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ISSN 1366-7300

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University College London

RESEARCH REPORT

No. 76

Critical loads of sulphur and nitrogen for surface waters in Northern Ireland

Report to the Environment and Heritage Service of the

Department of the Environment Northern Ireland

Contract No. CON4/3(14)

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March 2001

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EXECUTIVE SUMMARY

A survey of 140 surface waters (lakes, streams and reservoirs) across Northern Ireland was carried out in March 2000. One site was selected to represent each 10km OS NI grid square in Northern Ireland using a map of freshwater sensitivity to identify the most acid sensitive water body in each grid square.

Acid waters (pH<5.6) were found in only very localised areas of Northern Ireland within just 11% of sampled 10km grid squares, mostly in the Sperrins around the Tyrone-Londonderry border, around Mullaghcarn to the north and north-east of Omagh, the Mourne Mountains in County Down, on Slieve Beagh south of Clogher, and around Lower Lough Erne in Fermanagh. Using an arbitrary maximum value for acid neutralizing capacity (ANC) of 200 μeql^{-1} to define acid-sensitivity, around 20% of grid squares contain acid-sensitive water bodies. Acidification caused by atmospheric deposition is therefore only likely to be a localised problem in Northern Ireland.

Application of the First-order Acidity Balance model (FAB) determined which sites would be acidified by sulphur and nitrogen deposition to an ANC value less than 20 μeql^{-1} under the most recently available deposition levels (1995-97) and after implementation of the Gothenburg Protocol in 2010.

Under 1995-97 mean levels of deposition, 18 sites (13%) exceeded their critical load of acidity, with S and N deposition contributing equally to the number of sites exceeded. At these sites, surface water ANC would at some point decline to less than 20 μeql^{-1} under constant deposition levels and in many cases it has already done so.

Assuming full implementation of the Gothenburg Protocol to reduce acid deposition by 2010, 13 sites (9%) will still be exceeding their critical loads, indicating that the Gothenburg Protocol emissions reductions are insufficient to protect all Northern Irish surface waters from a decline in ANC to less than 20 μeql^{-1}.

Almost all of the sites acidified by atmospheric deposition under 1995-97 or 2010 deposition levels are sites with high concentrations of total organic carbon (TOC), which means that they are naturally acid, with a pH depressed by organic acidity. At these sites the critical loads $CL_{max}(S)$ or $CL_{max}(N)$ are very close to zero, since any extra leaching of acidity would cause a further decrease in the naturally low values of ANC. It is unlikely that any feasible reductions in S or N emissions would be sufficient to prevent critical load exceedance at such sites, and this should be borne in mind when considering the possible options for protection of the most acid-sensitive surface waters in Northern Ireland.

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1 INTRODUCTION

1.1 Status of existing freshwaters dataset for Northern Ireland

Data for freshwaters in Northern Ireland were excluded from UK critical loads submissions to international negotiations for the UNECE multi-pollutant, multi-effect Protocol, which was signed in Gothenburg on 30th November 1999. This omission was due to the lack of the necessary catchment-based data required for application of the First-Order Acidity Balance (FAB) model (Posch *et al.*, 1997), which is the recommended model in the UNECE Mapping Manual (UBA, 1996) for freshwaters critical loads and is the only model which can provide the necessary inputs for Integrated Assessment modelling at the European level. It is also the only model that can be used to assess the possible impacts of different N deposition scenarios.

A previous survey of freshwaters in Northern Ireland, undertaken in 1991-92 as part of a UK wide project for modelling critical loads of sulphur, was of poor quality for several reasons. The freshwater sensitivity map (Hornung *et al.*, 1995), compiled at 1km resolution for Great Britain from geological and soils data, was unavailable at the time of the survey in Northern Ireland. Thus it was not possible to apply the same stringent site selection criteria as in Great Britain, whereupon the lake or stream site occupying the most sensitive area of a given 10km grid square was selected to represent that square. The major associated problems with the previous freshwaters database for Northern Ireland are listed below.

- 1km resolution freshwater sensitivity maps (derived from soils and geology) were unavailable at time of sampling.
- Coarse resolution geology maps (1:625,000) were used for site selection. This meant that a lower intensity of sampling occurred in regions deemed geologically non-sensitive (one site per 20km square rather than in each 10km square) when later sensitivity maps indicated that a greater sampling intensity was required.
- No account was taken of the *catchment* of each water body because only sulphur critical loads were modelled and terrestrial nitrogen processes were not considered.
- The sampling grid changed from the Irish to the extended GB grid halfway through the sampling period - which meant some sites would be inappropriate for the grid square they moved into, and some grid squares were not represented.
- Preference was always given to lakes, thereby neglecting more sensitive stream sites in many grid squares - this problem was later rectified for sites in Great Britain but not Northern Ireland.

The original population of 93 sites comprised 65 lakes, 17 reservoirs and 11 streams. Of these, only 13 exceeded their critical load for total acidity according to the steady-state water chemistry (SSWC) model (Henriksen *et al.*, 1992), and 15 were exceeded according to the more sensitive diatom model (Battarbee *et al.*, 1996). However, it is likely that these figures were an underestimate of the extent of the acidification problem for the reasons given above.

2. METHODS

2.1 Selection of new survey sites

Freshwater sensitivity maps for Northern Ireland, produced by CEH Monks Wood, became available in 1998. In order to assess the suitability of the existing water chemistry database for FAB model application, a desk study was undertaken, and a re-selection of sites was carried out using the same rigorous selection criteria used in Great Britain. In addition, it was possible to take account of the location of the catchment of each site and ensure that both the site and its catchment were located in the most sensitive part of each grid square. In this respect, the selection criteria are superior to those employed in Great Britain, because the selection of sites there prior to the development of the catchment based FAB model meant that only the location of the water body, and not its catchment, was taken into account.

In the site re-selection exercise, the suitability of sites with existing data was noted. The stages of the desk study are summarised below.

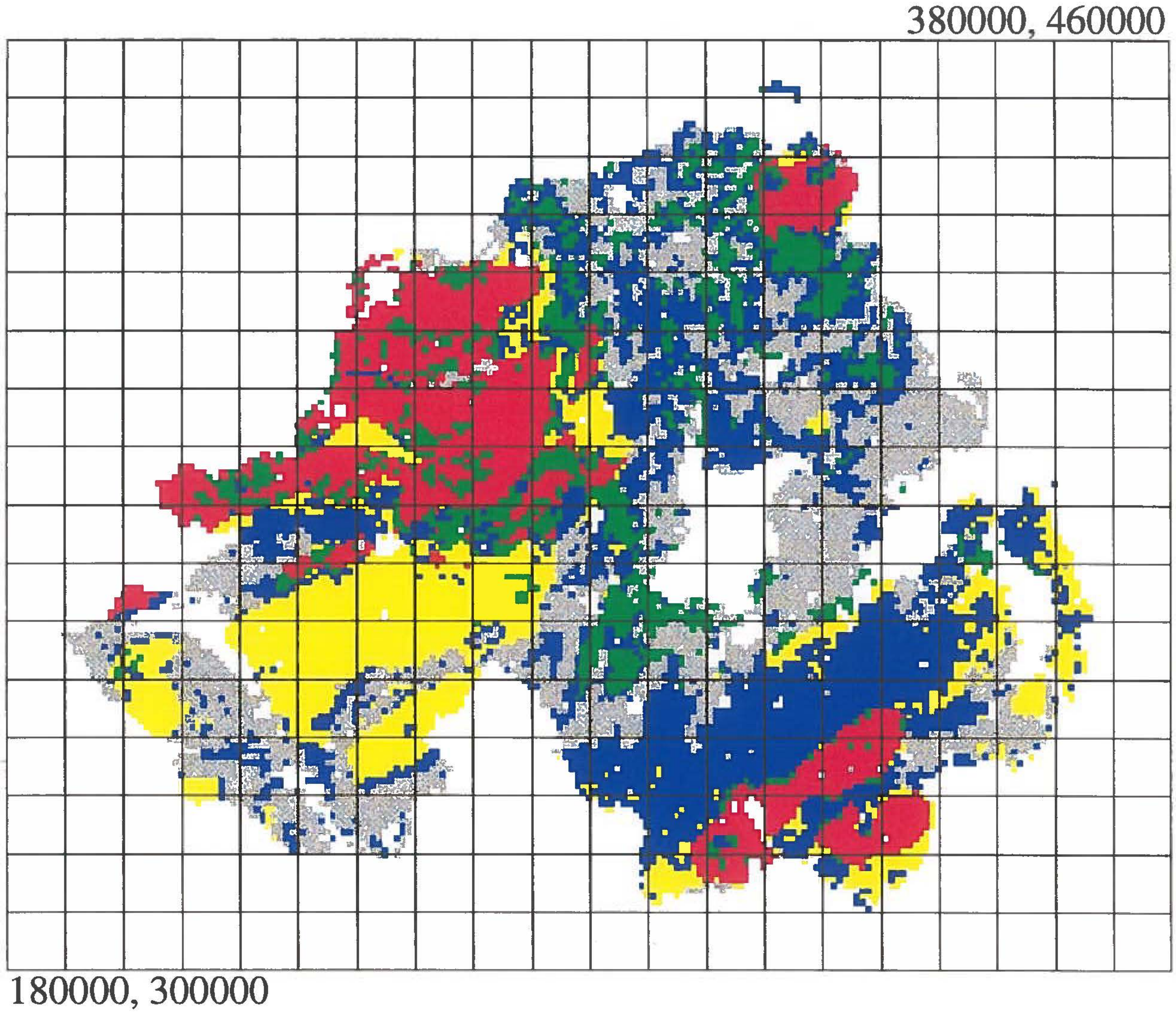
1. Definition of the mapping area and inclusion of 10km grid squares
From the freshwater sensitivity map (Fig. 1) it can be seen that there are no regions of "non-sensitivity" and it is not possible to identify areas where a 20km sampling resolution would suffice (cf. Great Britain where large areas of the lowlands are uniformly non-sensitive). The only criterion for inclusion of a grid square is therefore that at least 50% of its area comprises land within Northern Ireland. On this basis, 140 grid squares are defined, with excluded squares found along the coast, the border with the Republic and the shores of inland waters (Fig. 2).

