UCL ENVIRONMENTAL CHANGE RESEARCH CENTRE

UCL

Reconstructing the past Monitoring the present Modelling the future

Research Report # 151

Freshwater acidity critical loads for the UK; an assessment of the proposed Hunterston multi-fuel power station on freshwater acidity status

G L Simpson

August 2012

Freshwater Acidity Critical Loads for the UK; an assessment of the effect of the proposed Hunterston multi-fuel power station on freshwater acidity status

Gavin L. Simpson

August 3, 2012

Contents

List of Tables

List of Figures

Chapter 1

Introduction

Freshwater critical loads are based upon the maintenance of acid neutralising capacity (ANC) above a critical concentration (ANC_{crit}). The critical concentration is defined with respect to a target organism, such as population status of brown trout, or with respect to some other concentration determined a priori as representative of natural ANC. For example, in the UK $ANC_{crit} = 20$ is now used for all sites in the national critical loads submissions other than those where other evidence (notably palaeolimnological data) indicates that ANC concentrations of waters are naturally low (Curtis and Simpson, 2004). In such cases $ANC_{crit} = 0$ is used.

In the critical loads models routinely used ANC is defined as the sum of base cations minus the sum of strong acids (Henriksen et al., 1992). Measured chloride is assumed to be all of marine origin and hence associated with an equivalent amount of base cations. Chloride is therefore used to remove the marine contribution to base cation inputs. ANC is then defined as

$$\mathrm{ANC} = [\mathrm{BC}]^* - [\mathrm{AN}]^* \tag{1.1}$$

where [BC] is the sum of base cation concentrations, [AN] is the sum of acid anion concentrations (Curtis et al., 2000). The superscript * indicates the non-marine component.

Critical loads were calculated for the 1752 sites in the UK national critical loads mapping data set as used by UK Defra. Using two deposition scenarios based on FRAME-modelled future deposition for the year 2020 critical load exceedances were also computed on the basis of the derived critical loads. The two deposition scenarios are a baseline scenario and a scenario including emissions from the Hunterston multi-fuel power station. Two values of ANC_{crit} were proposed by SEPA; i) $ANC_{crit} = 40$, which corresponds to the Water Framework Directive (WFD) definition for the boundary between High and Good status, and ii) $ANC_{crit} = 80$, which is under consideration as a new standard for the boundary between High and Good status for rivers. In addition, critical loads for a third ANC_{crit} were computed; the national standard ANC_{crit} as used by UK Defra (see above).

The aim of this work is to assess the likely impact of the proposed Hunterston multi-fuel power station on designated conservation sites (Special Areas of Conservation [SACs], Special Protection Areas [SPAs] and Sites of Special Scientific Interest [SSSIs]) across the UK as part of the Appropriate Assessment via the critical loads approach.

1.1 Critical Loads Models

Two critical loads models have been used widely in the UK and Europe to relate deposition fluxes of sulphur and nitrogen to selected measures of environmental damage. These models are the Steady-State Water Chemistry (SSWC) model (Henriksen et al., 1992) and the First-Order Acidity Balance (FAB) model (Posch et al., 1997). The SSWC model is relative simple with few data requirements and can be used wherever major ion water chemistry (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, NO_3^{-}, Cl^{-}) are available along with estimates of net runoff (Q) and acid deposition. The SSWC model provides an estimate of the sustainable (pre-industrial) leaching rate of base cations and hence of ANC.

The FAB model is considerably more complex than, though builds upon, the SSWC model incorporating a mass balance for nitrogen (N) to allow for potential changes in N leaching. The N mass balance requires the availability of catchment scale soils data, lake:catchment area ratio and N fluxes in biomass removed by harvesting. The FAB mass balance for a catchment incorporates major sources and sinks of S and N is (Posch et al., 1997, Curtis et al., 1998)

$$\mathrm{N_{dep}} + \mathrm{S_{dep}} = f(\mathrm{N_{upt}}) + (1-r)(\mathrm{N_{imm}} + \mathrm{N_{den}}) + r\mathrm{N_{ret}} + r\mathrm{S_{ret}} + \mathrm{AN_{leach}} \tag{1.2}$$

where N_{dep} and S_{dep} are the total N and S deposition respectively, N_{upt} the net growth uptake of N by forest vegetation removed by harvesting, N_{imm} long-term immobilisation of N in catchment soils, N_{den} N lost through denitrification in catchment soils, N_{ret} and S_{ret} in-lake N and S retention, AN_{leach} leaching of acid anions ($S + N$) from the catchment, f the fraction of forested area in the catchment, and r the lake:catchment area ratio. All units (except f and r which are dimensionless) are equivalents per unit area and time.

The acid anion balance of the FAB model provides the critical leaching flux of acid anions (critical AN_{leach}) which will depress ANC below

ANC_{crit}. As a result, at critical load, AN_{leach} can be substituted into (1.2) as

$$AN_{leach} = (BC_{crit} - ANC_{crit}) \cdot Q \tag{1.3}$$

where BC_{crit} is the sustainable leaching flux of base cations from weathering and fixed deposition inputs computed via the SSWC model and Q is runoff, which is used to convert AN_{leach} into a flux.

1.2 Methods

As the FRAME desposition scenarios are on a 5km grid, deposition data for each of the 1752 sites in the FAB mapping data set were produced by overlaying the FAB sites onto the deposition grids.

All critical loads and exceedances were computed using the R statistical software (R Core Team, 2012) via the critical package (Simpson, unpublished code) to national standards. Critical loads and exceedances are presented in two ways.

The national critical loads data are traditionally presented as point data and mapped as such. This is in contrast to the original freshwater critical loads maps where the data were presented as grid square values. The reason for the change in presentation is that the national freshwater critical loads data set has been considerably expanded since compilation of the original data and now includes a number of intensive regional water chemistry surveys in areas sensitive to acid deposition. These regional data sets are better displayed as individual point data rather than being aggregated to grid square averages.

In addition to the point-based critical loads and exceedances, these data were also aggregated to a 5 km grid over the entirety of the UK. Grid average, minimum and maximum values were computed. A 5km grid was chosen as this was the same as the spatial resolution of the FRAME deposition data. Grid box minimum, mean and maximum values were generated.

The point data critical loads, critical load functions and exceedances were exported from R in ESRI™ shapefile format. The gridded data sets were exported as ESRI™ Arc ASCII Grid format files with a separate file for each variable. All files were exported in the Ordnance Survey national grid coordinate reference system (OSGB).

Chapter 2

Results

2.1 Point-based critical load exceedance

The numbers of sites that exceed their critical load under FRAME 2020 baseline and PEC deposition scenarios for the three values of ANC_{crit} used here are summarised in Tables 2.1, 2.2, 2.3.

With increasing ANC_{crit} there are consequently higher numbers of exceeded sites owing to the lower critical load required to maintain the higher ANC and thus provide a higher level of protection to a site. Differences between baseline and PEC deposition scenarios are small with a limited number of extra sites exceeding critical loads under PEC deposition. Given the small differences in modelled deposition, the increased numbers of exceeded sites in the PEC scenario most likely derive from those that are on the borderline of exceedance for a given ANC_{crit}.

