CCE* *Completed (target load data submited for surface waters)*	*Feb 2005*
M2.1	*New default estimates for forest N uptake* *Completed*	*Mar 2005*
M2.2	*Collation of new Welsh regional dataset* *Completed*	*Mar 2005*
M2.3	*New estimates for catchment C and N pools* *Completed*	*Oct 2005*
M2.4	*Model validation runs for AWMN sites* *Completed (in 2007)*	*Mar 2006*
M2.5	*Testing of biological predictions at AWMN sites* *Completed (in 2007)*	*Mar 2006*
M2.6	*Initial MAGIC calibration to all regions* *Completed (in 2005)*	*Mar 2006*
D2.2	*Regional-scale biological predictions* *Completed (in 2007)*	*Oct 2006*
D2.3	*Standard methodology for presenting results at national scale* *Completed*	*Oct 2006*
D2.4	*Final regional model applications and Target Loads* *Completed*	*Jun 2007*

All milestones and deliverables associated with Optional Acitivity B, the North York Moors survey, were also completed (see Evans et al., 2004, and Year 2 report).

Work Package 3: Coordination of critical load activities

PI: Jane Hall. Contributors: Richard Broughton, Susannah O'Hanlon, Elizabeth Heywood, Jackie Ullyett

3.1. Summary

- The UK critical loads are aimed at protecting broad habitats recognised under the UK Biodiversity Action Plan which are considered sensitive to acidification and/or eutrophication.
- Methods to determine the areas of designated sites at risk from the impacts of acidification and eutrophication have also been developed; this work is of relevance to the EU Habitats Directive and Birds Directive.
- No changes have been made to the national steady state critical loads data during this contract; the last updates to the data were in February 2004.
- The National Focal Centre (NFC) has, through its attendance at national and international meetings, maintained a watching brief on developments in critical loads. The current focus is on dynamic models and on critical load methods to consider the impacts of nitrogen deposition on biodiversity

3.2. Description of work

The national critical loads of acidity and nutrient N were significantly revised and updated in 2003 and 2004; no further changes have been made to the data sets since February 2004. The UK NFC has kept a watching brief on developments over the last three years by attendance at the annual CCE Workshops and ICP Mapping and Modelling (M&M) Task Force meetings (WP4(iv)), the Acid Rain conference in 2005, as well as attending national meetings, including those of the Defra Terrestrial Umbrella. The current focus of developments is on dynamic models (WP1 & 2), and the critical load methods that consider N impacts on biodiversity.

The impacts of N on the NATURA 2000 designated sites (SACs and SPAs) across Europe and the methods/models to assess them are becoming increasingly important in order to fulfil obligations under the EU Habitats Directive and Birds Directive. Additionally, in the UK, Common Standards Monitoring of SSSIs is aiming to include methods for assessing the impacts of atmospheric pollutants on features of these designated areas. The use and appropriate application of critical loads for site-specific assessments is therefore an important consideration. An example of the use of critical loads at the site-specific scale is given below.

Under this WP updated UK boundary data for SSSIs (Sites of Special Scientific Interest), SACs and SPAs were obtained from the statutory conservation agencies in 2005 and 2006. These data are used for generating statistics on the area of designated sites in exceeded habitat areas for scenario assessments under WP5. The boundary data are converted by the NFC to 1km gridded data sets (giving the areas of designated sites in each 1km grid square); this format of the data is compatible with the programs currently in use for scenario assessments, and allows a more rapid analysis than the original digital vector polygon data. However, all scenario assessments carried out after June 2005 that required exceedance statistics for SSSIs, SACs and SPAs, are based on the 2005 dataset. The designated area data were used in assessing the Air Quality Objectives for ecosystems and vegetation for the Air Quality Strategy (WP5.2.1.4). There is little difference in the total areas of designated sites between 2005 and 2006; GIS methods for carrying out future scenario analyses are in the process of being updated (see below), hence 2006 data have not yet been used routinely. As an example the exceedance statistics based on the CBED deposition data for 2001-2003 (see WP5) are shown in Tables 3.1 and 3.2 below.

The area of sites in Tables 3.1 and 3.2 refer only to the areas of designated sites that occur in 1km grid squares of the UK for which critical loads for terrestrial habitats are mapped. The exceeded areas are the areas of sites that fall within 1km grid squares for which the critical loads for any terrestrial habitat are exceeded (in this case by CBED deposition for 2001-03). Critical loads have not been assigned to the designated sites or their features in this exercise and therefore these statistics only provide an estimate of the stock at risk. Work funded by a consortium of SNIFFER/EA/SEPA/EHS has enabled "site-relevant" critical loads to be assigned to the designated features of SACs and SPAs in the UK and an example of their use is described under WP4.2.2. Site-relevant critical loads have not as yet been assigned to SSSIs in the UK. Further work is required in the development and use of site-specific critical loads before these critical loads could be applied in routine deposition scenario analysis.

Table 3.1. Acidity exceedance statistics for designated sites in the UK

Site type	Area (km^2)*	Exceeded area (km^2)	% exceeded area
SSSIs	16740	11536	68.9
SACs	10860	7600	70.0
SPAs	8531	5774	67.7

Table 3.2 Nutrient nitrogen exceedance statistics for designated sites in the UK

Site type	Area (km^2)*	Exceeded area (km^2)	% exceeded area
SSSIs	21061	14191	67.4
SACs	14625	9144	62.5
SPAs	12119	7081	58.4

Developments in GIS technology (from ArcInfo to ArcGIS) now permit easier and quicker spatial analysis using vector polygon data. CEH is core-funding GIS method development for application to critical loads research. This will involve updating all the current methods of performing scenario analysis; instead of running a suite of C programs from an ArcInfo macro, a suite of Python programs are being developed that can be run either from ArcGIS or independently. This approach has the advantages that it automatically creates digital maps of critical load exceedance data within the GIS as well as the summary exceedance statistics; it will be a fully automated process (with the exception of generating classified maps for distribution via packages such as Powerpoint); maps will include Northern Ireland in its correctly mapped position and projection; and it will be easier to modify/update the routines to address future Defra needs. It is anticipated that this new software will be operational by late 2007.

The NFC has also been involved in other critical load projects that are of relevance to this Defra contract:

(i) An investigation into the best method to combine national and local data to develop site-specific critical loads: project funded by the Environment Agency to develop methods for site-specific critical load assessments (Wadsworth & Hall, 2005).

(ii) Uncertainty in critical load assessment models: project funded by the Environment Agency, examining the uncertainties in critical loads at the site-specific, regional and national scales (Skeffington et al, 2007).

(iii) Assessing the risks of air pollution impacts to the condition of Areas/Sites of Special Scientific Interest in the UK: project funded by JNCC to consider the options for assessing the potential risks from acidification and eutrophication (in terms of critical loads and exceedances) to designated sites (Hall et al, 2006a).

3.3. Milestones and Deliverables

M3.1 *Updated SSSI, SAC, SPA boundary data* *May 2005*
Completed

M3.2 *Updated SSSI, SAC, SPA boundary data* *May 2006*
Completed

Work Package 4: National Focal Centre for Critical Loads and Dynamic Modelling

PI: Jane Hall. Contributors: Richard Broughton, Susannah O'Hanlon, Elizabeth Heywood, Jackie Ullyett

4.1. Summary

- The NFC has remained active, providing UK representation at meetings of the International Cooperative Programme on Mapping and Modelling (ICP M&M) and workshops of the Coordination Centre for Effects (CCE). This ensures the interests of the UK (Defra and the research community) are represented and that the UK feeds into policy related discussions (such as the use of critical loads data for Protocols and Directives) and is kept up to date with requirements under the Working Group on Effects (WGE) of the Convention on Long-Range Transboundary Air Pollution (CLRTAP).
- The NFC has responded as necessary to "calls for data" from the CCE, providing UK critical loads and dynamic modelling data which will be used in the review of the Gothenburg Protocol. In addition, in response to the Autumn 2006 call, the NFC also provided empirical nitrogen critical loads for UK SACs. These sites form part of the European Natura 2000 network of designated sites to be protected by the EU Habitats Directive.
- The NFC's web site ensures transparency of the methods and data used in the UK for critical loads (and dynamic modelling); new pages on uncertainties and site-specific critical loads have been added in the last year.

