STUDIES OF ACID DEPOSITION FROM THE UK POWER INDUSTRY

Stephen J. Griffiths
Power Technology, Powergen
Stephen.Griffiths@powertech.co.uk

ABSTRACT

It has long been established that the deposition of acid species can result in damage to sensitive ecosystems and this forms a strong regulatory driver for action to reduce the emissions of acid precursor species such as sulphur dioxide and nitrogen oxides. The UK electricity generators Joint Environmental Programme (JEP) has developed a UK and European version of the USEPA Models-3/CMAQ system in order to meet the acid deposition modelling needs of the power generation industry. Models-3 is able to simulate the wet and dry deposition of acid species on an hourly resolution.

In order to overcome the extensive run-times required to generate annual wet and dry deposition maps, an aggregation scheme was developed by UEA enabling single examples of periods of similar meteorology to be modelled and the multiplied up by their frequency of occurrence to generate the full annual deposition results.

The aggregation scheme has been tested and applied to an annual study of the impacts of power station emissions on acid deposition in the UK. The impact of power station emissions on acid critical loads based on 1999 emissions has been assessed and found to be minor, with only one of the nine ecosystem types being exceeded over greater than 1% of the total area. A significant proportion of critical load exceedances due to power stations alone were found to be associated with very low assigned critical loads, rather than high deposition values.

INTRODUCTION

The reduction of damage to ecosystems due to acid deposition forms a strong regulatory driver for action to decrease emissions of the species which contribute to acidity, primarily sulphur dioxide, nitrogen oxides and ammonia. Critical loads are used to estimate the degree to which acid deposition results in adverse effects on ecosystems and this effects-based approach is used to guide policy both in the UK and internationally. As significant emitters of SO_2 and NO_x in the UK, it is important for the power industry to be aware of the impacts of their emissions in terms of acid deposition. Critical loads in the UK are calculated and mapped by the Centre for Ecology and Hydrology (CEH). The UK critical loads for acidity were revised in February 2003 [1] to take account of developments in mapping of habitats and methods for calculating critical loads. Notably, the number of ecosystems for which acid critical loads were available increased from six to nine, namely, acid grassland, calcareous grassland, bog, dwarf shrub heath, coniferous woodland, broad-leaved, mixed and yew woodland (unmanaged), broad-leaved, mixed and yew woodland (managed), montane and freshwaters. Models-3 has been used to generate maps of acid deposition arising from emissions from the JEP company coal and oil-fired power stations in the UK and these fields have been used to assess the impacts in terms of the revised critical loads

MODEL SET-UP

Models-3 is an Eulerian model simulating emissions, meteorology, transport, chemistry and deposition on an hour by hour basis. The model has been adapted for use in the UK by the JEP and extensive documentation and validation has been carried out [2]. The model domain used in this study consists of 3 horizontal nested grids; an outer grid covering Europe, at a 108km grid cell resolution, a 36km resolution grid covering the UK and a 12km resolution grid covering England and Wales corresponding to the area shown in Figures 1 and 2. A twenty-one layer vertical grid corresponding to a total atmospheric height of 15 km was used for all three grids, the surface layer depth being 40 metres. The RADM2 chemical scheme, coupled with aerosol and aqueous chemistry was selected from the schemes available in Models-3.

Meteorological data were supplied by the UK Met Office and emissions data were derived from the UK National Atmospheric Emissions Inventory [3] and EMEP [4]. The emissions data were processed using the SMOKE emissions modelling system [5] to produce temporally resolved and speciated data suitable for input to Models-3. SMOKE was also used to vertically resolve high-level point source emissions using a plume-rise algorithm. A more detailed discussion of the model set-up can be found elsewhere [6], [7].

AGGREGATION SCHEME

Due to the detailed hourly modelling performed by Models-3, full annual runs are computationally time-consuming. In order to reduce run times, an aggregation scheme has been developed by UEA [8]. This scheme involves modelling a selection of 5-day ‘clusters’, each associated with a specific weather type and multiplying the results up by their frequency of occurrence and then aggregating the results. The scheme was validated against a full year annual run [9] and found to reproduce the spatial pattern of deposition very well. The original methodology for application of the scheme resulted in an under-estimation of around 11% (due to the decision not to model cluster types associated with very dry weather to further reduce run-times) and modelled results from the aggregation scheme presented in this report have been scaled up to account for this.

Models-3 was run twice using the aggregation scheme, once including all UK sources and once including all UK sources with the exception of JEP coal and oil-fired power stations. The difference between these two runs was mapped for the 12km domain to produce the deposition fields due to UK power stations. Sulphur deposition includes SO_2, H_2SO_4 and aerosol sulphate, whilst nitrogen deposition includes NO, NO_2, HNO_3, aerosol nitrate and ammonia. Note that ammonia emissions from power plant are negligible. Figures 1 and 2 show the modelled total deposition fields for acidity associated with sulphur and nitrogen respectively. The different patterns reflect the dominance of SO_2 dry deposition for sulphur, whilst for nitrogen, longer range conversion processes are important with aerosol nitrate contributing significantly.