Note that the proportions of sites exceeded are not representative for regions as a whole as the data are not a random sample from the population of sites and include greater sampling effort in several of the most acid sensitive upland areas of the UK.

Table 2.4 shows a breakdown of the numbers of sites in the entire data set by critical load exceedance class for combinations of deposition scenario and ANC_{crit}. Whilst fewer sites are not exceeded under the PEC deposition scenario, the effect it largest for the UK standard ANC_{crit} with only two and three additional exceeded sites respectively for critical loads using $ANC_{crit} = 40$ $ANC_{crit} = 80$.

The change in the number of sites within each exceedance class between baseline and PEC deposition scenarios is shown in Table 2.5, again underlining the fact that change in critical load exceedance is limited.

Critical load exceedance maps for the combinations of ANC_{crit} and deposition scenario are shown in Figures 2.1–2.6

Table 2.1: Breakdown of critical load exceedance for freshwaters under FRAME-modelled 2020 deposition for baselines and PEC scenarios. The UK standard ANC_{crit} of 20 (0 for some naturally acid systems) was used to calculate critical loads.

	Sites	Baseline	%	PEC	%
England	425	196	46.12	196	46.12
Wales	856	128	14.95	133	15.54
Scotland	344	98	28.49	99	28.78
Northern Ireland	127	17	13.39	17	13.39
UK	1752	439	25.06	445	25.40

Table 2.2: Breakdown of critical load exceedance for freshwaters under FRAME-modelled 2020 deposition for baselines and PEC scenarios. $ANC_{crit} = 40$ was used to calculate critical loads.

	Sites	Baseline	%	PEC	%
England	425	208	48.94	209	49.18
Wales	856	222	25.93	224	26.17
Scotland	344	143	41.57	143	41.57
Northern Ireland	127	19	14.96	19	14.96
UK	1752	592	33.79	595	33.96

Table 2.3: Breakdown of critical load exceedance for freshwaters under FRAME-modelled 2020 deposition for baselines and PEC scenarios. $ANC_{crit} = 80$ was used to calculate critical loads.

	Sites	Baseline	%	PEC	%
England	425	222	52.24	222	52.24
Wales	856	345	40.30	347	40.54
Scotland	344	219	63.66	219	63.66
Northern Ireland	127	26	20.47	26	20.47
UK	1752	812	46.35	814	46.46

Table 2.4: Breakdown of critical load exceedance for freshwaters under FRAME-modelled 2020 deposition for baselines and PEC scenarios. The table shows the number of sites within each exceedance class for combinations of deposition scenario and AND_{crit}.

		Critical Load Exceedance				
Deposition	ANC_{crit}	Not exceeded	≤ 0.5	0.5–1	1–2	>2
Baseline	UK	1313	244	135	60	0
PEC	UK	1307	247	134	64	0
Baseline	40	1160	264	192	131	5
PEC	40	1157	263	194	132	6
Baseline	80	940	213	221	319	59
PEC	80	938	210	222	321	61

Table 2.5: Breakdown of change in critical load exceedance for freshwaters under FRAME-modelled 2020 deposition for baselines and PEC scenarios. The table shows the change in the number of sites within each exceedance class between the FRAME baseline and PEC scenarios for three values of AND_{crit}. A negative value indicates fewer sites in an exceedance class under PEC deposition than under baseline deposition.

	Critical Load Exceedance				
ANC_{crit}	Not exceeded	≤ 0.5	0.5–1	1–2	>2
UK	-6	3	-1	4	0
40	-3	-1	2	1	1
80	-2	-3	1	2	2

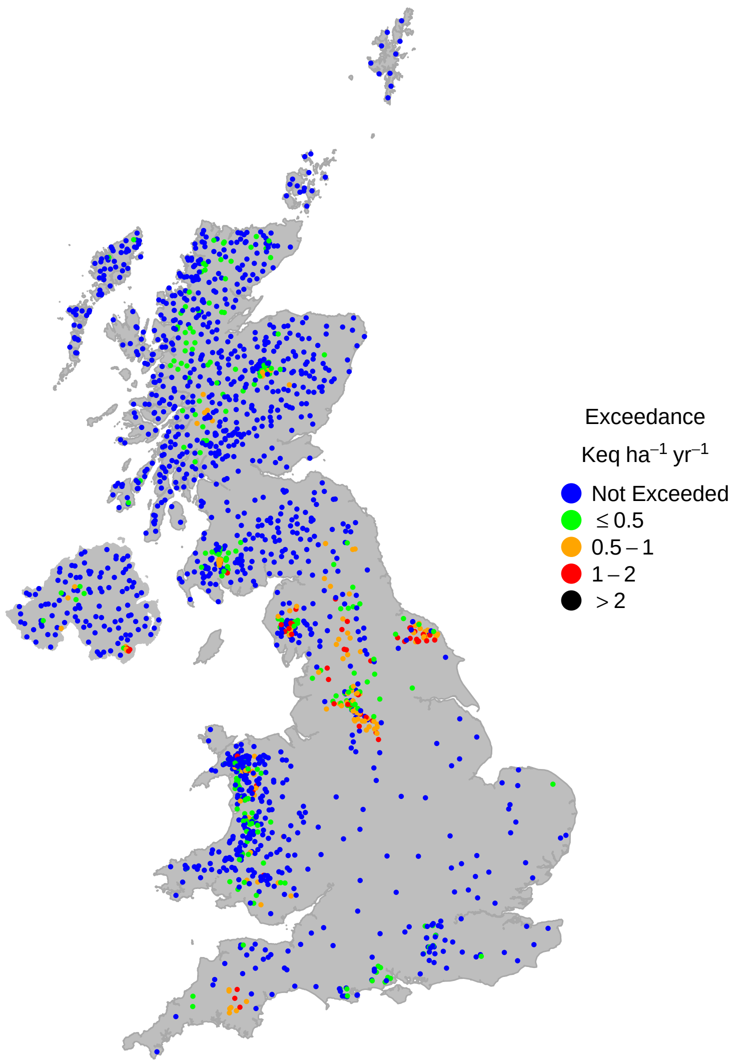

Figure 2.1: FAB model critical load exceedance map for freshwaters for the FRAME 2020 baseline deposition scenario and the UK standard ANC_{crit}.