4.2. Description of work

4.2.1. National critical loads and dynamic modelling databases

As explained in WP3 the national critical loads database was last updated in February 2004. The national 1km data are maintained and securely stored in a UNIX environment with access via ArcInfo and ArcGIS. A copy of the data as submitted to the CCE in February 2004 is maintained in an Access database. An additional Access database has been created which also contains input parameters required to run dynamic models for any 1km grid square of the UK included in the national scale modelling work for WP1.

In preparing data submissions to the CCE in Spring 2007 (see below), Access databases have been generated that hold the dynamic modelling outputs for acidity for:

- 310 freshwater catchments
- ~70% of the 1km squares for which terrestrial habitat critical loads data are available.

4.2.2. Provision of critical loads and dynamic modelling to UNECE CCE

The NFC has provided UK data sets in response to "calls for data" from the CCE in February 2005, February 2007 and March 2007. These data are used by the CCE for activities under the CLRTAP.

In February 2005 acidity dynamic modelling output data for 256 standing waters and 64 streams were submitted to the CCE. All sites were from the UK FAB critical loads data set; the steady-state critical loads for these (and all other sites and habitats) remained unchanged from those submitted in 2004.

In October 2005 the CCE announced an *optional* call for data (critical loads for acidity eutrophication or heavy metals, and data on dynamic modelling of acidification).The UK NFC contacted relevant Defra contractors and agreed not to submit data, on the following grounds:

- No updates had been made to the national steady state critical loads for acidification and eutrophication since the data submission in February 2004.
- Dynamic modelling outputs for acidity (freshwaters) were submitted to the CCE in February 2005 and were consistent with the steady-state data submitted in 2004. There was insufficient time to obtain all the data required and calculate steady-state critical loads for all other freshwater sites to which dynamic models could be applied.
- No updates had been made to the national critical loads for heavy metals since the data submission in December 2004 [Heavy Metal critical loads for cadmium and lead were submitted to the CCE in December 2004 under Defra contract "Development of an effects-based approach for toxic metals", EPG 1/3/188.]
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In the Autumn of 2006 the CCE issued two calls for voluntary contributions on:

(i) empirical critical loads in relation to a surplus of nitrogen
(ii) critical loads of N and S and dynamic modelling data

Prior to call (i), few countries had applied and submitted empirical nitrogen critical loads; the majority had previously been submitting modelled (mass balance) critical loads, mainly for forest ecosystems. The UK has (since 2003) been applying the empirical approach to non-woodland terrestrial habitats and also to unmanaged woodland habitats (Hall et al, 2003a & 2004a), and the mass balance approach to managed woodland habitats. The UK did not wish to make any changes to the empirical (or mass balance) critical loads previously submitted to the CCE in 2004. However, in this call countries were asked to specifically record the nature protection status of the site data being submitted as:

- no specific nature protection applies
- Special Protection Area (SPA), Birds Directive applies
- Special Area of Conservation (SAC), Habitat Directive applies
- A national nature protection programme applies

The latter description has been applied to the UK habitat data submitted in 2004, since the aim is to protect UK Broad Habitats under the UK Biodiversity Action Plans. As there was a particular interest from the CCE (and hence, CLRTAP and the WGE) in nature protection areas, the NFC submitted a database of "site-relevant" empirical nutrient nitrogen critical loads for 472 UK SACs. These data were submitted to provide an example of an approach that may be applied to designated sites. Site relevant critical loads were assigned to SACs under work previously carried out by CEH and funded by a consortium of SNIFFER/EA/SEPA/EHS to assess the extent to which the sites may be under threat by current and future emissions of air pollution from major point and area sources. Briefly, site relevant nutrient nitrogen critical loads were assigned as follows:

- Individual features (Annex 1 habitats, Annex II plant species) were assessed in terms of their sensitivity to eutrophication.
- Corresponding EUNIS habitat class(es) (i.e., the European habitat classes to which empirical critical loads have been assigned) of the sensitive features were identified.
- If empirical nutrient nitrogen critical loads for the EUNIS class exist, they were applied. Where this was not the case, a critical load for a similar EUNIS class was applied where appropriate.
- The critical load values identified by EUNIS class were assigned to the corresponding feature for each SAC, i.e. no additional site-specific information was used in the assignment.

More information on the site-relevant empirical nutrient nitrogen critical loads data submitted to the CCE can be found in Appendix 1, and more generally on the site-relevant approaches for acidity and nitrogen in Hall et al (2006a).

In response to the call for S & N critical loads and dynamic modelling data (ii above), the NFC submitted:

- Acidity dynamic modelling outputs for 310 previously calibrated lakes and streams, covering the acid sensitive regions of the UK (Snowdonia, Cambrian Mountains, Lake District, South Pennines, Galloway, Cairngorms, Mourne Mountains). The data consisted of MAGIC outputs for 27 scenarios as specified in the call (see WP5).
- Acidity dynamic modelling outputs (from the VSD) for seven terrestrial habitats for all 1km grid squares in the UK which contained 1ha or more of the habitat (equating to approximately 70% of the 1km squares for which critical loads are mapped in the UK). These largely represent the acid sensitive regions of the UK for which soils data are available from the survey by Evans et al (2004). Details of the modelling work can be found in WP1, and information on the data submission in Appendix 2.

No changes were made to the national steady state critical loads for terrestrial or freshwater habitats. Some critical load tables from 2004 were re-submitted, but only to update the "Dynamic Modelling Status" column, for those squares where the dynamic models have been applied.

4.2.3. Maintenance of the website and provision of data

The UK NFC website (http://critloads.ceh.ac.uk) has been maintained and updated as necessary and still provides a key contact point for those seeking information on the methods used as well as those requiring data. The website fulfils the role of making the methods and data used in critical loads research in the UK transparent to any interested party (including industry). Developments to the website during this contract include pages containing:

- Critical load and exceedance maps
- Habitat distribution maps
- Dynamic modelling reports (under Reports section)
- Uncertainties (in critical loads & exceedances)
- Site-specific critical loads issues

The national 1km critical loads data are freely available to anyone on request. Data are provided under a standard CEH data licence agreement with access via a password-protected FTP site. In addition, data will shortly be available directly from the web site; users will complete an online form before being given access to the data. This will be available as soon as the online form system has been integrated into the server setup by CEH Computer Services.

4.2.4. Representation at UNECE meetings

For the duration of this contract Jane Hall has continued as the Head of the UK NFC. In this role she has attended the annual meetings of the International Cooperative Programme on Modelling and Mapping (ICP M&M) as the main UK delegate. This ensures that the interests of the UK are represented, and that the UK has the opportunity to feed into the policy related issues (e.g. calls for data; use of data for Protocols and Directives, development; progress with and application of methods); and that this project (and other Defra Umbrellas) is kept up to date with, and can contribute to the requirements of the WGE under CLRTAP. Copies of the official minutes of these meetings are circulated (by the NFC) to Defra and the leaders of the Umbrella projects. Minutes are also available on the ICP MM website (http://www.oekodata.com/icpmapping/).

Annual workshops of the Coordination Centre for Effects (CCE) are also attended by Jane Hall along with other project members and scientists from other Defra Umbrella projects. The UK makes a considerable contribution to these workshops via presentations/discussions and is often seen to lead the way in terms of method development and application. The presentations and conclusions of these meetings are published on the CCE website (http://www.mnp.nl/cce) and reports of data submissions are published in the CCE Status Reports (also available from the CCE website).