2. Site selection within grid squares
- The first priority was to identify a site (and catchment) in the most sensitive part of the square; this requirement over-rides the priority given to standing waters.
- All other things being equal, priority was given to lakes, then reservoirs, then streams, because of the less variable chemistry (temporally) of standing waters.
- Site altitude was also considered after the above prioritisation; the site at the highest altitude or with the highest catchment was selected.
- For standing waters, a minimum surface area of 0.5 hectares was required.
- Sites with more than 50% of their catchment in adjacent grid squares were omitted.
- Un-named sites were named according to a nearby obvious place-name on the map where possible

The final selection of 140 sites includes 68 lakes, 64 streams and 8 reservoirs (Appendix 1) - a much greater proportion of streams (46%) than in the original 93 site dataset (12%) and for the UK as a whole (20%). These figures differ slightly from those provided in the original desk study because a number of sites were reselected during the field survey, where the proposed site was found to be inappropriate (e.g. exposed to major agricultural pollution running directly into the site – see Appendix 1).

3. Overlap with existing freshwaters database
Using the new site selection criteria described above, only 28 of the 140 sites selected were included in the previous survey and 30 have existing chemistry data, generally

Figure 1: Freshwater Sensitivity map for Northern Ireland with 10km grid overlaid.



- High Sensitivity
- Medium High Sensitivity
- Medium Low Sensitivity
- Low Sensitivity
- Non-Sensitive

Acknowledgements
SSLRC, MLURI,BGS,
Mike Hornung.

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from the period 1991-92. It was therefore decided that a new survey would be required for a full regional application of the FAB model.

2.2 The surface waters sampling survey, March 2000

Since the chemistry of surface waters is known to vary seasonally, it was decided to carry out a survey of all selected sites within as short a time as possible during the period of spring overturn (i.e. when standing waters are likely to be well mixed and provide a representative water sample). The whole survey was therefore carried out within a 10 day period from 14th – 24th March 2000.

Dip samples for water chemistry were taken in acid-washed 0.5L plastic bottles at elbow depth (where possible). For standing waters the sample was taken from the major outflow stream if present. Water samples were refrigerated at 4°C in the dark for up to 2 days before posting to the Scottish Office Freshwater Fisheries Laboratory, Pitlochry, Scotland. Samples were analysed within one week for the chemical species listed in Table 1, according to the methods of Harriman *et al.* (1990). Derived values of acid neutralizing capacity (ANC) were calculated using two methods (Appendix 2). The ion-balance ANC was calculated according to the method of Henriksen *et al.* (1992) as the sum of base cations minus the sum of strong acid anions. The Cantrell ANC, which accounts directly for the extra buffering afforded by organic anions, was calculated as [alkalinity] + (5×[TOC]) (modified from Cantrell *et al.* (1990) to account for alkalinity titration to an endpoint of pH 4.2-4.5).

Table 1: Chemical analyses performed on survey samples

Analysis	Units
pH	pH units
Alkalinity	μeq/l
Conductivity	μS/cm
Sodium	μeq/l
Potassium	μeq/l
Magnesium	μeq/l
Calcium	μeq/l
Ammonium	μeq/l
Chloride	μeq/l
Nitrate	μeq/l
Sulphate	μeq/l
Silicate	μg/l
Phosphate - P	μg/l
Total organic carbon (TOC)	mg/l
Absorbance at 250 nm	-

Epilithic or epiphytic diatom samples were taken and preserved (these samples are in storage, since their analysis is beyond the scope of this study). Site details, including observations on catchments vegetation, disturbance and macrophytes, were noted on site sheets in the field. All sites were photographed.

2.3 Catchment data derivation and FAB modelling

The catchment data required for FAB model application include catchment area, surface area of standing waters, percentage cover of major soil and vegetation types, and estimates of mean annual runoff from the catchment. For most sites, these data were derived at EHS through an automated procedure within a Geographic Information System (GIS) incorporating a Digital Terrain Model (DTM). Since this procedure was carried out prior to the field survey, sites which were reselected in the field were treated differently, as were sites for which the automated procedure could not generate a catchment boundary (Appendix 1: see below).

Automated catchment generation

A 50m DTM was used to generate a catchment automatically within a GIS from a given grid reference (on a stream or lake outflow point). Catchment and lake area were calculated automatically. The catchment outline was then overlaid onto digital datasets to extract catchment specific data for soils and vegetation. The soils map for Northern Ireland (1:10,000 scale) provided percentage cover of soil types, while 100m resolution CORINE landcover data provided the percentage forest cover required by FAB.

Manual digitising and catchment data derivation

For 35 of the 140 survey catchments it was not possible to use the above procedure, either because new catchments were selected after the above exercise was complete (labelled "R" in Appendix 1) or because of the inability of the DTM to define a catchment in areas of low relief (labelled "MD" for "manually digitised" in Appendix 1). In these cases, catchment and lake outlines were manually digitised from 1:50,000 OS NI maps with catchment boundaries estimated by eye. The resulting catchment outlines were then used to extract soils and landcover data as above.

Runoff and deposition data

The runoff data are derived from 1km resolution, 30-year mean (1961-1990) values for rainfall and potential evapotranspiration (PE) calculated according to the Penman-Monteith equation. Catchment weighted values were derived automatically using the DTM defined catchments.

The best available dataset for "current" deposition is the CEH Bush 1995-97 mean dataset on a 5km grid resolution. This national dataset is based on an interpolation of measured values (see RGAR, 1997). These data have been used to calculate best estimates of "current" critical load exceedance using the FAB model.

Deposition data for 2010 (post implementation of the Gothenburg Protocol) have been scaled from the 1995-97 dataset described above, using two separate models for different species (Jane Hall, pers. comm.).

Figure 2a. Map showing site types in each 10km grid square.

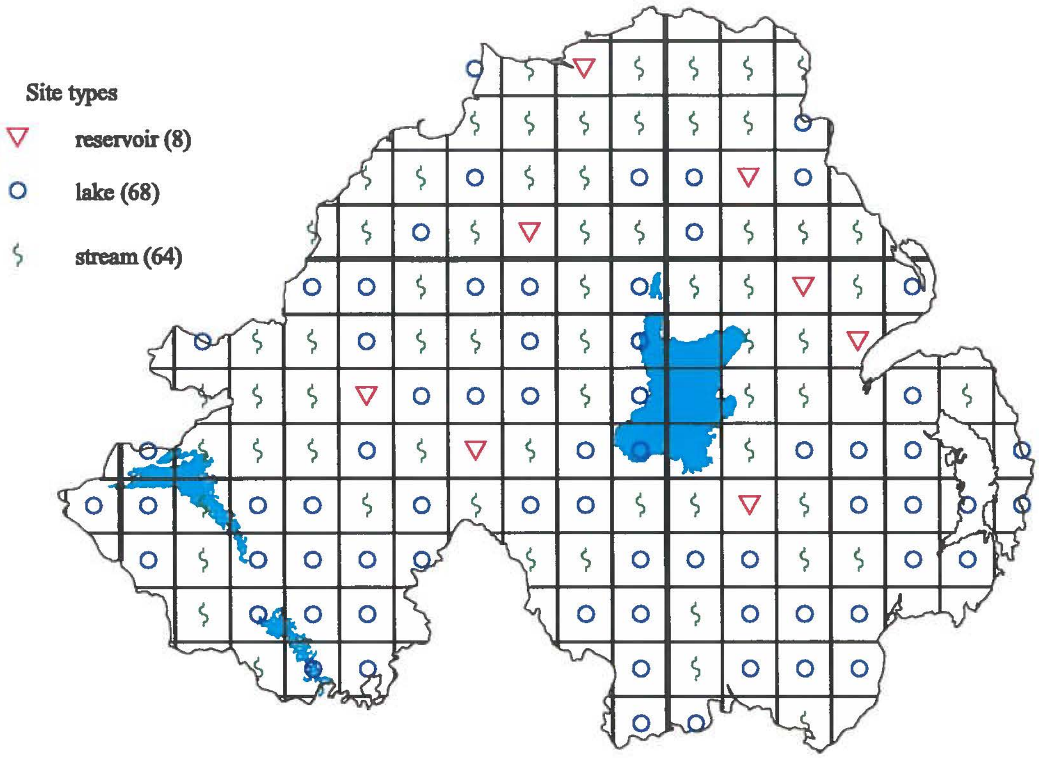
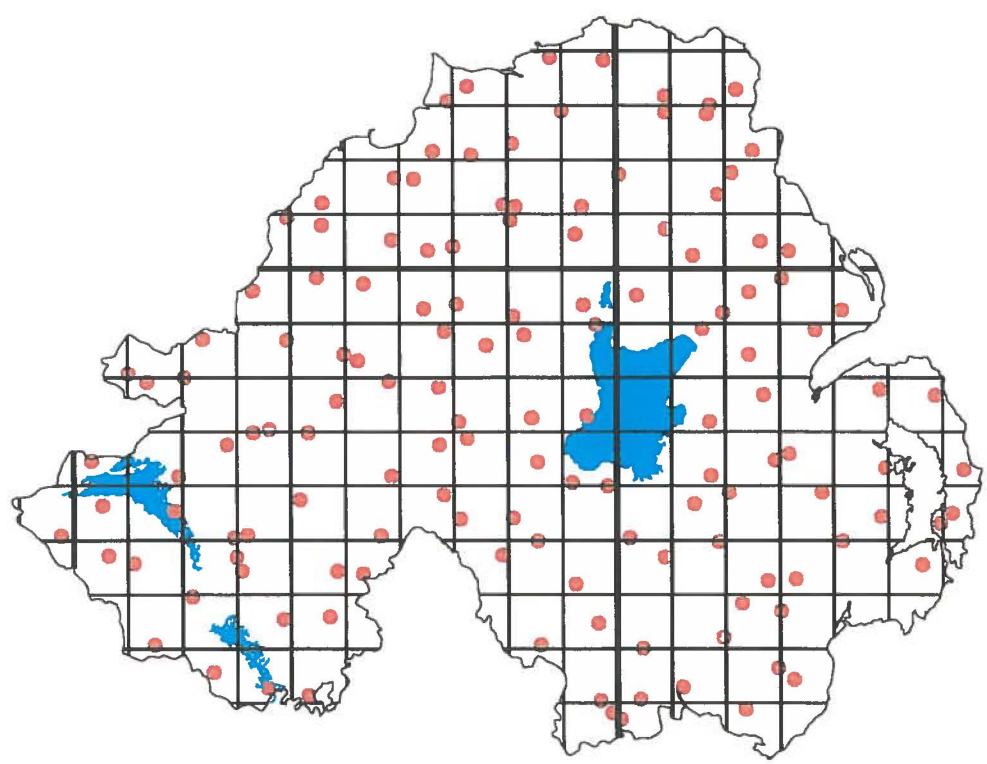