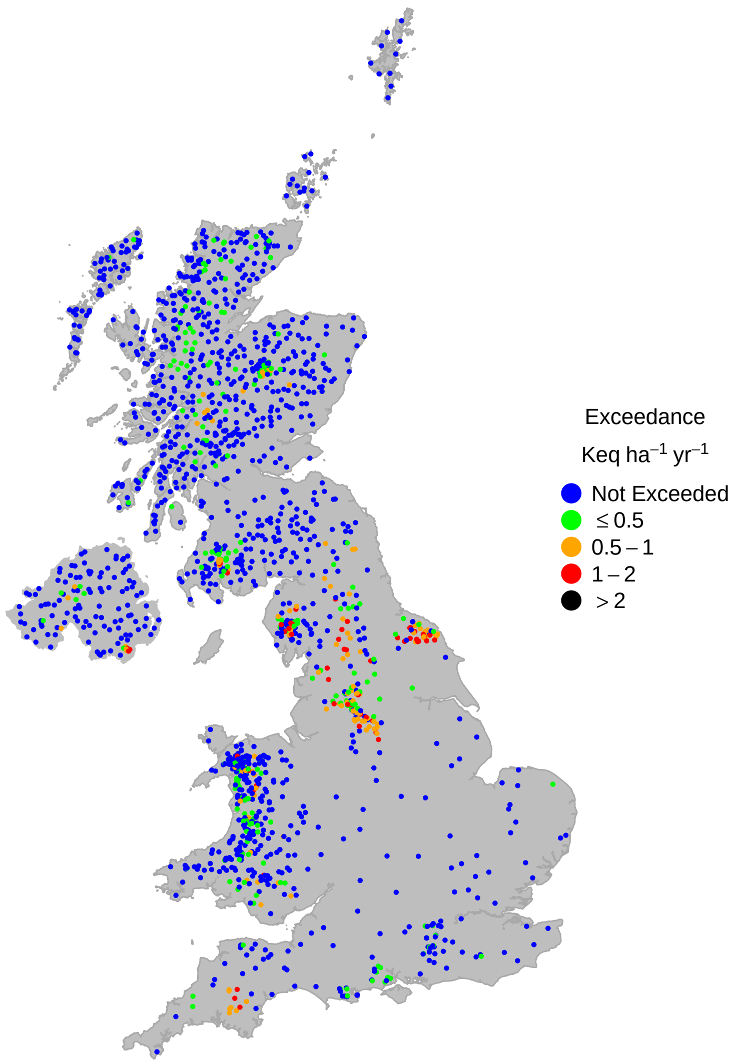

Figure 2.2: FAB model critical load exceedance map for freshwaters for the FRAME 2020 PEC deposition scenario and the UK standard ANC_{crit}.

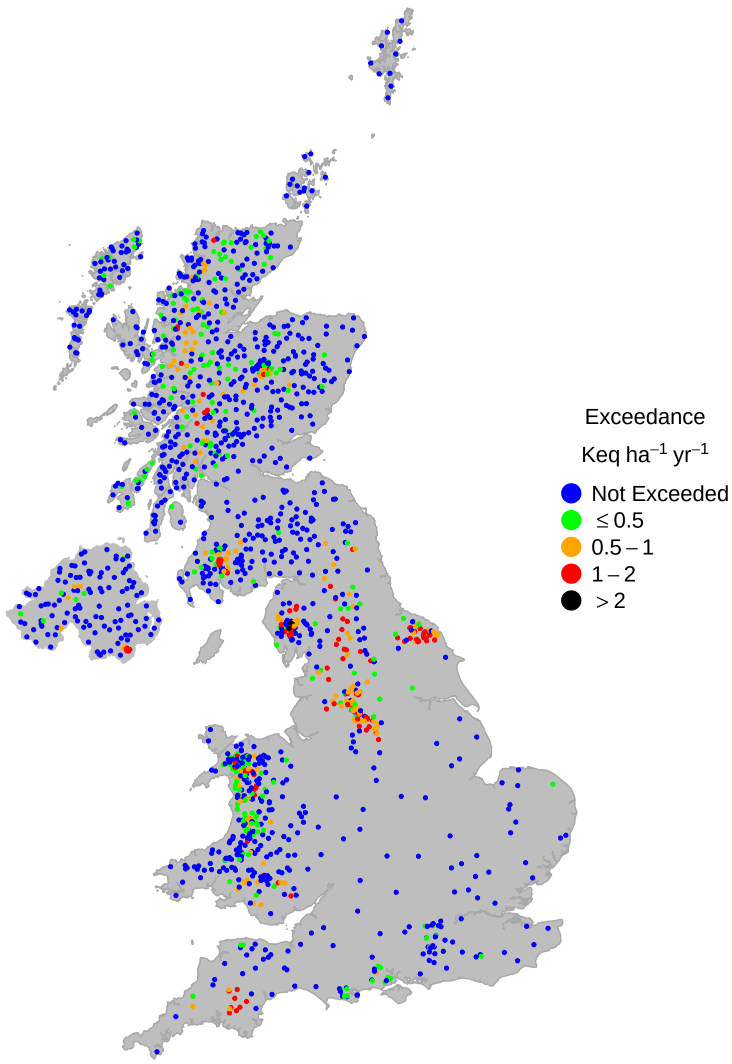

Figure 2.3: FAB model critical load exceedance map for freshwaters for the FRAME 2020 baseline deposition scenario and $ANC_{crit} = 40$.

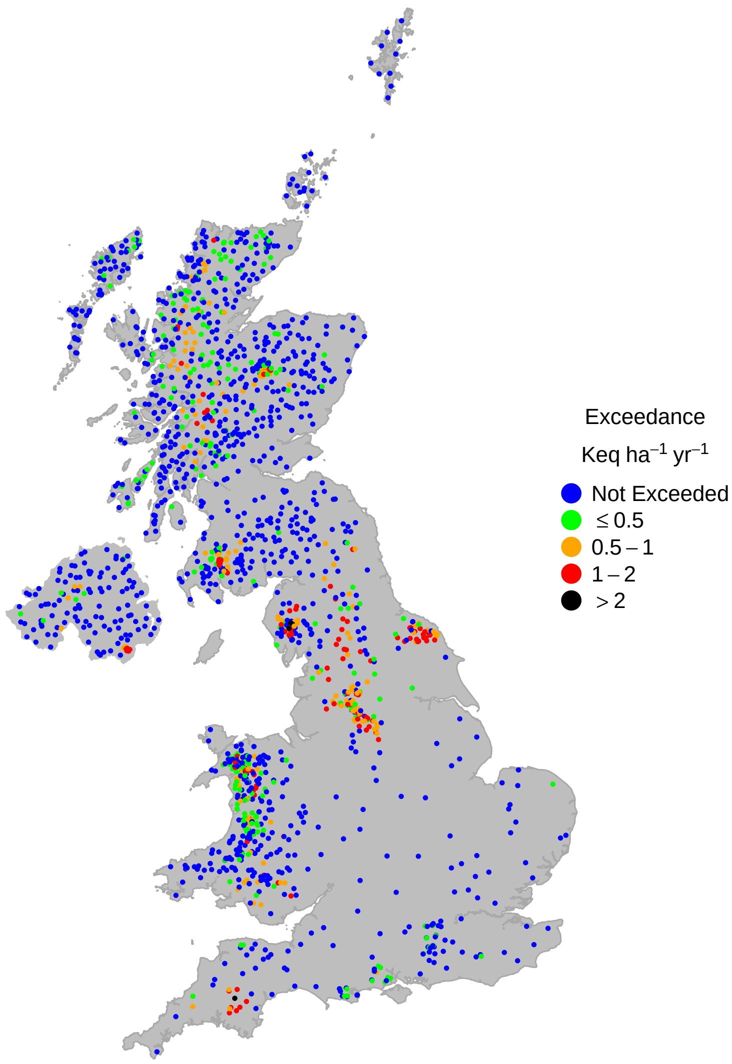

Figure 2.4: FAB model critical load exceedance map for freshwaters for the FRAME 2020 PEC deposition scenario and $ANC_{crit} = 40$.