4.3. Milestones and Deliverables

M4.1	*Updates to UK dynamic modelling database* Completed	*Jan 2005*
D4.1	*UK Dynamic Modelling Status Report uploaded to NFC web site* Completed	*Jan 2005*
D4.2	*Respond to CCE call for data* Completed	*Feb 2005*
M4.2	*Updates to UK dynamic modelling database* Completed (prior to data submission in Feb 2005)	*Jan 2006*
D4.3	*Respond to CCE call for data* Deliverable not applicable due to decision not to submit data at that time.	*Feb 2006*
M4.3	*Updates to UK dynamic modelling database* Completed	*Jan 2007*
D4.4	*Respond to CCE call for data* Completed	*Feb 2007*

Work Package 5: Scenario analysis and advice to Defra and devolved administrations

PI: Jane Hall. Contributors: Ed Rowe, Chris Evans, Richard Broughton, Susannah O'Hanlon, Elizabeth Heywood, Jackie Ullyett, Julian Aherne, Rachel Helliwell, Mike Hutchins

5.1. Summary

- This WP has provided exceedance statistics, maps, and dynamic modelling predictions, to (a) inform policy development for the UK Air Quality Strategy, the National Emissions Ceiling Directive, the Gothenburg Protocol and the RIA Marine Fuels Directive; (b) incorporate the impacts of acidification and eutrophication on ecosystems and habitats into national indicators for sustainable development.
- Analysis based on the latest (2002-04) CBED deposition showed that 56% of sensitive habitat areas remain exceeded in the UK for acidity, and 60% for nutrient nitrogen.
- The most recent FRAME predictions of deposition for 2020 reduce these exceeded areas to 41% for acidity and 48% for nutrient nitrogen.
- Scenarios analysed for the Air Quality Strategy are predicted to decrease these exceeded areas further, especially the recent "scenario R" based on reductions in NOx from traffic and SO_2 and NOx from shipping. This scenario would reduce the area exceeded by a further 3.3% for acidity and 4.8% for nutrient nitrogen relative to the baseline 2020 scenario.
- Dynamic model scenario assessments have been undertaken on for all VSD-modelled terrestrial habitats and MAGIC-modelled surface waters, and results submitted to the CCE in response to the 2006/07 call for data
- Dynamic model simulations indicate a substantial but incomplete recovery from acidification under current legislation (CLE) by 2030, with persistence of acid conditions (ANC < 0, pH < 4.4) in upland areas close emission source regions (e.g. Pennines, North York Moors, South Wales and adjacent to the Scottish Central Belt), and in localised acid-sensitive areas of lowland England (e.g. Berkshire and New Forest heaths, lowland broadleaf woodland).
- Further emissions reductions (to the Maximum Feasible Reduction, MFR) generate additional recovery relative to the CLE, most notably in the spatial extent of the most acid conditions for bogs, heathland and broadleaf woodland. Acidification is predicted to remain extensive beneath managed conifer forestry throughout much of the UK.
- N leaching is predicted to remain fairly constant under CLE forecasts, with small increases in some areas, and maximum N concentrations modelled beneath heathland in the South Pennines, and areas of lowland woodland.
- Reducing N emissions to the MFR is predicted to lead to major decreases in N leaching across all habitat types.
- Advice, maps, data and summary statistics have been provided on request to other bodies including the Environment Agency, statutory Conservation Agencies, universities, industry and other Defra funded projects (Terrestrial Umbrella, Freshwater Umbrella, UK Integrated Assessment Modelling).

5.2 Description of work

5.2.1. Critical load assessments

The potential impacts of deposition scenarios are assessed by calculating critical load exceedances for acidity and nutrient nitrogen. Results are summarised to give the area and percentage of habitats in the UK (and by individual country) where the critical loads are exceeded. In addition, if required, exceedance maps are also generated. Summary exceedance statistics have been used:

- As a national indicator by Defra for Sustainable Development: http://www.sustainable-development.gov.uk/progress/national/index.htm
- In the Defra E-Digest of Statistics: http://www.defra.gov.uk/environment/statistics/airqual/index.htm
- To inform the Defra review of the UK Air Quality Strategy: http://www.defra.gov.uk/corporate/consult/airqualstrat-review/index.htm
- To inform the RIA Marine Fuels Directive

Critical load exceedances are calculated using the 2004 national critical loads data (Hall et al, 2004a) and deposition data from CEH Edinburgh (funded under separate Defra contracts). Deposition data may either be based on current measurements – this is the so-called "Concentration Based Estimated Deposition" (CBED) data, or may be FRAME modelled data which provides hindcast, forecast or current estimates of deposition. The critical loads data are (with the exception of the freshwater catchments) at 1km resolution and the deposition data at 5km resolution. For the purposes of this work the deposition is assumed to be constant for all 25 x 1km grid squares within each 5x5km square. Further information on the calculation of critical load exceedances can be found in Hall et al, (2003b). The sections below give an overview of the scenarios analysed during this contract.

5.2.1.1. Trends in critical load exceedance using CBED data

The CBED data are provided as annual means for a 3-year period and since 2001 have been updated on an annual basis. Trends in critical load exceedances based on CBED data for 1995-97, 1998-2000, 1999-2001 and FRAME data for 2010 were reported to Defra in July 2004 (Hall et al, 2004b). The latest exceedance statistics presented here are those based on the 2002-2004 CBED deposition data. The 2003-2005 data were received at the time of writing this report and hence have not yet been analysed and are not included in this report. Summary statistics on percentage area of habitats exceeded used by Defra as an indicator for sustainable development and for the E-Digest are updated annually.

Tables 5.1 and 5.2 summarise trends in exceedance using deposition data from 1995-97 through to 2002-2004. Deposition data for 1995-97, 1998-2000 and 1999-2001 are all based on the same methodology (data version March 2004). Data for 2001-2003 additionally include nitric acid, and those for 2002-2004 additionally include aerosols. Results show that whilst the area exceeded has continually and gradually decreased for acidity (in line with reductions seen in sulphur deposition), the reductions in exceeded areas for nutrient N are smaller over the same time period, reflecting the smaller changes in nitrogen deposition.

Table 5.1. Summary exceedance statistics for acidity

Country	Percentage habitat area exceeded by deposition data for:				
	1995-1997	1998-2000	1999-2001	2001-2003	2002-2004
England	75.7	71.4	71.6	72.1	71.9
Wales	89.9	82.6	82.5	81.6	81.1
Scotland	68.0	52.4	51.4	42.6	44.4
NI	81.1	70.8	70.3	71.3	73.4
UK	72.6	60.8	60.2	54.8	55.9

Based on CBED acid deposition (S + NOx + NHx) data

Table 5.2. Summary exceedance statistics for nutrient nitrogen

Country	Percentage habitat area exceeded by deposition data for:				
	1995-1997	1998-2000	1999-2001	2001-2003	2002-2004
England	94	91.8	92.3	93.1	88.9
Wales	94.5	84.3	82.7	87.4	86.1

Scotland	45.5	36.1	37.8	37.5	39.5
NI	89.3	73.2	76.6	82.0	82.8
UK	65.5	57.6	58.7	59.5	59.5

Based on CBED nitrogen (NOx + NHx) data

5.2.1.2. Trends in critical load exceedance using FRAME modelled deposition data

For this study the exceedance statistics based on the 2001-2003 CBED deposition were compared against exceedance statistics derived using FRAME modelled deposition for 1970 and 2020, where the FRAME output was calibrated using the 2001-2003 CBED data for consistency. FRAME was also run to generate deposition data for 1980 and 1990, but critical load exceedances were not calculated using these data. A summary of the results together with exceedance maps were included in the 2006 final report to Defra on the FRAME model (contract EPG1/3/302, Dore et al, 2006). The exceedance statistics are summarised below by country (Table 5.3).