Figure 2b. Map showing actual site locations within 10km grid squares.



Deposition of sulphur and NO_x was scaled with data generated by the Hull Acid Rain Model (HARM) for 1995-97 and 2010 i.e. 2010 deposition = (CEH 1995-97) × (HARM 2010 / HARM 1995-97). Since HARM is thought to underestimate NH_x deposition the FRAME model was used to scale NH_x deposition, so that 2010 NH_x deposition = (CEH 1995-97) × (FRAME 2010 / FRAME 1996). These data have been used to calculate FAB critical load exceedance in 2010 assuming that the Gothenburg Protocol will have been fully implemented.

FAB model application

The water chemistry, catchment and deposition data described above were used as inputs in two applications of the FAB model (using 1995-97 and 2010 deposition data), for which the general methods are described in Curtis *et al.* (2000).

Soil specific parameters (N immobilisation, denitrification) were obtained for each soil type present from the most similar corresponding British soil type listed in Hall *et al.* (1997). Soil percentage cover was reclassified as a percentage of the terrestrial catchment soils (i.e. surface waters excluded). Where part of the catchment lies within the Republic of Ireland (Class 13 in Northern Ireland soils data) it was assumed that the proportion of soil types was the same as in the rest of the catchment. For parts of the catchment classified as "Urban areas" (Class 7 in Northern Ireland soils data) N sink terms were set to zero. The soil classification used is presented in Table 2.

Only coniferous forest (CORINE class 312) was considered a sink for N through harvesting, i.e. deciduous forest was omitted from the model application, as in Great Britain (Curtis *et al.*, 2000). Percentage cover of coniferous forest was recalculated after omission of the CORINE class for "water bodies" (class 512), since it must be expressed as a percentage of the terrestrial catchment in the FAB model. As for the application of FAB in the rest of the UK, a single, mean N uptake figure (N_{upt}) of 0.279 keq ha^{-1} yr^{-1} or c. 4 kgN ha^{-1} yr^{-1} was used.

It is not possible to define a single value to represent the critical load of total acidity using the FAB model, since the acid anions sulphate and nitrate behave differently in the way they are transported with hydrogen ions; one unit of deposition of S will not have the same net effect on surface water ANC as an equivalent unit of N deposition. The FAB model defines three critical deposition load values, called $CL_{max}(S)$, $CL_{min}(N)$ and $CL_{max}(N)$, which together define the critical load function (Posch *et al.*, 1997). $CL_{max}(S)$ defines the critical load for sulphur when total N deposition is less than $CL_{min}(N)$. When S deposition exceeds $CL_{max}(S)$, the critical load is exceeded by S alone, regardless of the level of N deposition.

The contribution of N deposition to an increase in exceedance over that resulting from S alone is determined by the FAB charge balance. $CL_{min}(N)$ defines the deposition of total N (NH_x + NO_x) at which terrestrial catchment processes effectively remove all N, so that N deposition loads lower than $CL_{min}(N)$ result in no net leaching of nitrate. The terrestrial sinks for N are fixed by soil type and coniferous forest cover, as described above. An important assumption here is that all N deposition is transported through the terrestrial part of the catchment, i.e. in lake catchments there is negligible deposition directly onto the lake surface.

Table 2: Conversion of NI to equivalent GB soils classification

NI Soil No.	Soil description	CEH No.	Soil description	Nimm KgN/ha/yr	Nden
1	Brown Earth >40cm to C Horizon	5.4	Brown earths	1	1
2	Surface Water Gley 1	7	Surface-water gley soils	1	4
3	Surface Water Gley 2	7	Surface-water gley soils	1	4
4	Ground Water Gley 2	8	Ground-water gley soils	1	4
5	Ground Water Gley 3	8	Ground-water gley soils	1	4
6	All types of peat >50cm	10	Peat soils	3	1
7	Urban areas & other built-up areas	0	Unclassified	0	0
8	Disturbed land	9.2	Disturbed soils	1	1
9	Humic ranker	3.1	Rankers	1	1
10	Humic ranker complex	3.1	Rankers	1	1
11	Surface Water Humic Gley	8.7	Humic gley soils	1	4
12	Water	0	EXCLUDED	N/A	N/A
13	Republic of Ireland	0	EXCLUDED	N/A	N/A
14	Brown Rankers(inc BE & BP rankers)	3.1	Rankers	1	1
15	Brown Podzolic(with Bs horizon)	6.1	Brown podzolic soils	3	1
16	Shallow Brown Earths(40-60cm deep)	5.4	Brown earths	1	1
17	Alluvium - mineral with var. textures	3.3	Ranker-like alluvial soils	1	1
18	Raw Skeletal	1	Terrestrial raw soil	3	1
19	Brown Rankers(inc BE & BP rankers) complex	3.1	Rankers	1	1
20	Organic/Mineral Alluvium	3.3	Ranker-like alluvial soils	1	1
21	Podzol	6	Podzolic soils	3	1
22	Peat podzols	6	Podzolic soils	3	1
23	Gleyic rankers	2	Raw gley soils	1	1
24	Raw Skeletal complex	1	Terrestrial raw soil	3	1
25	Peat podzols	6	Podzolic soils	3	1
26	Brown Podzolic(with Bs horizon)	6.1	Brown podzolic soils	3	1
27	Surface Water Gley 3	7	Surface-water gley soils	1	4
28	Ground Water Gley 1	8	Ground-water gley soils	1	4
29	Lake shore alluvium(L.Neagh)Sandy	3.3	Ranker-like alluvial soils	1	1
30	Peat complex	10	Peat soils	3	1
31	Shallow brown podzol	6.1	Brown podzolic soils	3	1
32	Not surveyed (n/s)	0	EXCLUDED	N/A	N/A
33	Gleyic rankers complex	3.1	Rankers	1	1
34	Stagno-Humic Gley	7.2	Stagnohumic gley soils	3	4
35	Shallow brown podzol	6.1	Brown podzolic soils	3	1
36	Calcareous brown earth	5.1	Brown calcareous earths	1	1
37	Shallow Brown Earths(40-60cm deep) complex	5.4	Brown earths	1	1
38	Surface Water Humic Gley complex	8.7	Humic gley soils	1	4
39	Peaty ranker	3.1	Rankers	1	1
40	Gleyed brown earth	7	Surface-water gley soils	1	4
41	Ground Water Gley 2 complex	8	Ground-water gley soils	1	4
42	Shallow podzol	6	Podzolic soils	3	1
43	Shallow peaty podzol	6	Podzolic soils	3	1
44	Ferritic brown earth	5.4	Brown earths	1	1
45	Ferritic ranker	3.1	Rankers	1	1
46	Brown Earth >40cm to C Horizon complex	5.4	Brown earths	1	1
47	Stagno-podzol	6.5	Stagnopodzols	3	1
48	Surface Water Gley 1 complex	7	Surface-water gley soils	1	4
49	Pelosols	4	Pelosols	1	2
50	Diatomite	0	Unclassified	0	0
51	Marine alluvium	0	Unclassified	0	0
52	Surface Water Gley 2	7	Surface-water gley soils	1	4

$CL_{max}(N)$ defines the critical load for total N deposition when S deposition is zero. When total N deposition exceeds $CL_{max}(N)$ the critical load is exceeded by N deposition alone, although critical load exceedance may be further increased by S deposition.