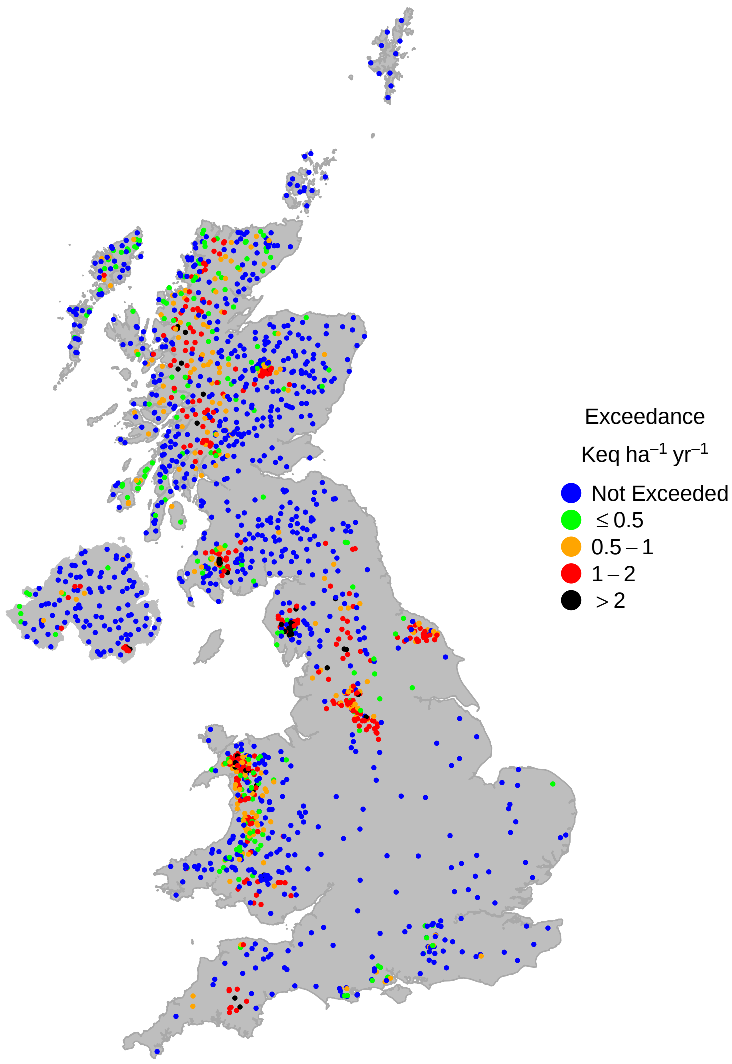

Figure 2.5: FAB model critical load exceedance map for freshwaters for the FRAME 2020 baseline deposition scenario and $\mathrm{ANC_{crit}} = 80$.

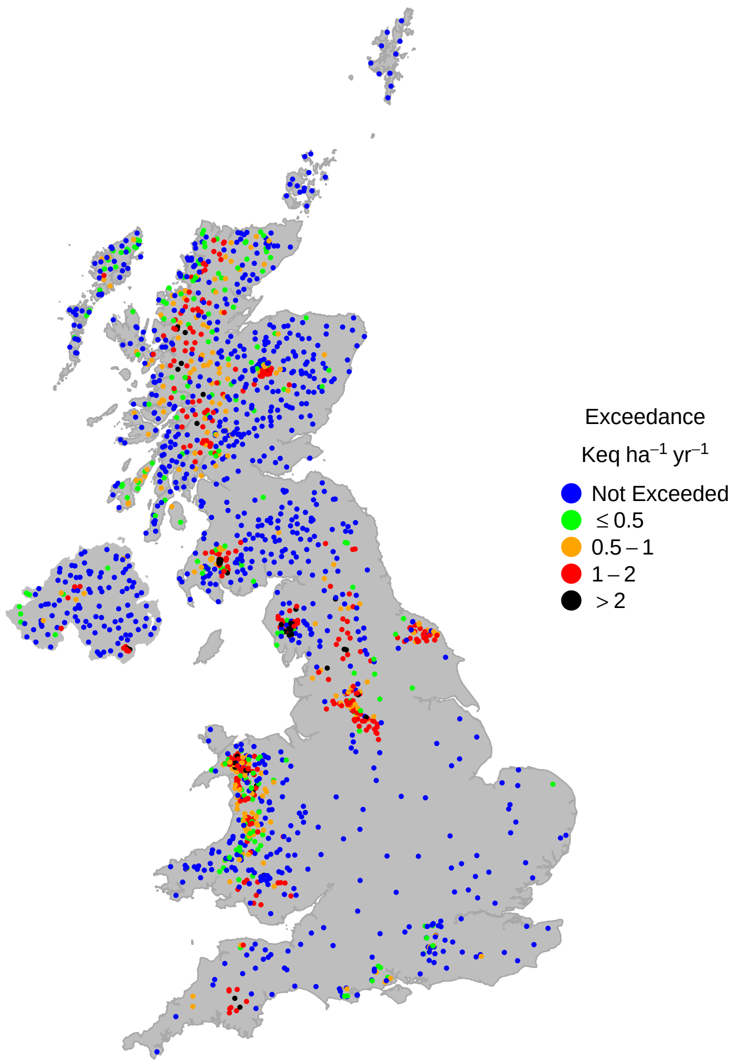

Figure 2.6: FAB model critical load exceedance map for freshwaters for the FRAME 2020 PEC deposition scenario and $ANC_{crit} = 80$.

2.2 Grid based critical load exceedance

Figures 2.7–2.12 show critical load exceedance for the various deposition scenario and ANC_{crit} combinations. Grid box minimums, means, and maximums are presented for each combination of deposition scenario and ANC_{crit}.

We do not discuss these results further as they present a biased view of acidity status of freshwaters in the UK and are inconsistent with the way critical load exceedances are reported to UK Government and to international initiatives.

The grid-based results may be used however to infer critical load exceedance for sites not in the UK national critical loads data set.