Table 5.3. 1970 and 2020 exceedance statistics by country based on FRAME outputs

Country	% habitat exceeded for acidity:			% habitat exceeded for nutrient N:		
	1970	2001-03	2020	1970	2001-03	2020
England	82.7	72.1	63.3	96.9	93.1	85.3
Wales	95.7	81.6	67.8	93.7	87.4	75.2
Scotland	91.0	42.6	24.1	50.9	37.5	24.6
NI	89.9	71.3	59.7	85.4	82.0	70.4
UK	89.4	54.8	39.4	69.1	59.5	48.1

For acidity the total area of sensitive habitats exceeded fell by almost 35% between 1970 and 2001-03, and is predicted to fall to less than half the area exceeded in 1970 by 2020. Reductions in habitat areas exceeded for nutrient N are also significant, but smaller than those for acidity, with a predicted reduction of 21% between 1970 and 2020. However, for the woodland habitats the areas exceeded for nutrient nitrogen show much smaller decreases over this time period (e.g. only ~4% for unmanaged woodland); this is largely due to the dominant role of dry deposition of ammonia to tall vegetation.

The exceedance results clearly follow the reductions seen in emissions and deposition between 1970 and the present day. For the year 1970, sulphur accounted for over half of the total acid deposition to forest. During the period 1970-1990, oxidised nitrogen accounted for 30% of the total nitrogen deposition to forest. However, for a recent emissions year (2005), reductions in emissions of SO_2 and NO_x mean that NH_x is making the greatest contribution to both acid deposition (64%) and total nitrogen deposition (78%) to forest. Without future reductions in ammonia emissions, NH_x deposition is forecast to increasingly dominate acid and total nitrogen deposition (Dore et al, 2006).

5.2.1.3. RIA Marine Fuels Directive

Exceedance statistics were calculated for four scenarios to provide information to ENTEC (Defra contractors) in relation to the RIA Marine Fuels Directive. The scenarios consisted of a baseline for the year 2007 and three comparative scenarios with 4.6%, 5.3% and 7.8% reductions in sulphur deposition. The scenario deposition was generated at CEH Edinburgh using the FRAME model. The exceedance statistics were reported to ENTEC and to Defra. As the focus was on reductions in sulphur, nutrient nitrogen exceedances were only calculated for the baseline scenario. These reductions in the sulphur deposition had a very small impact on the area of habitats exceeded: the area exceeded for acidity for the most stringent scenario (7.8% reduction) resulted in the "protection" of 824 km^2 more habitat area than the baseline, equating to a difference of 1% in the habitat area exceeded. The accumulated exceedance for this scenario was 2.4% lower than that of the baseline scenario, showing that the magnitude of exceedance had also decreased.

5.2.1.4. Air Quality Strategy

The UK Air Quality Strategy (AQS) sets air quality standards and objectives for eight key pollutants, two of which (SO_2 and NO_x) are responsible for acidification and eutrophication. In addition to assessing the potential impacts of deposition scenarios, air quality (AQ) objectives for the protection of vegetation and ecosystems from the gaseous concentrations of these pollutants were also examined. No AQ objective has been set for NH_3 and therefore the critical level for NH_3, recommended by ICP Vegetation and WHO, was used.

The NFC has analysed a number of scenarios over the three years of the contract. The results of each group of scenarios have been reported previously to Defra, in the form of Excel spreadsheets and summary tables, and as a supporting document for the Consultation on the Review of the AQS (Hall et al, 2006b). The following briefly summarises these results:

i) Scenario set 1 (scenarios: 2, 11, 14, 16, 17, 18): This set of scenarios was based on reductions in SOx and/or NOx as outlined in Table 5.4; the NHy total was the same (131 kt N) for all scenarios.

Table 5.4. Deposition budgets and exceedance statistics for scenario set 1

Scenario	Description	SOx (kT S)	NOx (kT N)	% habitat area exceeded	
				Acidity	Nutrient N
Baseline	Business as usual 2020	68.3	65.2	33.7	39.1
2	Reduce NOx from vehicles	68.5	51.2	29.8	34.5
11	Introduce low NOx burners to power stations	68.3	62.0	32.7	38.0
14	Reduce NOx and SO_2 from ships	61.1	61.9	31.1	38.3
16	Reduce vehicle emissions & early uptake of Euro V and V1 standards	68.2	61.9	32.9	38.3
17	Reduce NOx: tighter NOx emission standards for gas fired domestic appliances, low NOx burners for power stations, reduction in emissions from small combustion plants	68.3	58.3	31.4	36.5
18	Reduce NOx: tighter NOx emission standards for gas fired domestic appliances, low NOx burners for power stations, reduction in emissions from small combustion plants, early uptake of Euro V and V1 standards	68.4	54.0	30.4	35.3

Results show that scenario 14 (reduction in emissions of sulphur from all shipping, including international shipping) has the greatest reduction on SOx deposition and scenario 2 (reductions in vehicle emissions) on NOx deposition. The greatest reductions in percentage habitat area exceeded for both acidity and nutrient nitrogen are achieved by reducing NOx from vehicles (scenario 2).

ii) Scenario set 2: (scenarios: A, B, C, K, N, O, P, Q): To provide some baseline statistics, critical load exceedances were calculated for the years 2001-03 (CBED data), 2010 and 2020. For acidity, 54.8% of UK sensitive habitats are exceeded for 2001-03, decreasing to 39.4% in 2020. For nutrient nitrogen there is a slightly smaller decrease over this time period, from 59.5% exceeded in 2001-03 to 48.1% in 2020, reflecting the smaller reductions expected in nitrogen deposition.

Eight emission abatement scenarios were then considered and compared with the 2020 baseline. The eight scenarios gave similar results (Table 5.5); differences in the habitat areas exceeded were only 0.8% for acidity and 2.2% for nutrient nitrogen. Overall, Scenario B (Euro high) with the large reductions in nitrogen deposition gave the lowest areas exceeded for both acidity and nutrient nitrogen and for all countries within the UK. Scenario N (shipping emission reductions) gave the smallest reduction in areas exceeded for acidity in England and NI, and in all countries for nutrient nitrogen since nitrogen deposition was only decreased by 1.7% for this scenario. However this scenario gave the greatest reduction in area of exceedance in Scotland. However, the results need to be interpreted with care; the area of habitat exceeded can be the same for different scenarios, but the magnitude of that exceedance can differ. The accumulated exceedance (AE) integrates both the area exceeded and the magnitude of exceedance, but different combinations of these two parameters, such as a large area with a small exceedance, or a small area with a large exceedance, may give the same AE value.

Table 5.5. Deposition budgets and exceedance statistics for scenario set 2

Scenario	Description	Deposition budgets [% reduction from base]		% habitat area exceeded	
		NO_y (kT N)	SO_x (kT S)	Acidity	Nutrient N
Baseline	2020	72.7	87.5	39.4	48.1
A	Euro-low: traffic reductions	68.8 [5.4]	87.5 [0]	38.7	46.8
B	Euro-high: traffic reductions	64.2 [12]	87.5 [0]	37.9	45.6
C	Early Euro-low: traffic reductions	68.6 [5.6]	87.5 [0]	38.7	46.7
K	Large Combustion Plant	66.5 [9]	87.5 [0]	38.2	45.7
N	Shipping reductions	71.5 [1.7]	82.6 [5.9]	38.5	47.8
O	Early Euro-low & LEV*	67.8 [6.7]	87.5 [0]	38.6	46.5
P	Early Euro-low & SCP**	67.9 [6.6]	86.2 [1.5]	38.5	46.5
Q	Early Euro-low & LEV & SCP	67.2 [7.6]	86.2 [1.5]	38.4	46.3

** Low Emission Vehicles; ** Small Combustion Plant*

<u>*iii) Deposition scenario set 3 (scenarios A2, C2, R, S):*</u> Scenarios A2 and C2 were updates to scenarios A and C above. R and S were new scenarios. The deposition budgets are given in Table 5.6 and summary exceedance statistics used by Defra in Tables 5.7 and 5.8 (NB. These tables exclude results for scenario S, as results in this format not required by Defra).