Critical load exceedance can be expressed in two different ways. Although a single critical load value cannot be determined for S and N, it is possible to calculate the degree to which S plus N deposition exceeds the critical flux of acid anion leaching from the mass balance. The exceedance can then be expressed in units of deposition (i.e. keq ha^{-1} yr^{-1}). This figure does not indicate the magnitude of the deposition reduction required, however, because reductions in S deposition will have a different effect on the leaching flux of acid anions (and acidity) as the same reductions in N deposition. An alternative way to express exceedance is to indicate which acid species are contributing to exceedance, i.e. whether S, N or some combination of the two is causing critical load exceedance. Several permutations are possible, involving the specific or optional reductions of either S or N, or both, in order to protect the site.

3. RESULTS

The water chemistry of survey sites provides information on the current distribution of acid waters in Northern Ireland without taking into account the possible causes. Summary data are presented in Section 3.1. Application of the FAB critical load model indicates which water bodies are likely to be most affected by atmospheric deposition at present, and which ones will be adversely affected in the future under given levels of deposition (Section 3.2).

3.1 Summary results of water chemistry survey

The water chemistry survey provides information on the distribution of potentially sensitive, low pH and low alkalinity waters in Northern Ireland. Summary statistics are provided for all sites and by site type in Tables 3a-3d (units as presented in Table 1). Raw data are presented in Appendix 2.

The survey sites cover a very broad chemical range, from dilute to very high ionic strength waters (conductivity range 43 – 681 μScm^{-1}) and from highly acidic to very alkaline conditions (pH range 4.2 – 9.0, alkalinity –71 – 6275 μeql^{-1}). This gradient was to be expected, since the survey sites occupy the whole range of catchment conditions to be found within Northern Ireland, from upland lakes and moorland pools impacted only by atmospheric pollution to lowland farm ponds and channels which are directly impacted by agricultural fertiliser and other effluents.

A principal components analysis (PCA) was undertaken to explore the structure of the data. This identifies the main gradients of chemical variation and highlights the main variables associated with these. The angles between the arrows representing each variable in the bi-plot (Fig. 3) indicate the magnitude of the correlation between variables. Strong positive correlations between variables are illustrated by acute angles between vectors while obtuse angles are indicative of strong negative correlations. The PCA clearly picks out a major gradient in ionic strength along the first axis, which explains over half of the variation in the data (Table 4).

Table 3a: Summary statistics for water chemistry – all sites

	No. Obs.	Mean	Median	Min.	Max.	Range	S. Dev.
PH	140	7.21	7.55	4.2	9	4.8	1.04
Alkalinity	140	1404	1125	-71	6275	6346	1406
Conductivity	139	214	183	43	681	638	152
Na^+	140	486	424	216	1342	1126	223
K^+	140	59	34	3	347	344	64
Mg^{2+}	140	588	375	52	2349	2297	552
Ca^{2+}	140	1308	960	24	6589	6565	1279
Cl^-	140	550	468	216	1501	1285	264
NO_3^-	140	63	15	0	510	510	98
SO_4^{2-}	140	187	120	10	1781	1771	204
SiO_2	140	6426	4795	110	26300	26190	5807
PO_4-P	139	36	5	0	455	455	72
Abs. 250nm	140	0.43	0.34	0.03	2.65	2.63	0.38
TOC	140	10.1	8.2	1.4	97.0	95.6	9.9
NH_4^+	140	6	0	0	222	222	21

Table 3b: Summary statistics for water chemistry – lakes

	No. Obs.	Mean	Median	Min.	Max.	Range	S. Dev.
PH	68	6.88	7.43	4.20	9.00	4.80	1.32
Alkalinity	68	1144	860	-71	5230	5301	1206
Conductivity	68	197	183	43	681	638	139
Na^+	68	498	444	216	1342	1126	258
K^+	68	80	61	3	347	344	79
Mg^{2+}	68	445	280	52	2319	2267	438
Ca^{2+}	68	1165	995	24	4642	4618	1133
Cl^-	68	595	489	231	1501	1270	311
NO_3^-	68	47	9	0	497	497	86
SO_4^{2-}	68	191	144	10	727	717	161
SiO_2	68	3822	2055	110	17950	17840	4083
PO_4-P	68	41	7	0	279	279	69
Abs. 250nm	68	0.43	0.37	0.03	2.65	2.63	0.37
TOC	68	11.0	9.3	1.6	97.0	95.4	11.7
NH_4^+	68	5	0	0	23	23	7

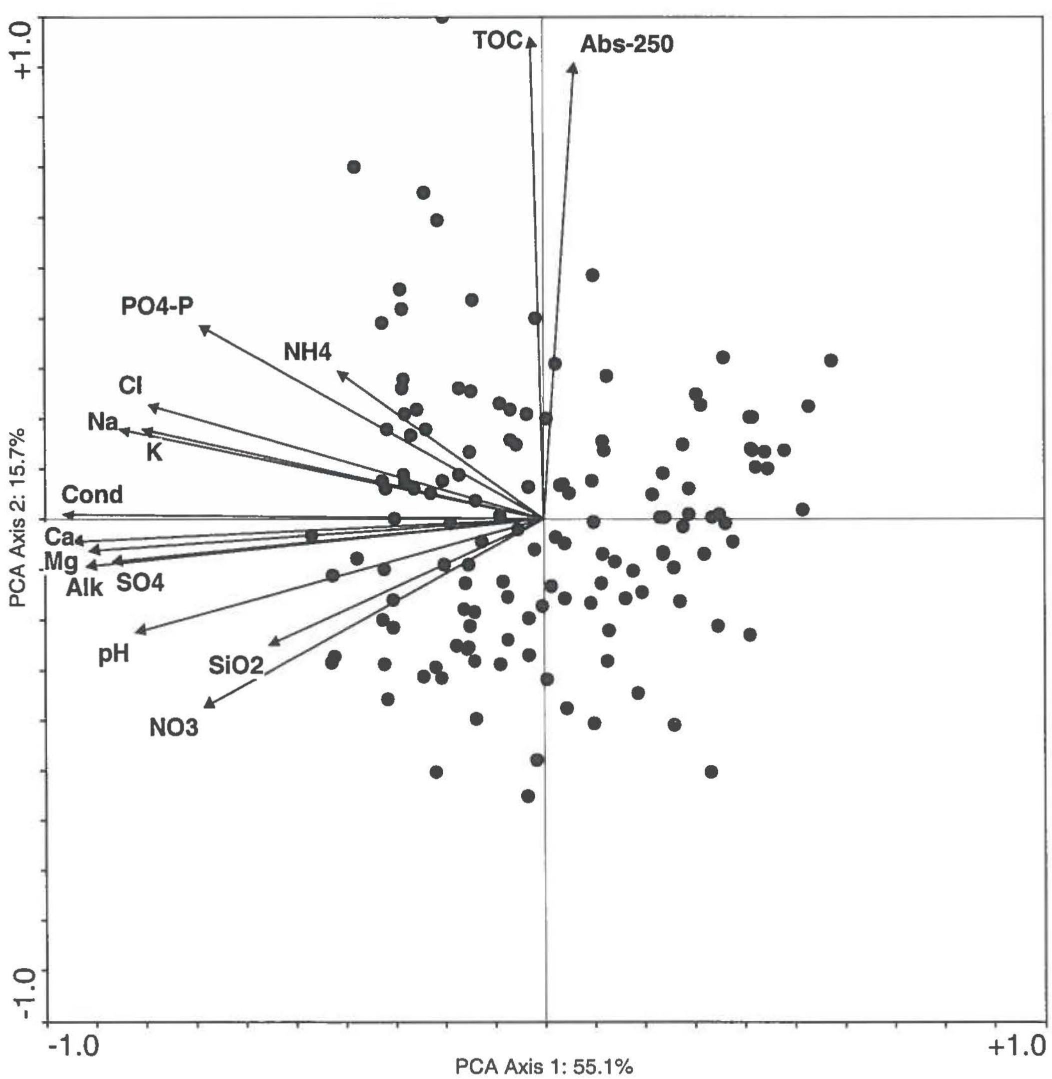
Table 3c: Summary statistics for water chemistry – streams

	No. Obs.	Mean	Median	Min.	Max.	Range	S. Dev.
PH	64	7.55	7.59	6.20	8.29	2.09	0.48
Alkalinity	64	1715	1319	31	6275	6244	1574
Conductivity	64	234	183	46	660	614	166
Na^+	64	479	418	250	1037	787	188
K^+	64	40	24	5	182	177	37
Mg^{2+}	64	734	479	86	2349	2263	621
Ca^{2+}	64	1501	953	77	6589	6512	1439
Cl^-	64	510	459	216	1168	952	210
NO_3^-	64	78	24	1	510	509	104
SO_4^{2-}	64	186	97	14	1781	1767	250
SiO_2	64	9251	8185	430	26300	25870	6196
PO_4-P	63	33	5	0	455	455	79
Abs. 250nm	64	0.43	0.33	0.03	2.26	2.22	0.40
TOC	64	9.4	7	1.4	46	44.6	8.0
NH_4^+	64	8	0	0	222	222	31

Table 3d: Summary statistics for water chemistry – artificial water bodies

	No. Obs.	Mean	Median	Min.	Max.	Range	S. Dev.
pH	8	7.26	7.38	6.14	8.38	2.24	0.80
Alkalinity	8	1120	744	48	3037	2989	1179
Conductivity	7	201	217	65	428	363	140
Na^+	8	448	409	291	779	488	163
K^+	8	35	27	10	101	91	29
Mg^{2+}	8	642	573	112	1736	1624	580
Ca^{2+}	8	970	685	156	2589	2433	927
Cl^-	8	494	450	338	735	397	151
NO_3^-	8	82	19	4	362	358	129
SO_4^{2-}	8	170	130	50	369	319	120
SiO_2	8	5955	4010	1320	14640	13320	5045
PO_4-P	8	17	3	0	75	75	28
Abs. 250nm	8	0.37	0.26	0.12	0.87	0.75	0.27
TOC	8	8.5	6.3	4.1	18.6	14.5	4.9
NH_4^+	8	5	0	0	19	19	7

Figure 3: Principal Components Analysis of water chemistry data



The second axis is driven almost entirely by the organic carbon content of the water, as indicated by the very high scores for TOC and absorbance at 250 nm (a measure of water colour).