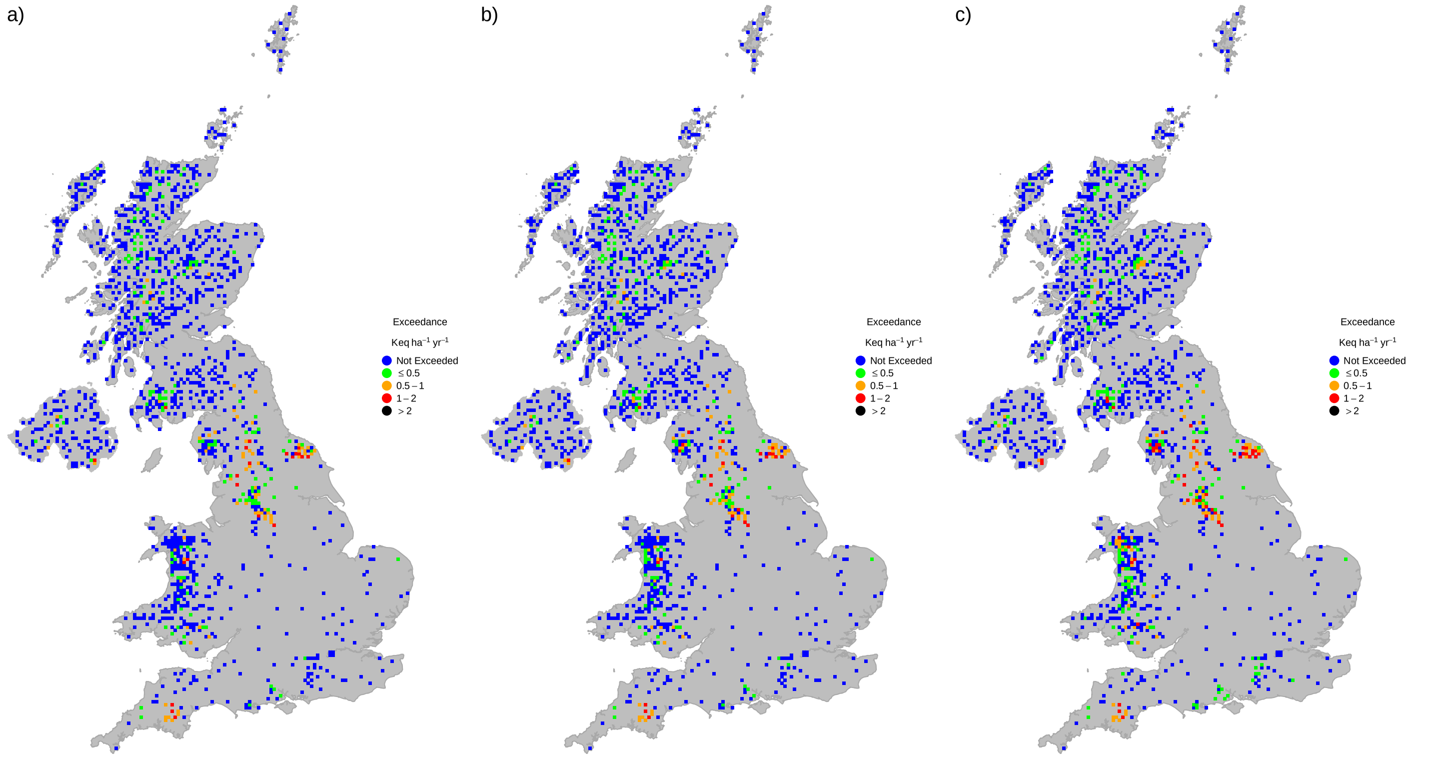

Figure 2.7: FAB model critical load exceedance map for freshwaters for the FRAME 2020 baseline deposition scenario and UK standard ANC_{crit} on a 5km grid. Exceedances are shown as the grid box a) minimum, b) mean, and c) maximum respectively.

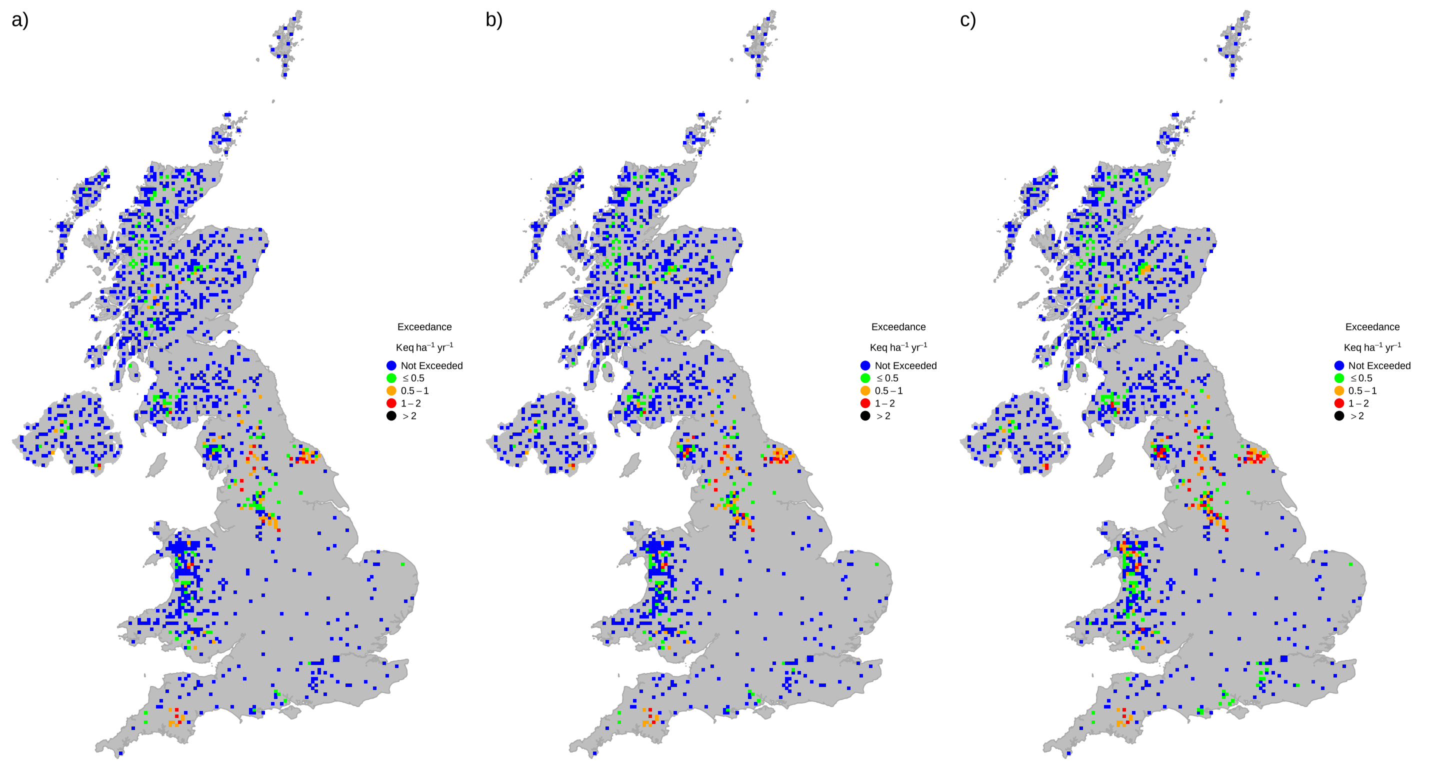

Figure 2.8: FAB model critical load exceedance map for freshwaters for the FRAME 2020 baseline deposition scenario and UK standard ANC_{crit} on a 5km grid. Exceedances are shown as the grid box a) minimum, b) mean, and c) maximum respectively.