Table 5.6. Deposition budgets for scenario set 3

Scenario*	Description	Deposition budgets	
		NO_y (kT N)	SO_y (kT S)
Baseline	2020 baseline*		96.7
A2	9.4% decrease in NO_y relative to baseline	123.1	96.7
C2	10% decrease in NO_y relative to baseline	122.2	96.7
R	Reductions in NO_x from traffic and SO_2 and NO_x from shipping	119.7	91.1
S		120.6	91.1

** These scenarios were based on an updated version of FRAME compared to the data used for the earlier scenarios in Table 5.5.*

Table 5.7. UK exceedance statistics for acidity, scenario set 3

Scenario	Habitat area exceeded ($km^2 * 10^3$)	% reduction (habitat area exceeded) against baseline	Accumulated Exceedance (AE) (Meq/yr)	% reduction (AE) against baseline
baseline	31.9	-	1739	-
A2	31.0	2.8%	1607	7.6%
C2	30.9	3.1%	1598	8.1%
R	30.1	3.3%	1530	12.0%

Table 5.8. UK exceedance statistics for acidity, scenario set 3

Scenario	Habitat area exceeded ($km^2 * 10^3$)	% reduction (habitat area exceeded) against baseline	Accumulated Exceedance (AE) (Meq/yr)	% reduction (AE) against baseline
baseline	35.5	-	2579	-
A2	34.3	3.4%	2391	7.3%
C2	34.2	3.7%	2379	7.8%
R	33.8	4.8%	2347	9.0%

These results clearly show that, not surprisingly, larger reductions in emissions of both NOx and SOx (rather than NOx alone) have the greatest impact on reducing areas of critical load exceedance. However, larger reductions in NOx alone might achieve similar results.

iv) Assessment of the AQ objectives for ecosystems and vegetation: This assessment was based on identifying and calculating the areas of designated sites (rather than critical load broad habitats) where the AQ objectives were exceeded. Assessment of the air quality objectives for SO_2 (20µg m^{-3}) and NO_x (30µg m^{-3}) identify some areas (typically <1%) where the objectives are exceeded in 2003 for designated sites falling outside the "exclusion zone". Areas are classified as being outside the zone if they are more than 20km from agglomerations and 5km from motorways, other urban areas and industrial installations. The concentration data used for the AQS report included 1km and 5km resolution data that included urban areas (i.e., areas within the exclusion zone). Therefore this result is in contrast to reporting under the EU Daughter Directive (DD) in which no exceedance is recorded. However, the reporting for the DD is based on 30km resolution mean concentration data calculated for rural areas only, to prevent the influence of any urban area appearing unrealistically large on adjacent vegetated areas.

The potential impact of reducing the SO_2 objective to 10µg m^{-3} was also examined using 1km and 5km concentration data; this resulted in some small areas of exceedance but represented <1% of the areas of designated sites outside the exclusion zone. For NH_3, the objective of 8µg m^{-3}, as recommended by the World Health Organisation and ICP Vegetation, was investigated. This was exceeded in only a few areas, coinciding with <0.1% of the area of designated sites in the UK, both for 2002 and 2020.

5.2.2. Dynamic modelling assessments

The full UK dynamic modelling dataset (238,888 VSD 1 km^2 applications for 6 terrestrial habitat types, 310 MAGIC-calibrated surface waters) was used as the basis for submitting scenario assessments in response to the 2006/07 CCE call for data. The methods used are described further in Appendix 3. Following the specifications in the call, a total of 27 scenarios were run based on EMEP forecasts of i) currently legislated emissions forecasts (CLE); maximum feasible reduction (MFR); background deposition; and a set of different combinations of N and S deposition interpolated between the CLE and MFR forecasts. Model code for running these scenarios in the VSD was provided by the CCE, and for MAGIC new code was developed by Jack Cosby in support of the project. For simplicity, results are presented here for the MFR and CLE scenarios only, as the most stringent and least stringent levels of control that are realistically achievable. Due to space limitations, it is not possible to present all model outputs here. Therefore, scenario assessment maps for 2010, 2030 (CLE) and 2030 (MFR) for ANC, pH, total inorganic nitrogen concentration and soil C/N ratio and included in Appendix 4. Predictions for ANC and pH are summarised by habitat class in Table 5.9.

5.2.2.1 Bog

For bogs (Figures A4.1-A4.3), VSD outputs for 2010 show acidic (ANC < 0, pH < 4.4) conditions extending across most areas where this habitat class occurs in Northern England, and locally in southern/central Scotland and western Northern Ireland. Conditions are less acid in Northern Scotland, and where this habitat occurs in Wales and Southwest England. By 2030, there is predicted to be a marked decrease in the extent of the most acidified areas (ANC < -50 µeq l^{-1}, pH < 4.2) for the CLE scenario, and further emissions reductions to the MFR scenario lead to significant additional improvements, e.g. in the pH of Pennine bogs. Organic bog soils are generally effective in retaining N, and substantial N leaching is only predicted from the most high-deposition regions of the Pennines (corresponding to observed high NO_3 leaching from peatland catchments in this region), and locally in parts of northwest Northern Ireland. The CLE scenario has little impact on N leaching relative to 2010, but reductions under the MFR scenario are predicted to achieve major reductions in N leaching, for example from > 20 to < 5 µeq l^{-1} in some areas of the North Pennines.

Table 5.9. VSD-modelled ANC and leachate inorganic N concentrations by habitat class for 2010, 2030 (Current Legislation) and 2030 (Maximum Feasible Reduction)

Bog

ANC ($\mu eq\ l^{-1}$)	2010	2030 CLE	2030 MFR	N_{inorg} ($\mu eq\ l^{-1}$)	2010	2030 CLE	2030 MFR
< -50	8%	5%	1%	> 40	5%	4%	1%
-50 - 0	25%	24%	24%	20 - 40	13%	11%	2%
0 - 20	14%	15%	17%	10 - 20	16%	14%	5%
20 - 50	20%	21%	22%	5 - 10	8%	11%	7%
50 - 100	25%	25%	26%	2.5 - 5	2%	2%	7%
> 100	7%	9%	10%	< 2.5	56%	58%	78%

Montane

ANC ($\mu eq\ l^{-1}$)	2010	2030 CLE	2030 MFR	N_{inorg} ($\mu eq\ l^{-1}$)	2010	2030 CLE	2030 MFR
< -50	0%	19%	14%	> 40	0%	0%	0%
-50 - 0	29%	40%	41%	20 - 40	3%	1%	0%
0 - 20	40%	32%	35%	10 - 20	17%	9%	0%
20 - 50	23%	9%	10%	5 - 10	19%	20%	4%
50 - 100	8%	0%	0%	2.5 - 5	12%	11%	5%
> 100	0%	0%	0%	< 2.5	49%	59%	90%

Acid grassland

ANC ($\mu eq\ l^{-1}$)	2010	2030 CLE	2030 MFR	N_{inorg} ($\mu eq\ l^{-1}$)	2010	2030 CLE	2030 MFR
< -50	6%	4%	2%	> 40	6%	5%	1%
-50 - 0	14%	12%	12%	20 - 40	7%	6%	2%
0 - 20	22%	19%	18%	10 - 20	11%	9%	3%
20 - 50	28%	32%	35%	5 - 10	7%	8%	3%
50 - 100	20%	22%	22%	2.5 - 5	4%	4%	3%
> 100	9%	11%	12%	< 2.5	65%	68%	87%