Table 4: Water chemistry – PCA Axis scores

	Axis 1	Axis 2	Axis 3	Axis 4
% explained	55.1	15.7	7.9	6.0
pH	**-0.8166**	-0.2228	0.3602	-0.0144
Alkalinity	**-0.9142**	-0.0952	0.2777	0.0580
Conductivity	**-0.9600**	0.0102	-0.0044	-0.0286
Na^{2+}	**-0.8461**	0.1799	-0.2326	-0.3107
K^{+}	**-0.8007**	0.1795	-0.3221	0.1518
Mg^{2+}	**-0.9091**	-0.0632	0.1951	-0.0935
Ca^{2+}	**-0.9418**	-0.0453	0.1779	0.0495
Cl^{-}	**-0.7882**	0.2264	-0.4100	-0.2757
NO_3^{-}	-0.6809	-0.3726	-0.1328	0.0982
SO_4^{2-}	**-0.8620**	-0.0853	-0.2801	-0.0567
SiO_2	-0.5511	-0.2488	**0.5951**	-0.0810
PO_4- P	-0.6859	0.3833	-0.1119	0.1063
Abs.- 250	0.0635	**0.9062**	0.2942	-0.1288
TOC	-0.0246	**0.9574**	0.1902	-0.0589
NH_4^{+}	-0.4122	0.2922	-0.0394	**0.8009**

High scores indicate close association with a particular axis.

The distribution of low pH and alkalinity sites is shown in Figs. 4-5. In most of Northern Ireland, the surveyed sites have a pH greater than 7, but there are areas of lower pH which correspond with the most acid-sensitive areas defined on the freshwater sensitivity map (Fig. 1). Acidic waters may be defined as those having a pH lower than that of distilled water in equilibrium with the atmosphere, i.e. pH less than 5.6 (Hemond, 1994). Since only one site has a pH in the range 5.6 – 6 (site no.9 – see Appendix 2), the distribution of sites with pH less than 6 in Fig. 4 closely reflects the distribution of acidic waters in Northern Ireland. There are 16 acidic sites (c. 11% of those surveyed), found in the Mourne Mountains in County Down, the Sperrins around the Tyrone-Londonderry border, around Mullaghcarn to the north and north-east of Omagh, on Slieve Beagh – right on the border with the Republic south of Clogher, and around Lower Lough Erne in Fermanagh. Of note is that these sites are all lakes, with a minimum pH of 4.2 and alkalinity of –71 μeql^{-1}.

Surface waters in Northern Ireland appear to be characterised by relatively high TOC values (mean 10.1 mgl^{-1}) compared with Great Britain (mean 5.4 mgl^{-1}). TOC values are highest to the west and north of Lough Neagh and high values are widespread in Fermanagh (Fig. 6). High TOC values can contribute to naturally low pH values which lead to low critical loads in some cases (see below).

Figure 4. pH

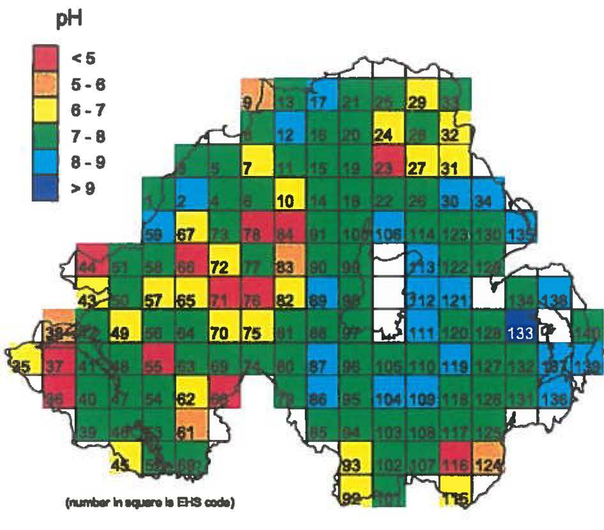


Figure 5. Alkalinity

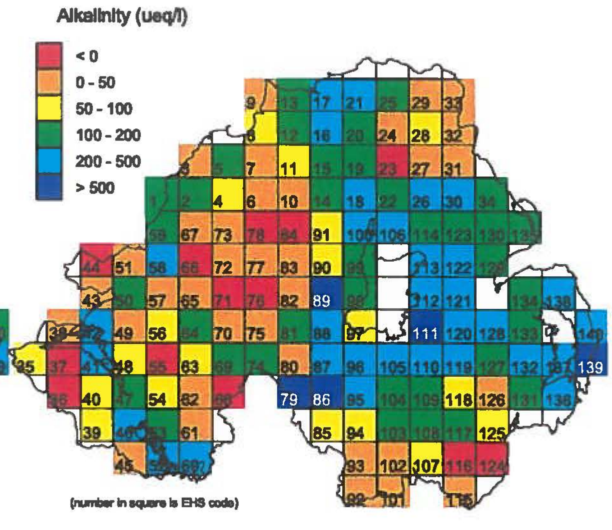


Figure 6. Total Organic Carbon

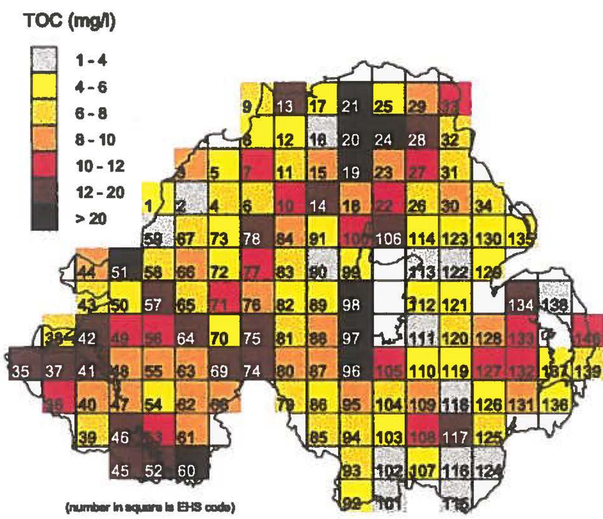
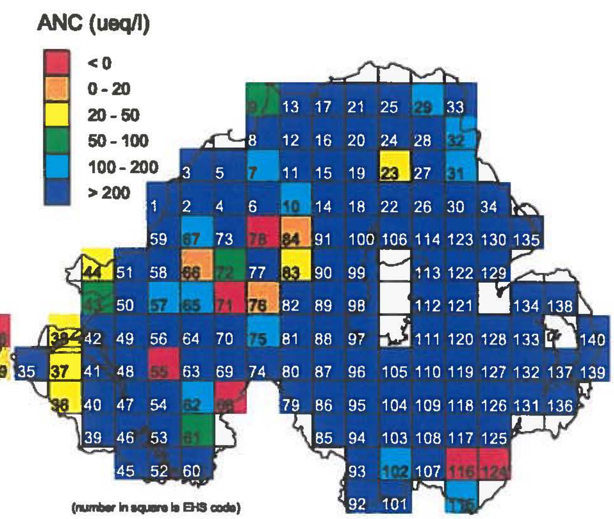


Figure 7. Cantrell ANC



The distribution of low ANC values closely mirrors that of low alkalinity values (Fig. 7) but ANC is increased by TOC concentrations (see above). Only 27 – 29 sites have acid neutralizing capacity (ANC) values of less than 200 μeql^{-1} (an arbitrary and conservative cut-off for acid-sensitive waters), depending on the method used (see Appendix 2). Therefore, assuming the site selection method to be effective in identifying the most appropriate sites, less than a quarter of 10km OS NI grid squares contain acid-sensitive water bodies.

3.2 Results of FAB model applications: critical loads and exceedance in Northern Irish surface waters

In the following applications of the FAB Model a critical ANC value of 20 μeql^{-1} is used. Exceedance of the critical load therefore indicates that at steady state with deposition inputs, the ANC of surface waters will decline to below this value. Since FAB is a static model (i.e. assumes a steady-state and provides no indication of the timescale of acidification) it cannot determine whether acidification has already occurred or the process is still moving towards a steady-state.