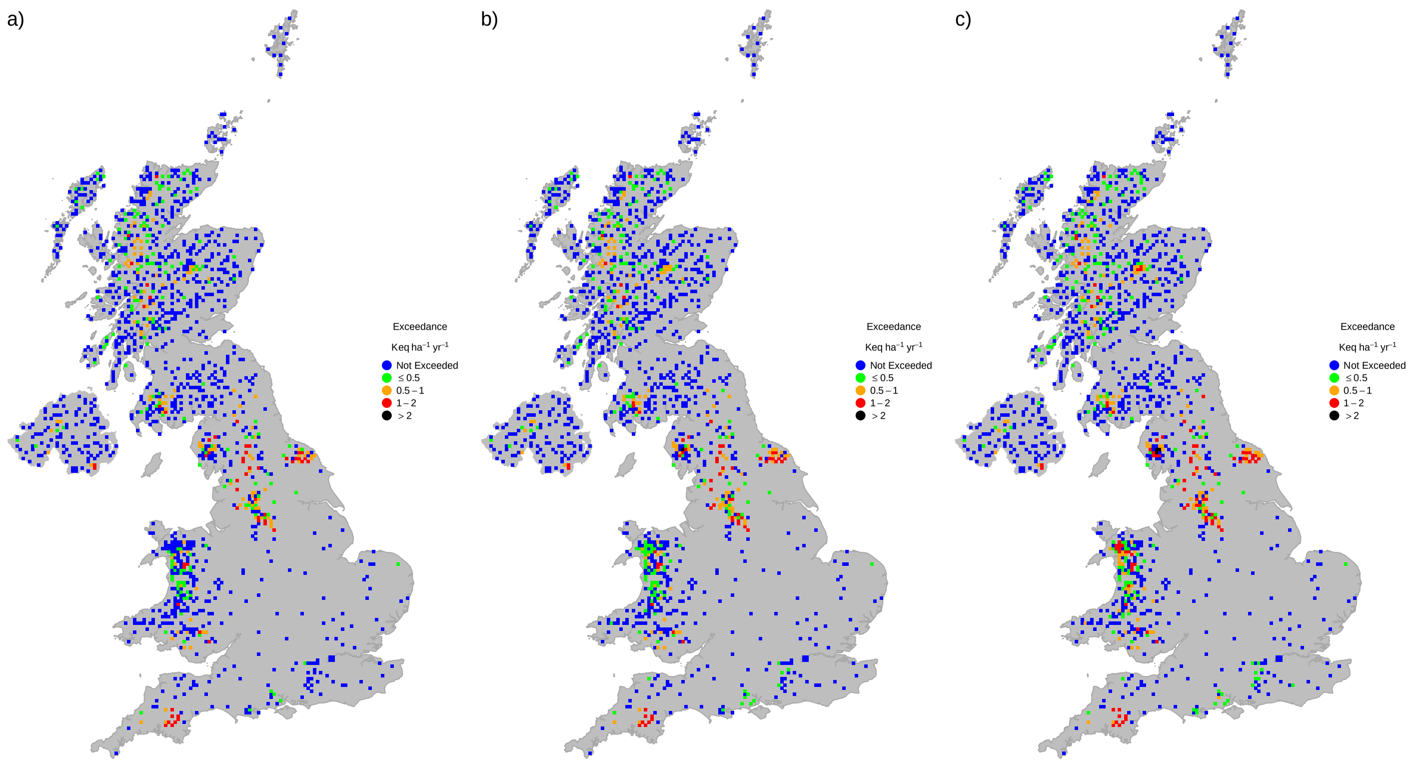

Figure 2.9: FAB model critical load exceedance map for freshwaters for the FRAME 2020 baseline deposition scenario and $ANC_{crit} = 40$ on a 5km grid. Exceedances are shown as the grid box a) minimum, b) mean, and c) maximum respectively.

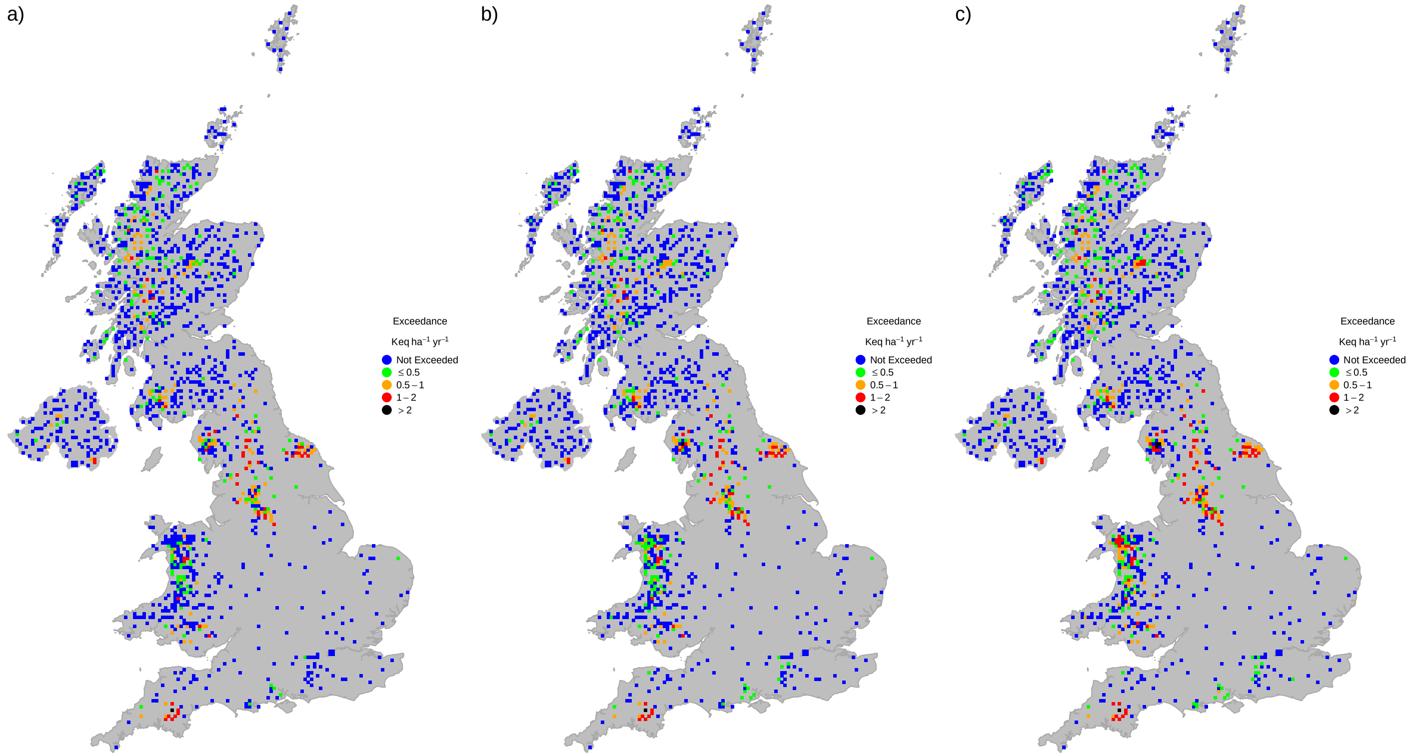

Figure 2.10: FAB model critical load exceedance map for freshwaters for the FRAME 2020 baseline deposition scenario and $ANC_{crit} = 40$ on a 5km grid. Exceedances are shown as the grid box a) minimum, b) mean, and c) maximum respectively.