Heathland

ANC ($\mu eq\ l^{-1}$)	2010	2030 CLE	2030 MFR	N_{inorg} ($\mu eq\ l^{-1}$)	2010	2030 CLE	2030 MFR
< -50	6%	4%	1%	> 40	10%	9%	2%
-50 - 0	14%	13%	11%	20 - 40	9%	8%	5%
0 - 20	22%	19%	18%	10 - 20	11%	10%	5%
20 - 50	29%	33%	36%	5 - 10	10%	10%	4%
50 - 100	22%	24%	24%	2.5 - 5	4%	5%	3%
> 100	7%	8%	9%	< 2.5	56%	59%	81%

Managed broadleaf woodland

ANC ($\mu eq\ l^{-1}$)	2010	2030 CLE	2030 MFR	N_{inorg} ($\mu eq\ l^{-1}$)	2010	2030 CLE	2030 MFR
< -50	40%	37%	21%	> 40	19%	30%	2%
-50 - 0	22%	21%	30%	20 - 40	21%	14%	5%
0 - 20	9%	11%	16%	10 - 20	15%	13%	9%
20 - 50	9%	10%	11%	5 - 10	8%	7%	14%
50 - 100	9%	10%	10%	2.5 - 5	6%	6%	8%
> 100	11%	11%	13%	< 2.5	31%	31%	62%

Managed coniferous woodland

ANC ($\mu eq\ l^{-1}$)	2010	2030 CLE	2030 MFR	N_{inorg} ($\mu eq\ l^{-1}$)	2010	2030 CLE	2030 MFR
< -50	38%	31%	19%	> 40	46%	41%	22%
-50 - 0	33%	34%	37%	20 - 40	20%	18%	10%
0 - 20	11%	14%	21%	10 - 20	15%	17%	9%
20 - 50	10%	12%	14%	5 - 10	4%	5%	7%
50 - 100	5%	6%	6%	2.5 - 5	3%	2%	6%
> 100	3%	3%	4%	< 2.5	12%	17%	46%

Unmanaged woodland

ANC ($\mu eq\ l^{-1}$)	2010	2030 CLE	2030 MFR	N_{inorg} ($\mu eq\ l^{-1}$)	2010	2030 CLE	2030 MFR
< -50	30%	29%	17%	> 40	35%	42%	22%
-50 - 0	24%	22%	27%	20 - 40	19%	18%	17%
0 - 20	13%	14%	18%	10 - 20	11%	9%	16%
20 - 50	14%	15%	16%	5 - 10	5%	3%	9%
50 - 100	9%	10%	10%	2.5 - 5	1%	1%	4%
> 100	10%	10%	11%	< 2.5	28%	28%	32%

Data shown as a percentage of all modelled squares in that habitat class (model runs were only undertaken for 1km grids on acid-sensitive soils). Colours shown correspond to those used in maps in Appendix 4, with black indicating the most severe degree of acidity and N concentration.

5.2.2.2 Montane

Montane ecosystems (Figures A4.4-A4.6) are limited in extent largely to Northern Scotland, where deposition levels are relatively low. As a consequence, most areas in this habitat class are not acidic, and have low N leaching. The exception appears to be the area of the higher-deposition montane region of the eastern Grampians, where greater acidity and N leaching are predicted. The Lochnagar montane AWMN catchment falls within this area, and has acid and high-NO_3 lake concentrations, so these simulations appear plausible. Substantial predicted future changes are largely restricted to this area, which although predicted to remain acidic is expected to show decreasing N leaching, particularly under the MFR scenario.

5.2.2.3 Acid grassland

Acid grasslands are present across most of the UK upland area, and VSD outputs (Figures A4.7-A4.9) show pronounced modelled gradients in acidity and N leaching related to spatial patterns in deposition. In general, pH levels are rarely predicted to be below 4.4 in 2010, but areas of negative ANC are widespread, extending from south and east Wales across most areas of central and northern England (excluding the Lake District) where this habitat type occurs, and into areas of parts of southern and central Scotland (the critical limit for this habitat class is zero ANC). Reductions in the extent of habitat with negative ANC are predicted for 2030 under the CLE scenario, and to a somewhat greater extent for the MFR scenario, but large areas of negative ANC persist. Modelled N leaching shows a somewhat different distribution to ANC or pH, with maximum concentrations in parts of the Welsh borders, the eastern part of the Scottish southern uplands, and southeast Northern Ireland. These areas of N saturation appear to be associated with a combination of relatively high N deposition (e.g. associated with high agricultural NHx emissions) and more mineral soils, with a limited capacity to retain N. Emission reductions under the MFR scenario lead to a dramatic decrease in N leaching across most of these areas, with the apparent exception of some areas of Northern Ireland.

5.2.2.4 Heathland

Heathlands extend across much of Scotland, upland Northern England, Wales and Northern Ireland, together with smaller areas of lowland heath in England such as the New Forest and Surrey Heaths. VSD-modelled ANC for 2010 (Figure A4.10) is highly negative in the Pennines, North York Moors, New Forest and Surrey, with more limited low-ANC areas in Wales, Scotland and Northern Ireland. Modelled pH (Figure A4.11) follows a similar distribution, the lowest pH values simulated for heathlands on blanket peat in Northern England. Many areas of low ANC and pH persist to 2030 under the CLE scenario, but the extent of the most acid ANC and pH classes decreases substantially under the MFR scenario, suggesting that this will lead to significant additional benefits for acidified heathland ecosystems. Modelled N leaching (Figure 4.12) is highest in the South Pennines, Welsh borders, eastern Scottish borders and southeast Northern Ireland. As for acid grassland, this largely reflects the spatial pattern of N deposition. Future changes under the CLE scenario are small, whilst the MFR scenario leads to clear reductions in most areas. For example, N leaching from heathlands across much of Wales, Dartmoor, the English Lake District and Galloway (four regions known to have significant N leaching to surface waters draining moorland catchments at present) is predicted to fall close to background levels under this scenario. As for acid grassland, a striking exception to this general prediction of reduced N leaching under the MFR scenario arises in eastern Northern Ireland, where continued high leaching is simulated.

5.2.2.5 Managed broadleaf woodland

Model outputs for managed broadleaf woodland (Figures A4.13-A4.15) suggest a surprising degree of acidification of this habitat type, extending across most of England (with the exception of areas of Cornwall and the southeast, and to a less severe extent across much of Wales and Scotland). It must be emphasised that these simulations are specifically for areas of managed broadleaf woodland on acid-sensitive soils, not the whole extent of this habitat type, much of which occurs on non-sensitive geology (for example, the Savernake Level II site modelled in Section 1.2.1). Because broadleaf woodland only occurs on mineral soils, organic acidity is typically low, which explains why predicted pH levels are somewhat higher relative to the very low modelled ANCs (in organic soils, by contrast, both mineral and organic acids contribute to low characteristic pH levels for a given ANC). Acidity forecasts suggest limited ecosystem recovery under the CLE scenario, with some improvement under the MFR scenario, but nevertheless considerable persistence of acidic conditions. Modelled N leachate concentrations are greatest in high deposition (and low rainfall) of central and southern England, becoming higher in many regions by 2030 under the CLE scenario due to modelled intensification of N saturation in these soils. As for other terrestrial habitats modelled, modelled N leaching greatly reduces under the MFR scenario

5.2.2.6 Managed coniferous woodland

Most of the UK area of managed conifer occurs in upland areas of Wales and Scotland (Figures A4.16-A4.18). The combination of low soil buffering capacity, high tree base cation uptake, and high rates of S and N deposition to forests contribute to widespread negative modelled 2010 ANCs across much of this area, with the exception of northern Scotland. Smaller areas of this habitat on sensitive soils in England generally have very low modelled ANC, including conifer afforested area of the North York Moors (c.f. surface water data from conifer catchments in this area presented in Section 2.2.2.2.), Sherwood Forest and New Forest. As for managed broadleaf areas, predicted recovery in most areas is slight, even under the MFR scenario. Modelled leachate N concentrations are high across large parts of the country, consistent with many previous studies that have shown higher N leaching from forest versus adjacent moorland catchments. Small N emission reductions under the CLE scenario are sufficient to keep N leaching approximately stable to 2030. Greater reductions under the MFR scenario lead to widespread predicted decreases in N leaching, but with concentrations remaining well above background levels in many areas.