ASSESSMENT PROCESS

The sulphur and nitrogen deposition fields arising from JEP power plant were combined and reprojected from the Models-3 grid to the UK National Grid on which the critical loads are defined. For each of the nine acid critical load ecosystem types, the area over which the critical load was exceeded was determined as a percentage of the total ecosystem area within the Models-3 grid. The areas over which the sulphur acid critical load parameter (MaxS) and the nitrogen critical load parameters (MaxN and MinN) were exceeded were also examined in order to determine which pollutant was driving the exceedances.

RESULTS

The actual and percentage area of each of the ecosystem types exceeded is shown in Table 1, together with the percentage area over which each of the three critical load parameters are exceeded. It can be seen that the figures are very low, with three ecosystems showing no exceedance and five exceeded over less than 1% of their total area. The freshwater ecosystem was exceeded over 3% of its area. Figures 3 and 4 show the area exceeded for two of the ecosystems. Note that the grey line indicates the extent of the Models-3 domain. Examination of similar maps for each of the Habitat types showed that the exceedance is highly regional, with exceeded areas primarily located in the Midlands and the North where deposition totals are highest. It is also evident that the level of exceedance is low, being less that 0.2keqH^+/ha/yr in most cases.

Examination of the critical load parameter exceedances shows that the acidity critical load exceedances are driven by sulphur (ie. exceedance of MaxS) with no exceedance of MaxN for any ecosystem. Values of MaxS for acid grassland, bog and dwarf shrub heath (0.16 to 0.45 keqH^+/ha/yr) appear reasonable, however for the woodland and freshwater habitats, 33-44% of exceeded MaxS values were below 0.005 keqH^+/ha/yr. There is some debate as to how such low critical levels should be applied and interpreted as in many areas these levels will have been exceeded for over a hundred years due to industrial emissions, implying that the ecosystems should in fact not exist.

JEP coal and oil-fired stations emitted a total of 680kt of SO_2 in 1999. The October 1998 White paper “Review of Energy Sources for Power Generation” set out a 365kt SO_2 emission target for 2005 for UK power stations. As a simple exercise, the 1999 power plant deposition field for sulphur acidity was scaled down by the ratio of these figures and reapplied to the critical loads assessment to ascertain how exceedances might change in the future. The results suggested that the acid grassland, bog and dwarf heath ecosystems would no longer be exceeded and that the areas of coniferous woodland, managed broad-leaved woodland and freshwater exceeded due to power station emissions alone would be reduced by 60%, 34% and 35% respectively. In all cases, the remaining exceedances were almost wholly associated with the exceptionally low MaxS values.

Ecosystem Type	Total Area km^2	Critical Load Exceeded Area km^2	Critical Load Exceeded area %	MaxS Exceeded area %	MaxN Exceeded area %	MinN Exceeded area %
Acid grassland	8106.6	24.9	0.3%	0.3%	0.0%	0.0%
Bog	1572.9	1.8	0.1%	0.1%	0.0%	0.2%
Dwarf shrub heath	5392.3	1.2	0.02%	0.02%	0.0%	0.0%
Calcareous Grassland	1762.9	0.0	0.0%	0.0%	0.0%	0.0%
Montane	22.9	0.0	0.0%	0.0%	0.0%	0.3%
Coniferous Woodland	4625.6	31.4	0.7%	0.7%	0.0%	0.0%
Broad-leaved woodland (managed)	6709.4	53.0	0.8%	0.8%	0.0%	0.0%
Broad-leaved woodland (unmanaged)	2949.6	0.0	0.0%	0.0%	0.0%	1.6%
Freshwater	1243.6	37.1	3.0%	3.0%	0.0%	0.4%

Table 1. Critical load exceedance due to JEP coal & oil-fired power plant only

CONCLUSIONS

Assessment of acid critical load exceedances due to deposition arising from JEP coal and oil-fired power station emissions in the UK suggests that power plant makes only a minor contribution to critical load exceedances. Three ecosystem types show no exceedance, five were exceeded over less than 1% of their area and the freshwater critical load exceedance covers only 3% of its area. All critical load exceedances associated with power stations were due to exceedance of the MaxS parameter, and for freshwater and woodland habitats, a significant proportion of the exceedance was due to MaxS values below 0.005 $keqH^+$/ha/yr. There is some debate as to the robustness of using such low critical loads as these levels of deposition are likely to have been exceeded in the UK for in excess of a century in many areas, due to historical levels of industrial SO_2 emissions.

Scaling the sulphur deposition field downwards to reflect the projected 2005 sulphur dioxide power station emissions of 365kt suggested that only three ecosystem types would be exceeded and that these would almost wholly be due to the low MaxS critical loads. Given that legislation such as the National Emissions Ceilings Directive and the Large Combustion Plant Directive will deliver still further reductions in power station emissions, it is likely that power station emissions will make a very minor contribution to critical load exceedances by the end of the decade.