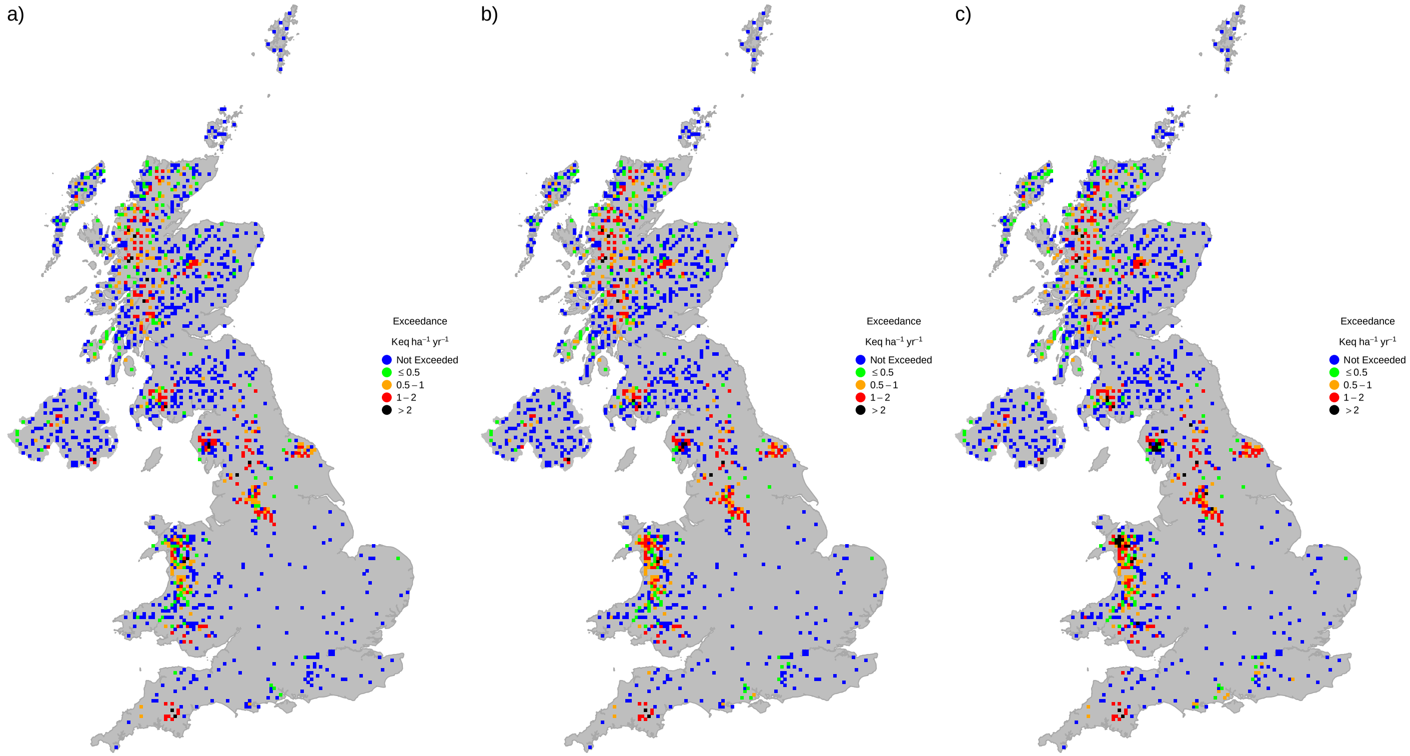

Figure 2.11: FAB model critical load exceedance map for freshwaters for the FRAME 2020 baseline deposition scenario and $ANC_{crit} = 80$ on a 5km grid. Exceedances are shown as the grid box a) minimum, b) mean, and c) maximum respectively.