5.2.2.7 Unmanaged woodland

Unmanaged (broadleaf and conifer) woodland areas show a generally similar distribution to the other woodland habitats modelled (Figures A4.19-A4.21), but the absence of forest uptake in unmanaged systems means that modelled acidification is slightly less severe than in managed systems, as the forest does not contribute to soil base cation depletion. On the other hand, N leaching is predicted to be slightly higher, due to the absence of any N removal in harvested biomass (similarly, 'old growth' forests in North America typically leak a greater proportion of N deposition than forests in which tree biomass is still accumulating). Even under the MFR scenario, high leachate N concentrations are predicted in unmanaged woodland areas of southeast England and the Welsh borders.

5.2.2.8 Surface waters

The different methodology for modelling surface waters (MAGIC rather than VSD model, calibration against sample data rather than use of default values for input parameters, application to catchments rather than to a 1km grid) necessitates some differences in output presentation. Given the smaller number of model runs and non-uniform distribution, outputs (Figures A4.22-

A4.23) are aggregated up to a 10km grid. Where multiple sites occur within a 10 km grid, outputs are presented as the lowest modelled ANC (most acid site) and highest modelled NO_3 concentration (most N saturated site). Sites are not distinguished by habitat, and include both moorland and forested catchments. Samples against which MAGIC was calibrated were collected between 1995 and 2002 (most 1999-2002), and the ANC plots for 2000 therefore approximately represent observed values at the time of sampling, with the most acidified sites recorded in the South Pennines, but with a wide distribution of surface waters with ANC < 0 in the Lake District, North Wales, central Galloway and at a small number of sites in the Cairngorms. Model forecasts (for 2050) based on the CLE scenario suggest that all surface waters in the Cairngorms and Galloway, and most of those in the Lake District and Wales, should have positive ANC by this time, but that a substantial number will remain below an ANC of 20 $\mu eq\ l^{-1}$, which is the critical limit for most surface waters. A larger number of surface waters will continue to have a negative ANC in the South Pennines. Further improvements under the MFR scenario are fairly limited in magnitude, suggesting that it may be difficult to achieve recovery in the most acidified surface waters.

Present-day observed surface water NO_3 concentrations (Figure A4.23a) show a spatial pattern that reflects spatial variations in UK N deposition (and which is largely similar to the predictions for soil N leaching from VSD simulations), with maximum concentrations in the South Pennines, lowest concentrations in the Cairngorms, and variable leaching dependent on land-use and soil type in other regions. Predictions for 2050 under the CLE scenario show increasing NO_3 concentrations in some squares but decreases in others (depending on whether or not the decrease in N deposition is offset by increasing N saturation), but limited overall change. Under the MFR scenario, however, substantial decreases are predicted in all areas.

5.2.3. Provision of advice/information to Defra and the devolved administrations

The NFC has responded to requests from Defra and the devolved administrations (and also the Environment Agency and the Conservation Agencies) for advice, information, data (e.g. exceedance statistics) and maps. Exceedance statistics and/or maps have been provided for:

- Defra headline indicators for sustainable development
- Defra e-Digest of Environmental Statistics
- SEPA State of the Environment Report.

In addition, the NFC provides data/maps/advice to researchers working on the Defra Terrestrial and Freshwater Umbrella projects, other Defra projects (eg, UK IAM), Universities, industry and other interested parties (see also WP3.2). In June 2007 the NFC was asked to comment on the EA Habitats Directive Consultation of the "Electricity Supply Industry: Application for Pollution Prevention and Control Permits". The Regulations state that a Permit can only be granted if it can be concluded that the activities it authorises will not adversely affect the integrity of the designated European sites (ie, SACs and SPAs). The preliminary conclusion of the Consultation was that "there will be no adverse effect on the integrity of European sites as a result of releases to air and water from those power stations". The NFC coordinated a response on behalf of CEH, commenting on the "Presentation of Material and Methods", "Site Selection and Site Condition Assessments", "Modelling and Assumptions", "Uncertainties in Modelling" and "Emissions Scaling". The CEH response summary statement concluded that: "*Whilst in some circumstances the contributions from power stations may be relatively small, and may not lead to critical load exceedance alone, they can enhance exceedance or provide the additional amount of deposition that leads to exceedance. We do not believe this consultation document demonstrates that the ESI is not causing an adverse effect; the evidence to support the conclusions drawn is neither clear or transparent.*"

5.3. Milestones and Deliverables

D5.1	*Critical load and dynamic model assessments*	*2004*
D5.2	*Critical load and dynamic model assessments*	*2005*
D5.3	*Critical load and dynamic model assessments*	*2006*
D5.4	*Critical load and dynamic model assessments*	*2007*

All completed

Optional Acitivity I, (Comparison of exceedance estimates based on EMEP and UK deposition data, was completed and reported separately in February 2005 (see Heywood et al, 2005).

Work Package 6: Chairmanship of the UNECE Dynamic Modelling Expert Group

PI: Alan Jenkins
Contributors: Chris Evans, Ed Rowe

6.1 Summary

- The JEG is responsible for guiding and reviewing the development and application of dynamic models for the Convention, and is an important mechanism through which scientific knowledge and outputs from the project are translated into policy relevant guidance to the Working Group on Effects.
- It was organised and held on three occasions during the project. Over this time, the JEG has advised on the terms of the 2004-2006 CCE calls for dynamic modelling data, and reviewed subsequent outputs.
- A major focus has been the development of a coherent international approach to modelling the impacts of N deposition on terrestrial biodiversity, and the JEG organised a one-off, Defra-supported workshop on N modelling in 2005, attended by around 40 international experts, and supported by a detailed 'state of science' review (Rowe et al., 2005).
- The workshop highlighted the potential application of dynamic models to predict eutrophication impacts under the Convention, led to significant progress in developing and integrating modelling approaches between individual countries, and identified data requirements for relating ecosystem chemical status to biological receptors. Development of approaches for modelling N impacts on terrestrial biodiversity are being continued within the auspices of the JEG.

6.2 Description of work

The 5th meeting of the JEG was held in Sitges, Spain, in October 2004 (Appendix 5a). The meeting reviewed outputs from the 2003 call for data and agreed an approach for submitting target loads and scenarios to the CCE for the 2004/05 call for data, including standardisation of certain methods (e.g. constant rates of plant uptake, rather than time-varying values in managed forests). A methodology for combining critical load and target load functions was developed, taking the minimum of the two as the appropriate basis for achieving both ecosystem recovery by the target date, and long-term sustainability of acceptable ecological condition. Issues relating to modelling N dynamics were discussed, and the group identified the need for more mechanistic descriptions of N cycling and better linkages between N cycling and ecosystem responses, and recommended that a workshop be held to bring together modellers and other experts on N processes and impacts on terrestrial ecosystems.

Following the recommendations above, the 6th JEG meeting was held in combination with a workshop on N processes and dynamic modelling in Brighton during October 2005). The N workshop(Appendix 5b) assessed the current state of knowledge for modelling both the biogeochemical cycling of N, and its impact on terrestrial biodiversity, and was supported by a background document prepared by CEH and IVL in Sweden (Rowe et al., 2005). The workshop concluded that current models contained the key pathways and processes required to model N accumulation and its effects, and although significant differences existed between models all incorporated some relationship between soil C/N ratio and N immobilisation. Priority areas for model development were identified, including better representation of C dynamics, internal N transformations, organic N loss and climate change. In terms of predicting N impacts on biodiversity, three levels of complexity were identified, i.e. empirical critical loads for nutrient N;

use of empirical survey-based models (e.g. GBMOVE, one of four national models so far developed), and dynamic models such as VEG and SUMO which are more complex and dynamically integrated with biogeochemical models. Data requirements increase with model complexity, and each approach therefore has applicability for different situations and spatial scales. Priorities for future work included model intercomparison studies, prediction of rare species, incorporation of plant-soil feedbacks, different effects of oxidised and reduced N, quantification of lag times, definition of reference conditions and damage thresholds, modelling the impact of episodic events as triggers for species change, and upscaling to the wider European area. The JEG meeting itself (Appendix 5c) reviewed target load data from the 2004/05 call, and noted the widespread requirement for emissions reductions below critical loads in order to achieve ecosystem recovery within the next 25-100 years.