The lowest values of $CL_{max}(S)$, indicating the sites most sensitive to acidification by S deposition, are found around the Sperrins and Mullaghcarn, northeast of Omagh, and around Lower Lough Erne (Fig. 8). Other sensitive areas include the Mournes and the Antrim Glens. The distribution of low values of $CL_{max}(N)$ is similar, as might be expected (Fig. 9). These values tend to be greater (i.e. less sensitive) than for sulphur because of the greater retention of acidity associated with N in terrestrial parts of the catchment.

According to mean deposition levels in 1995-97, 18 sites (13%) were exceeding their FAB critical loads (Fig. 10, Table 5). These sites closely reflect the distribution of low values of both $CL_{max}(S)$ and $CL_{max}(N)$ (Figs. 8-9). Nine sites required a reduction in *both* S and N deposition to prevent exceedance (Fig. 11), while one further site required a reduction in S and another in N. At the remaining 7 exceeded sites, a reduction in either S or N could achieve non-exceedance. Under 1995-97 deposition levels, S and N were therefore of equal importance in terms of the number of sites at which they contributed to critical load exceedance (although this is not to say that identical reductions in both were required).

Table 5: Deposition reduction requirements beyond 1995-97 levels

Species requiring reduction	Number of sites
None (not exceeded)	122
S only	0
S then S or N	1
S and N	9
S or N	7
N then S or N	1
Total exceeded:	18

After full implementation of the Gothenburg Protocol, which entails significant reductions in both S and N deposition compared with 1995-97 levels, 13 of the 140 survey sites (9%) in Northern Ireland will still exceed their critical loads (Fig. 12, Table 6). Seven of the sites could be protected by reductions in N alone, while only 3 could be protected by reductions in just S deposition but these are also sites where N reductions could also prevent exceedance (Fig. 13). Ten sites require reductions specifically in N deposition while only 6 sites require reductions specifically in S and these are a subset of the sites at which N reductions are definitely required to achieve non-exceedance.

Of the 5 sites exceeded under 1995-97 deposition levels but protected under the Gothenburg Protocol, 4 are located around Lower Lough Erne and one in the Mournes. While there are 13 sites remaining with critical load exceedance by 2010 (Fig. 12) the magnitude of exceedance is less at all sites (cf. Fig. 10) than under 1995-97 deposition. The Gothenburg Protocol is only partially successful in preventing the acidification of Northern Irish freshwaters. After its implementation the relative importance of N deposition increases, such that reductions in N deposition are essential at a greater number of sites than for S deposition.

Table 6: Deposition reduction requirements beyond the Gothenburg Protocol

Species requiring reduction	Number of sites
None (not exceeded)	127
S only	0
S then S or N	0
S and N	6
S or N	3
N then S or N	4
Total exceeded:	13

4 CONCLUSIONS

The survey of Northern Irish surface waters in the most acid-sensitive areas defined by the freshwater sensitivity map has demonstrated that acid waters (pH<5.6) are present in only very localised areas within just 11% of the 140 OS NI 10km grid squares covering Northern Ireland, assuming that the site selection method successfully identified the most acidic waters. Using an arbitrary ANC cut-off for acid sensitivity of 200 μeql^{-1} around 20% of grid squares contain acid-sensitive water bodies. Acidification caused by atmospheric deposition is therefore only likely to be a localised problem in Northern Ireland.

The assessment of the acidification risk from atmospheric deposition has been carried out through critical loads modelling with the FAB model. Exceedance of FAB critical loads can be caused by either S or N deposition, or more commonly by some combination of the two, and indicates the sites where, under the given levels of deposition, the acid neutralizing capacity of the water will decline to less than the selected critical value (here 20 μeql^{-1}).

Under 1995-97 mean levels of deposition, 18 sites (13%) exceeded their critical load of acidity, with S and N deposition contributing equally to the number of sites exceeded. At these sites, surface water ANC would at some point decline to less than 20 μeql^{-1} under 1995-97 deposition levels and in many cases it has already done so.

If levels of S and N deposition have declined to those required by the Gothenburg Protocol by 2010, 13 sites (9%) will still be exceeding their critical loads.

Figure 8. CLmax (S)

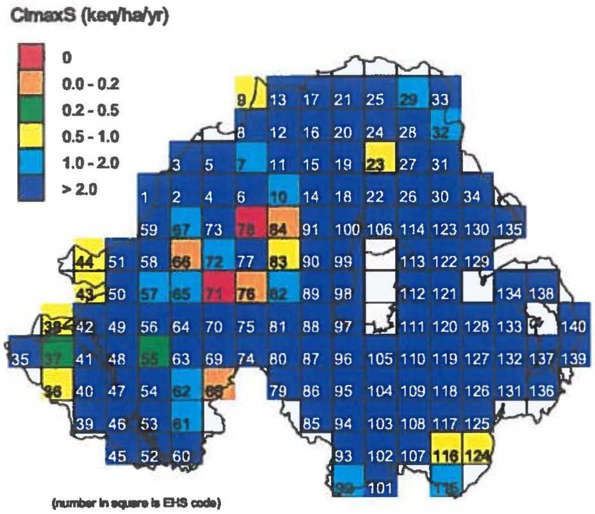


Figure 9. CLmax (N)

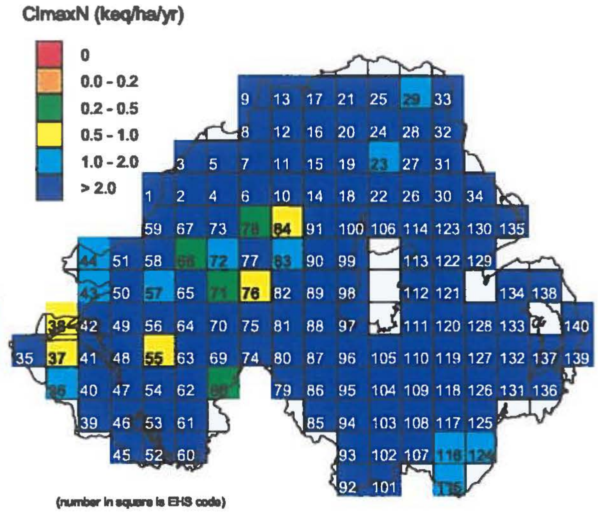


Figure 10. FAB exceedance (1995-97 mean data)

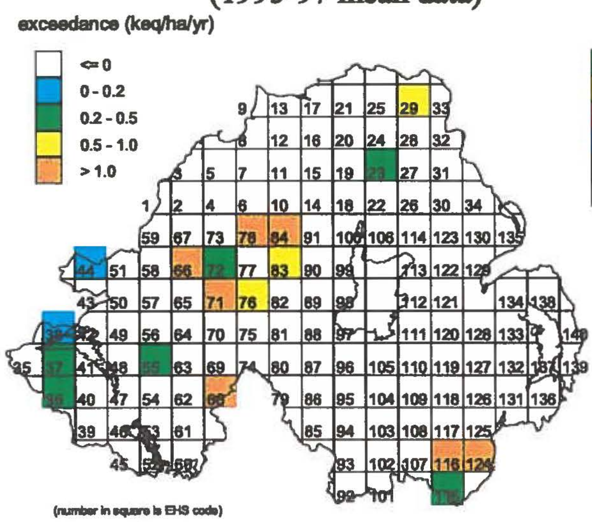


Figure 11. FAB class (1995-97 mean data)

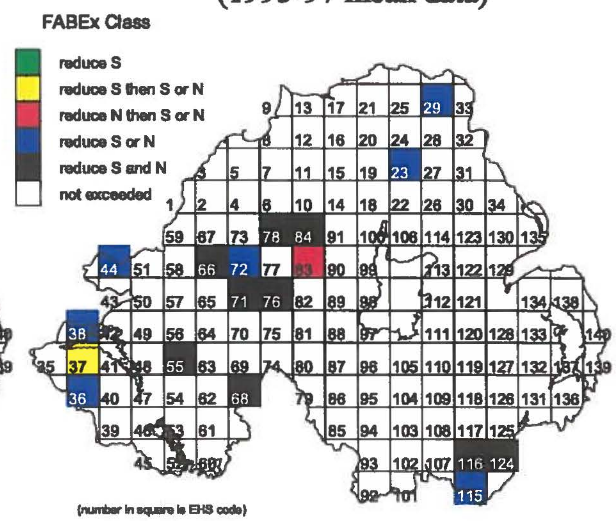


Figure 12. FAB exceedance (2010 Gothenburg Protocol)