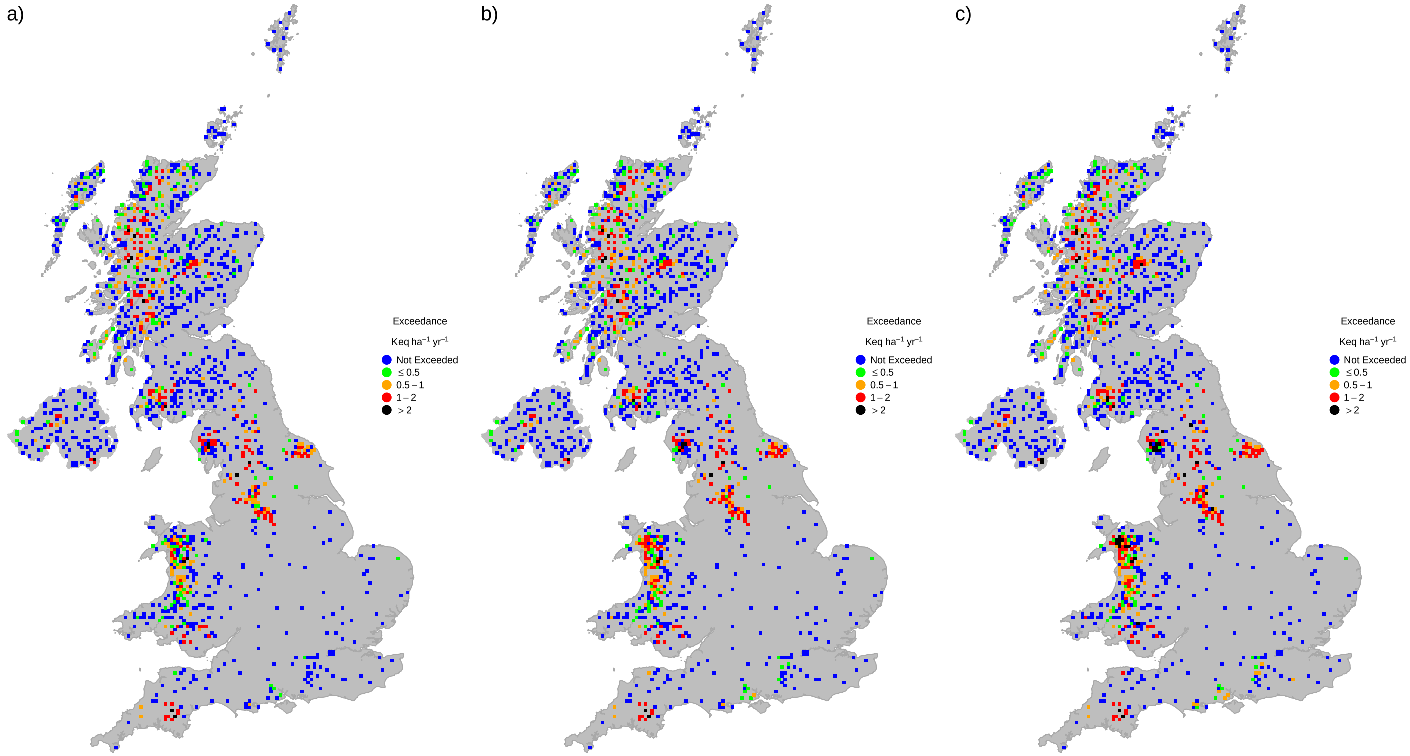

Figure 2.12: FAB model critical load exceedance map for freshwaters for the FRAME 2020 baseline deposition scenario and $ANC_{crit} = 80$ on a 5km grid. Exceedances are shown as the grid box a) minimum, b) mean, and c) maximum respectively.

Chapter 3

Conclusions

This report presents results from an assessment of the status of UK freshwaters for two deposition scenarios for the year 2020. Status was assessed using the FAB freshwater acidity critical load model for three values of ANC_{crit}; i) the UK standard ($ANC_{crit} = 20$, with $ANC_{crit} = 0$ used for some naturally acid systems), ii) $ANC_{crit} = 40$ and $ANC_{crit} = 80$.

The model-predicted change in critical load exceedance is small, with between six and two additional sites exceeded under the PEC scenario compared with the baseline. There is a general movement towards higher numbers of exceeded sites in exceedance classes $> 0.5 \mathrm{Keqha}^{-1}\mathrm{yr}^{-1}$, though it should be repeated that changes are small.

Far greater differences in the number of exceeded sites are apparent for the three values of ANC_{crit} used here. The use of higher values of ANC_{crit}, as employed for the WFD High/Good boundary, leads to far higher numbers of exceeded sites and dwarfs the effect of increased deposition under the PEC scenario. The suitability of the higher values of ANC_{crit} for many sites in the national critical loads data set is questionable, particularly so for $ANC_{crit} = 80$. The UK has adopted $ANC_{crit} = 20$ as the national standard for critical loads modelling except for naturally acid systems. These systems are unlikely to ever have naturally supported an ANC as high as 20 and consequently $ANC_{crit} = 0$ is used instead.

3.1 Interpretation of FAB model outputs

To interpret the outputs from the FAB model an understanding of several critical factors is required. Importantly these relate to an interpretation of the magnitude of exceedance, the timing of potential damage from acidification, and extrapolation of the exceedance grids to other freshwater sites (Curtis et al., 2000).

3.1.1 The magnitude of critical load exceedance

The magnitude of critical load exceedance should not be used as an indicator of by how much deposition of S or N must be reduced in order to meet the critical load. The reduction in S or N deposition required to meet the critical load will be higher than the indicated exceedance in terms of equivalents of acidity because catchment processes which retain a proportion of inputs. Critical loads models are best employed in comparison and assessment of deposition scenarios such as that present here (Curtis et al., 2000).

3.1.2 The timing of acidification damage

Critical load exceedance does not immediately lead to the conclusion that a water body has been affected by acidification to date nor should it be concluded that an exceeded site has been affected by acid deposition. Critical loads are defined for steady-state conditions. For an exceeded site, all that can be concluded is that the critical chemical threshold will be exceeded at an unspecified future date (Curtis et al., 2000). An alternative way of interpreting exceedance is that the deposition load specified in the scenario is unsustainable if an exceeded site is to be protected. The current state of a water body may be determined via a dynamic model such as MAGIC (e.g., Jenkins et al., 1997).

3.1.3 Extrapolating gridded critical load exceedances

The sampling strategy for the initial national critical loads data set focused on the most sensitive sites within each 10 km grid square of the UK. One impact of this sampling strategy heritage is that the national critical loads data set can not be used to extrapolate results to the whole population of British fresh water bodies.

The link between the most sensitive site within each 10 km grid square has since been lessened with the addition of intensively sampled regional data sets, often focused on highly acidified areas of the UK where critical load exceedance under 2020 deposition scenarios remains a problem. With the original critical loads data set it was possible, with some degree of confidence (e.g., Curtis et al., 1995), to extrapolate information from the sampled site to other unsampled sites within the same grid square. As the most sensitive site was sampled, if this site was protected under a stated deposition load then by definition the other less-sensitive sites in the grid square would also be protected. However, in two thirds of sites sampled to verify the accuracy of this extrapolation, Curtis et al. (1995) found that the sampled site was not the most sensitive in the 10 km grid square.

With the addition of the intensively-sampled regional data sets it is not possible to extrapolate data from the gridded results presented above to other sites within the same grid cells; the link to the most sensitive site within each cell being sampled is broken.

As such, it is best to view the critical load exceedance maps as a snapshot view of the potential impact of acid deposition loads on freshwaters in the UK and to not interpret the proportions of exceedance as being representative of the population of water bodies.

Chapter 4

References

C. Curtis and G. L. Simpson. Summary of research under Defra contract "Recovery of Acidified Waters in the UK EPG/1/3/183. Research Report 98, Environmental Change Research Centre, 2004.

C. Curtis, T. E. H. Allott, R. W. Battarbee, and R. Harriman. Validation of the UK critical loads for freshwaters: site selection and sensitivity. *Water, Air, and Soil Pollution*, 85:2467–2472, 1995.

C. Curtis, T. E. H. Allott, B. Reynolds, and R. Harriman. The prediction of nitrate leaching with the First-order Acidity Balance (FAB) model for upland catchment in Great Britain. *Water, Air, and Soil Pollution*, 105: 205–215, 1998.

C. Curtis, T. E. H. Allott, J. Hall, R. Harriman, R. Helliwell, M. Hughes, M. Kernan, B. Reynolds, and J. Ullyett. Critial loads of sulphur and nitrogen for freshwaters in Great Britain and assessment of deposition reduction requirements with the First-order Acidity Balance (FAB) model. *Hydrology & Earth Systems Science*, 4(1):125–140, 2000.

A. Henriksen, J. Kämäri, M. Posch, and A. Wilander. Critial loads of acidity: Nordic surface waters. *Ambio*, 21:356–363, 1992.

A. Jenkins, M. Renshaw, R. Helliwell, C. Sefton, R. Ferrier, and P. Swingewood. Modelling surface water acidification in the UK. Research Report 131, Institute of Hydrology, Wallingford, UK, 1997.

M. Posch, J. Kämäri, M. Forsius, A. Henriksen, and A. Wilander. Exceedance of critical loads for lakes in Finland, Norway, and Sweden: reduction requirements for acidifying nitrogen and sulphur deposition. *Environmental Management*, 21:291–304, 1997.

R Core Team. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria, 2012. URL `http://www.R-project.org/`. ISBN 3-900051-07-0.