The 7th JEG meeting, in Sitges during October 2007 (Appendix 5d), reviewed developments on N modelling, and noted the extent to which model development and application were constrained by data availability, including soils data for ecosystems sensitive to eutrophication but not acidification (e.g. calcareous grasslands), and on suitable indicators and damage thresholds for terrestrial ecosystems. It was recommended that modelling groups should liaise with national conservation agencies in order to identify priority ecosystems for protection, and appropriate recovery targets. A number of key inferences from dynamic models regarding to acidification and nutrient N in relation to the review of the Gothenburg Protocol; dose-response functions and stock at risk; and links between observations and critical thresholds, loads and levels.

6.3 Milestones and deliverables

M6.1	*5th JEG Meeting organised and held* *Completed*	*Oct 2004*
D6.1	*Draft report on 5th JEG Meeting completed* *Completed*	*Nov 2004*
D6.2	*Final report on 5th JEG Meeting submitted to WGE* *Completed*	*May 2005*
M6.2	*Report on 5th JEG Meeting delivered at WGE* *Completed*	*Aug 2005*
M6.3	*6th JEG Meeting organised and held* *Completed*	*Oct 2005*
D6.3	*Draft report on 6th JEG Meeting completed* *Completed*	*Nov 2005*
D6.4	*Final report on 6th JEG Meeting submitted to WGE* *Completed*	*May 2006*
M6.4	*Report on 6th JEG Meeting delivered at WGE* *Completed*	*Aug 2006*
M6.5	*7th JEG Meeting organised and held* *Completed*	*Oct 2006*
D6.5	*Draft report on 7th JEG Meeting completed* *Completed*	*Nov 2006*
D6.6	*Final report on 7th JEG Meeting submitted to WGE* *Completed*	*May 2007*
M6.6	*Report on 7th JEG Meeting delivered at WGE* *To be completed (on schedule, but after end of contract)*	*Aug 2007*

All deliverables associated with additional Defra-supported work for the Brighton Nitrogen workshop were also completed

Work Package 7: National Focal Point for ICP-Integrated Monitoring

PI: Mike Hutchins. Contributors: Muriel Bonjean

7.1 Summary

- The consortium has continued to contribute to ICP-IM by submitting UK data, attending Task Force meetings and participating in a European-level assessment of catchment target loads
- The possible effects of climate change on recovery from acidification and target loads have been investigated for a range of sites, with a focus in the UK on the Afon Hafren ICP-IM site. This assessment suggests that the most important detrimental climate change impacts may occur through the accelerated decomposition of organic matter, leading to release of stored nitrogen, leaching of acidic organic compounds, and depletion of soil base saturation.
- Although surface water acidity is sensitive to climate change, predicted changes by 2050 were fairly small, and had little impact on target loads. It is not therefore expected that climate change will either negate the benefits of, or indeed reduce the need for, reductions in S and N deposition on this timescale.
- Greater (probably negative) effects of climate change on acidity and N leaching were predicted towards the latter part of the century. These effects need to be included in model and policy assessments of ecosystem recovery from acidification and eutrophication, but uncertainties probably remain too great to support incorporating climate change factors in the current setting of emissions targets.
- The consortium has also contributed to a European-level assessment of catchment heavy metal budgets.

7.2 Description of work

Activity for this WP, in addition to routine submission of UK data to the ICP-IM data centre, has focused on assessing the impact of climate change on recovery from acidification and target loads. A standardised application of MAGIC, incorporating a range of predicted impacts of climate change relevant to recovery from acidification, was undertaken on 14 sites in Europe and North America, including 3 in the UK (Wright et al., 2006). This work suggested that sensitivity to the climatic factors identified was quite variable between catchments. Projected increases in sea-salt deposition had a negative impact on recovery of coastal sites (see also Evans, 2005), whilst increased decomposition of organic matter in response to climate change was predicted to cause soil and runoff (re)acidification as organic acid and nitrate leaching increased. The effect of increased organic acids is however complicated by concurrent predicted increases in base cation leaching (which buffer stream acidity, but further acidify the soil), and by growing evidence that much of the recently observed increase in organic acid (and DOC) concentrations may have occurred in response to recovery from acidification itself, rather than climatic factors (Evans et al., 2006d).

For ICP-IM, a stand-alone study based on site-specific modeling of Afon Hafren was undertaken, forming the basis for the deliverables from this WP (see below). The objective was to define a methodology for deriving target loads of acidifying S and N deposition at ICP-IM sites throughout Europe, incorporating climate change factors. The model recalibration showed:

- That MAGIC-derived critical loads were consistent (within 5%) of those calculated using the FAB critical load model
- That recovery to ANC > 20 μeq l^{-1} is predicted under current NECD deposition forecast, and that the recovery delay time is short (< 5 years), but that some re-acidification is predicted by 2100 due to increased nitrate leaching. MAGIC calculated 2100 target loads

(0.78 and 0.075 keq ha^{-1} yr^{-1} for total N and non-marine S respectively) are above critical loads.

- That the model is sensitive to climate-driven changes in soil decomposition rate and nitrogen release, which have an adverse effect on stream ANC and nitrate concentration. Overall, however, the combined effects of different predicted climate-induced changes on future stream ANC (and hence target loads) were slight.
- The uncertainty in predicted effects of climate change is high, and requires further research to improve representation of these processes in models. This should include climate-driven extreme events such as acid episodes and nitrate flushes.

For ICP-IM, catchment heavy metal budgets (Cu, Cd, Zn, Pb) have also been collated and analysed for many sites across Europe. The UK NFP has contributed data from Allt a'Mharcaidh for Cu and Zn (precipitation, air chemistry, runoff concentrations, soil water, groundwater). Results were submitted to the WGE Executive Body in 2005.

Further details of the work undertaken for this WP within the ICP-IM programme are contained in the 15th and 16th Annual ICP-IM reports, available on the ICP-IM Programme Centre website: http://www.environment.fi/default.asp?node=6333&lan=en.

7.3 Milestones and Deliverables

M7.1	*Completion of database for 2003* *Completed*	*Oct 2004*
M7.2	*Data transmission to EDC Helsinki* *Completed*	*Nov 2004*
M7.3	*Attendance at ICP-IM Task Force* *Completed*	*Apr 2005*
D7.1	*Interim report on dynamic modelling of climate interactions* *Completed (in 15th Annual ICP-IM report)*	*May 2005*
D7.2	*Final report on DM and climate interactions to WGE* *Completed (in 16th Annual ICP-IM report)*	*Aug 2005*
M7.4	*Completion of database for 2004* *Completed*	*Oct 2005*
M7.5	*Data transmission to EDC Helsinki* *Completed*	*Nov 2005*
M7.6	*Attendance at ICP-IM Task Force* *Completed*	*Apr 2006*
M7.7	*Completion of database for 2005* *Completed*	*Oct 2006*
M7.8	*Data transmission to EDC Helsinki* *Completed*	*Nov 2006*
M7.9	*Attendance at ICP-IM Task Force* *Completed*	*Apr 2007*
M7.10	*Completion of database for 2006* *To be completed (on schedule but after end of contract)*	*Oct 2007*
M7.11	*Data transmission to EDC Helsinki* *To be completed (on schedule but after end of contract)*	*Nov 2007*

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