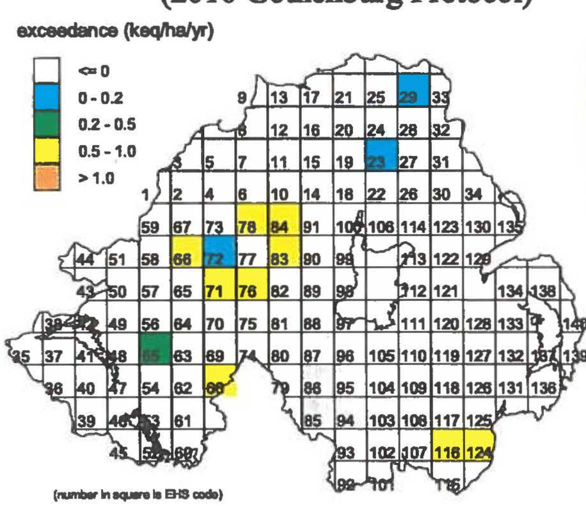
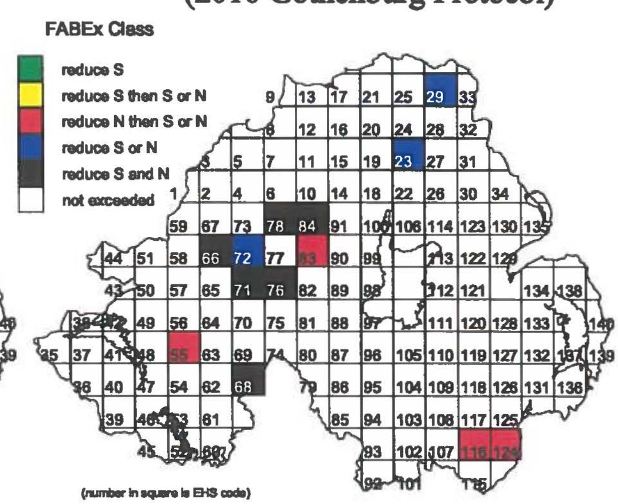


Figure 13. FAB class (2010 Gothenburg Protocol)



Of the five sites experiencing exceedance under 1995-97 deposition levels but protected by 2010, four are located around Lower Lough Erne and one is in the Mourne Mountains. At the 13 remaining exceeded sites, the Gothenburg Protocol emissions reductions are insufficient to protect the surface waters from a decline in ANC to less than 20 μeql^{-1}. The ANC at steady state with the reduced deposition will however be higher than if deposition had been maintained at 1995-97 levels, i.e. some reduction in the degree of acidification damage will have been achieved. After implementation of the Gothenburg Protocol the relative importance of N deposition increases, so that the requirement for reductions in N deposition to achieve non-exceedance becomes essential at a greater number of sites than for S deposition.

Almost all of the sites acidified by atmospheric deposition under 1995-97 or 2010 deposition levels are sites with high concentrations of total organic carbon (TOC), which means that they are naturally acid, with a pH depressed by organic acidity. Some of these sites may have had an ANC value which was close to or less than 20 μeql^{-1} prior to acidification by anthropogenic emissions of S and N. At these sites the critical loads $CL_{max}(S)$ or $CL_{max}(N)$ are very close to zero and any extra leaching of acidity would cause a further decrease in ANC. It is unlikely therefore that any feasible reductions in S or N emissions would be sufficient to prevent critical load exceedance at such sites, and this should be borne in mind when considering the possible options for protection of the most sensitive surface waters in Northern Ireland.

Acknowledgements

The authors would like to thank Jackie Ullyett and Jane Hall of CEH Monks Wood for the provision of the freshwater sensitivity map and the deposition data on the Irish Grid.

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APPENDIX 1

LIST OF NORTHERN IRELAND SURVEY SITES

KEY

Type
Site type (S=stream; L=lake; A=artificial standing water)

Name
Site name – “ ” indicates site named after nearest named feature on OS NI 1:50,000 map

Notes
R = reselected site (original from desk study found to be inappropriate in the field)
MD = manually digitised catchment (NB all reselected sites were also manually digitised)

APPENDIX 1: SITE LIST

EHS Number	10km Grid Square		Sitecode	Grid Ref. East	North	Type	Name	Notes
1	C	30	NIC30	394	93	S	"Coolmaghery Stream"	R
2	C	40	NIC40	458	79	S	Unnamed stream	
3	C	41	NIC41	459	120	S	Ardmore Stream	
4	C	50	NIC50	586	52	L	Straidarron Lough	MD
5	C	51	NIC51	592	167	S	"Dunbrock Burn"	
6	C	60	NIC60	654	33	S	"Mullaghash Burn"	
7	C	61	CZC61	628	164	L	Small Lough	MD
8	C	62	NIC62	663	215	S	"Sesnagh Stream"	R
9	C	63	CZ0859	690	307	L	Binevanagh Lake	
10	C	70	CZC70	697	40	A	Altnahegilsh Reservoir	
11	C	71	NIC71	792	117	S	"Ballyhone Burn"	
12	C	72	NIC72	734	208	S	"Terrydoo Burn"	R
13	C	73	NIC73	727	334	S	"Avish Burn"	R
14	C	80	NIC80	805	88	S	"Knockoneill Burn"	
15	C	81	NIC81	815	113	S	Brockaghboy River	
16	C	82	NIC82	808	229	S	"Ballymenagh Burn"	
17	C	83	CZ1059	878	387	A	"Craigahullier Reservoir"	R
18	C	90	NIC90	924	62	S	"Drumbae Burn"	
19	C	91	NIC91	936	113	L	Hugh's Lough	MD
20	C	92	NIC92	900	289	S	Un-named burn	R
21	C	93	NIC93	977	383	S	"Drumyaran Burn"	
22	D	0	NID00	90	72	L	Lough McGarrey	
23	D	1	CZ1157	5	172	L	Lough Naroon	MD
24	D	2	NID02	90	287	S	"Little Altarichard Burn"	
25	D	3	NID03	90	317	S	"Carrowlaverty Burn"	
26	D	10	NID10	141	24	S	"Deerfin Burn"	
27	D	11	CZD11	187	136	A	Quolie Reservoir 2	
28	D	12	NID12	167	283	S	Owennaglush River	R
29	D	13	BEAH	173	297	S	Beah's Burn (near AWMN)	
30	D	20	NID20	265	50	S	Owencloghy Burn	
31	D	21	CZD21	211	176	L	Loughgarve	
32	D	22	CZD22	250	216	L	Lough Natullig	
33	D	23	NID23	221	329	S	Clady Burn	
34	D	30	NID30	317	32	S	"Star Bog Burn"	
35	G	95	NIG95	977	507	L	Tullynanny Lough	R
36	H	4	NIH04	64	470	L	Lough Acrottan	
37	H	5	NIH05	54	563	L	Lough Anlaban	MD
38	H	6	NIH06	33	645	L	Lough Nafoola	MD
39	H	13	NIH13	148	306	S	"Aghatirourke Burn"	
40	H	14	NIH14	110	456	S	"Aghamore Burn"	
41	H	15	NIH15	185	553	S	"Rossgweer Burn"	
42	H	16	NIH16	193	617	S	"Quarry stream"	
43	H	17	NIH17	135	791	S	Essan Burn	
44	H	18	NIH18	101	806	L	Lough Sallagh	
45	H	22	NIH22	256	255	S	"College Stream"	
46	H	23	NIH23	218	395	L	"Upper Laragh Lough"	MD
47	H	24	NIH24	299	468	L	Largy Lough	
48	H	25	NIH25	294	504	L	Killee Lough	
49	H	26	NIH26	281	675	S	Glendurragh River	
50	H	27	NIH27	204	799	S	"Killeter Burn"	

APPENDIX 1: SITE LIST

EHS Number	10km Grid Square		Sitecode	Grid Ref. East	North	Type	Name	Notes
51	H	28	NIH28	238	870	S	"Barley Hill Stream"	
52	H	32	NIH32	356	227	L	Corraharra Lough	
53	H	33	NIH33	385	353	L	Forfey Lough	
54	H	34	CZ0450	309	442	L	Lough Skale	
55	H	35	NIH35	319	508	L	Lough Mulshane	MD
56	H	36	NIH36	330	697	S	"Dooish Burn"	
57	H	37	NIH37	360	703	S	"Pollnalaght Burn"	
58	H	38	NIH38	393	868	S	"Lisnatumey Stream"	R
59	H	39	NIH39	330	958	L	"Carricklee Lough"	MD
60	H	42	NIH42	430	213	L	Clonshannagh Lough	MD
61	H	43	CZ0549	471	358	L	Carnmore Lough	
62	H	44	NIH44	485	442	L	Crockacleaven Lough	
63	H	45	NIH45	416	573	S	"Stranisk Burn"	
64	H	46	CZ0553	431	697	L	Fireagh Lough	
65	H	47	CZH47	483	755	A	Boheragh Reservoir	
66	H	48	V065403	498	842	L	Oak Lough	
67	H	49	CZ0556	448	983	L	Moor Lough	MD
68	H	54	NIH54	532	437	L	Lough Sallagh	
69	H	55	NIH55	565	507	L	Dunroe Lough	
70	H	56	NIH56	585	617	S	"Slievemore Burn"	
71	H	57	NIH57	580	792	L	Un-named lough	
72	H	58	NIH58	523	830	S	Magharaboy Burn	
73	H	59	NIH59	534	971	S	"Legnagappoye Burn"	
74	H	65	NIH65	682	583	S	"Derganagh Burn"	
75	H	66	CZH66	674	675	A	Backbridge Reservoir	
76	H	67	NIH67	673	781	L	Loughaslane	MD
77	H	68	NIH68	683	884	S	"Two Bridges Burn"	
78	H	69	CZH69	646	926	L	Lough Lark	MD
79	H	74	NIH74	789	472	S	"Disappearing Stream"	
80	H	75	CZ0851	712	538	L	Black Lough	
81	H	76	NIH76	725	687	S	"Shanmaghry Burn"	
82	H	77	NIH77	709	718	L	Cavanacaw Lake	MD
83	H	78	NIH78	760	858	L	The Fly Lough	MD
84	H	79	CZH79	706	934	L	Lough Ouske	
85	H	83	CZH83	858	306	L	Un-named lough	
86	H	84	NIH84	854	498	S	"Tullygarran Burn"	
87	H	85	CZ0951	808	540	L	Curran Lough	
88	H	86	NIH86	853	643	L	"Ballynakilly Lough"	MD
89	H	87	NIH87	843	725	S	"Doorah Stream"	
90	H	88	NIH88	830	877	S	"Windy Castle Stream"	
91	H	89	NIH89	810	911	S	"Crocknamohil Burn"	
92	H	91	CZH91	989	181	L	Mullaghbane Lough	MD
93	H	92	NIH92	968	203	L	Cashel Lough Lower	
94	H	93	CZH93	964	347	L	Ballylane Lough	MD
95	H	94	CZH94	923	419	L	Un-named pool	
96	H	95	NIH95	982	600	S	"Derryall Drain"	R
97	H	96	NIH96	917	605	L	Derryadd Lough	
98	H	97	NIH97	945	728	L	"Annagh Pond"	
99	H	98	NIH98	961	896	L	"Moyola Water Foot Pond"	MD
100	H	99	NIH99	939	933	L	"Grove Hill Pond"	MD