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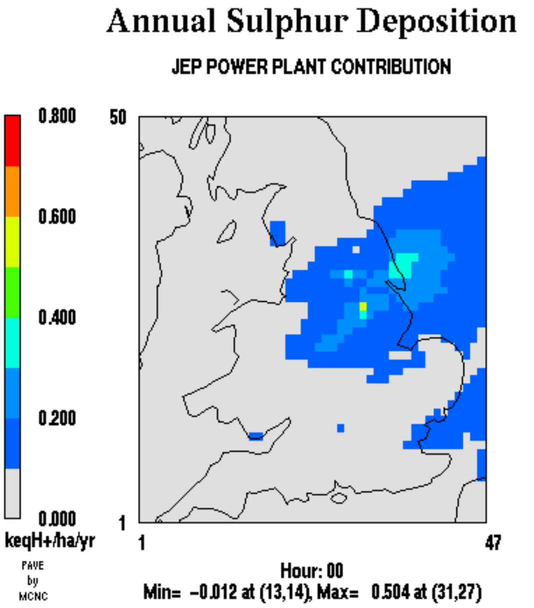

Figure 1. Annual sulphur deposition due to JEP power stations (keqH+/ha/yr)

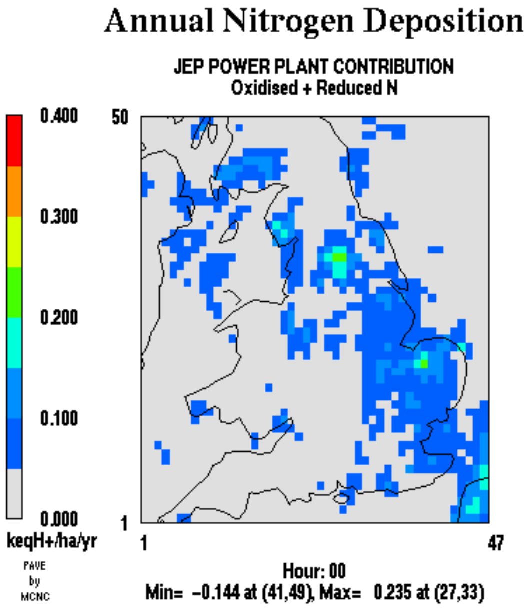

Figure 2. Annual nitrogen deposition due to JEP power stations (keqH$^+$/ha/yr)

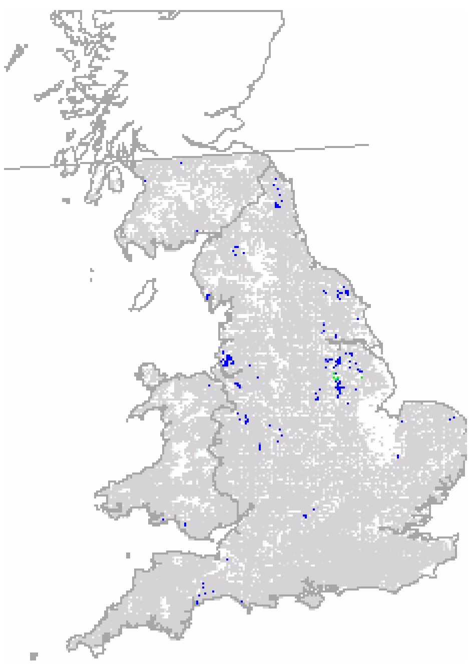

Figure 3. CL exceedance due to power station deposition only
Broad-leaved , mixed & yew (managed)

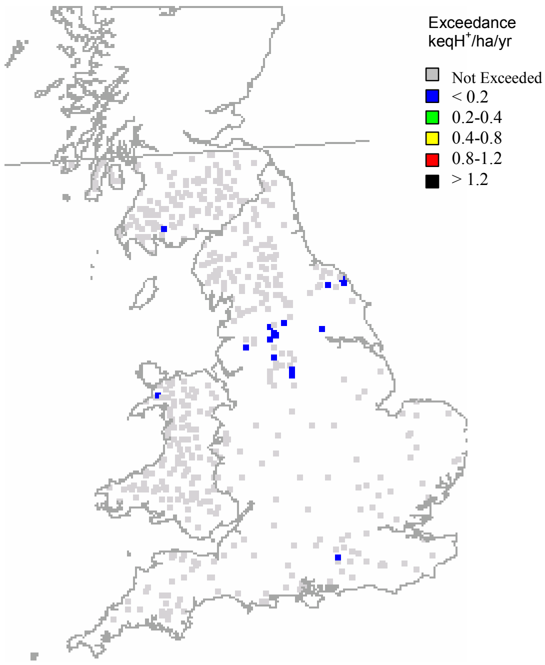

Figure 4. CL exceedance due to power station deposition only
Freshwater