APPENDIX 1: SITE LIST

EHS Number	10km Grid Square		Sitecode	Grid Ref. East	North	Type	Name	Notes
101	J	1	CZJ01	5	169	L	Un-named lough	
102	J	2	NIJ02	41	206	S	"Clonlum Burn"	
103	J	3	NIJ03	46	300	S	"Maytown Burn"	
104	J	4	CZJ04	87	468	L	Kernan Lake	
105	J	5	NIJ05	23	504	S	"Brackagh Burn"	
106	J	9	NIJ09	37	950	S	"Grange Stream"	
107	J	12	NIJ12	119	228	L	Greenan Lough	R
108	J	13	CZJ13	195	320	L	Drum Lough	MD
109	J	14	CZJ14	187	497	L	Magill's Dam	
110	J	15	NIJ15	142	566	A	Un-named pond	
111	J	16	NIJ16	172	618	S	"Trummery House Stream"	
112	J	17	NIJ17	170	717	S	"Smithvale Stream"	
113	J	18	NIJ18	157	889	S	"Bush Burn"	
114	J	19	NIJ19	195	918	S	"Dunany Burn"	
115	J	21	NIJ21	235	188	S	Cross Water	
116	J	22	NIJ22	295	264	L	Lough Shannagh	
117	J	23	CZJ23	229	383	L	Ballyroney Lake	
118	J	24	NIJ24	277	425	S	"Scotch Rock Burn"	
119	J	25	NIJ25	206	587	S	"Corcreeny Burn"	
120	J	26	NIJ26	291	647	L	"Hillhall Pond"	
121	J	27	NIJ27	269	767	S	Clady Water	
122	J	28	NIJ28	242	842	S	"Lyle's Hill Burn"	
123	J	29	CZJ29	244	956	A	Tildarg Dam	
124	J	32	NIJ32	325	243	L	Binnian Lough	
125	J	33	NIJ33	301	369	L	Ballymagreehan Lough	
126	J	34	NIJ34	328	428	S	"Slievenisky Burn"	
127	J	35	NIJ35	377	588	L	Lisbane Lough	
128	J	36	NIJ36	317	658	L	"Belvedere Pond"	MD
129	J	38	NIJ38	365	887	A	"Upper" South Woodburn Reservoir	
130	J	39	NIJ39	304	981	S	Killylane Burn	
131	J	44	CZ1550	415	498	L	Lough Mann	R
132	J	45	NIJ45	487	543	L	"South Jericho Lough"	
133	J	46	NIJ46	495	633	L	Ballymartin Lough	
134	J	47	NIJ47	484	777	L	Un-named pond	MD
135	J	49	NIJ49	415	923	L	Lough Mourne	
136	J	54	CZJ54	563	454	L	Lough Keelah	
137	J	55	NIJ55	596	530	L	Ballyherly Lough	
138	J	57	NIJ57	586	766	S	Ballycopeland Burn	
139	J	65	NIJ65	618	548	L	Ballyfinragh Lough	
140	J	66	CZJ66	639	629	L	NT Pools	

APPENDIX 2

MEASURED AND DERIVED WATER CHEMISTRY

(SEE TABLE 1 FOR KEY)

APPENDIX 2: WATER CHEMISTRY

EHS		Sample		Alk.	Cond.	Base cations (ueq/l)					Acid anions (ueq/l)			SiO2	PO4-P	Abs.	TOC	ANC (ueq/l)	
No.	Sitecode	date	pH	ueq/l	uS/cm	Na	K	Mg	Ca	NH4	Cl	NO3	SO4	ug/l	ug/l	250nm	mg/l	Ion balance	Cantrell
1	NIC30	18-Mar-00	7.62	1456	245	485	101	355	1701	9	691	121	245	3400	8	0.137	4.4	1585	1478
2	NIC40	18-Mar-00	8.11	1800	228	403	10	280	2004	0	453	66	130	5280	4	0.041	1.4	2048	1807
3	NIC41	18-Mar-00	7.28	418	133	590	25	210	520	0	703	6	81	6220	6	0.459	9.5	555	466
4	NIC50	20-Mar-00	7.72	566	148	590	49	158	712	0	718	6	103	490	6	0.160	6.9	682	601
5	NIC51	20-Mar-00	7.93	1396	176	403	19	658	950	0	400	2	39	8150		0.187	4.4	1589	1418
6	NIC60	20-Mar-00	7.37	360	77	318	13	189	308	0	322	6	41	10210	8	0.350	6.8	459	394
7	CZC61	20-Mar-00	6.51	104	62	323	21	118	150	0	390	1	29	910	14	0.417	11.2	192	160
8	NIC62	21-Mar-00	7.51	980	250	590	45	473	1547	0	757	265	385	8500	0	0.161	5.5	1248	1008
9	CZ0859	21-Mar-00	5.83	18	78	443	15	154	132	0	516	20	99	1120	0	0.451	7.8	109	57
10	CZC70	20-Mar-00	6.14	48		354	14	136	156	0	426	12	66	2140	0	0.578	11.5	156	106
11	NIC71	21-Mar-00	7.59	680	118	338	17	263	688	0	399	12	61	4890	0	0.406	7.2	834	716
12	NIC72	21-Mar-00	8.00	1376	182	492	20	823	821	7	443	23	67	9130	0	0.240	5.5	1623	1404
13	NIC73	21-Mar-00	7.79	1152	168	510	19	940	565	0	552	5	36	8190	5	0.845	15.3	1441	1229
14	NIC80	21-Mar-00	7.77	1060	139	307	21	530	763	0	318	3	45	8960	1	0.535	18.2	1255	1151
15	NIC81	21-Mar-00	7.48	1056	141	335	17	484	781	0	323	3	43	5850	0	0.490	8.2	1248	1097
16	NIC82	21-Mar-00	7.56	2350	337	691	24	1272	1872	0	664	244	277	12710	17	0.034	1.5	2674	2358
17	CZ1059	21-Mar-00	8.38	2440	326	779	49	922	2008	0	735	19	262	3180	0	0.116	4.9	2742	2465
18	NIC90	21-Mar-00	7.62	2586	343	628	44	1546	1825	14	628	195	229	13700	36	0.494	10.0	2991	2636
19	NIC91	21-Mar-00	7.60	1729	284	808	172	1125	1112	18	843	103	162	7450	237	0.978	22.0	2109	1839
20	NIC92	22-Mar-00	7.45	1942	310	723	60	1307	1737	0	784	66	360	14520	40	2.258	46.0	2617	2172
21	NIC93	21-Mar-00	7.69	2446	363	915	31	1269	2026	12	914	130	264	12660	23	1.220	25.0	2933	2571
22	NID00	21-Mar-00	7.00	1115	175	310	347	472	684	6	390	29	103	960	279	0.303	10.9	1291	1170
23	CZ1157	21-Mar-00	4.72	-20	53	273	13	93	78	0	337	7	53	170	0	0.508	9.3	61	27
24	NID02	22-Mar-00	6.96	345	115	519	12	384	362	0	611	1	53	5040	13	1.350	26.0	612	475
25	NID03	22-Mar-00	7.62	1292	183	477	37	714	914	0	478	6	82	7040	0	0.268	5.9	1576	1322
26	NID10	21-Mar-00	7.27	2432	354	594	120	1467	1833	110	503	262	325	15470	455	0.328	7.7	2924	2471
27	CZD11	22-Mar-00	6.97	248	71	291	10	251	220	8	338	4	50	5350	0	0.534	10.4	380	300
28	NID12	22-Mar-00	7.31	529	107	404	6	415	406	0	447	6	40	6630	11	0.762	12.1	738	590
29	BEAH	22-Mar-00	6.52	73	55	307	8	117	133	0	365	1	32	2220	0	0.451	8.4	167	115
30	NID20	22-Mar-00	8.28	3400	325	426	8	2140	1835	9	280	2	22	15300	16	0.377	8.8	4105	3444
31	CZD21	24-Mar-00	6.81	143	53	245	6	179	139	5	279	3	44	970	0	0.312	7.3	243	180
32	CZD22	24-Mar-00	6.60	85	56	285	8	174	106	6	339	5	50	1150	1	0.372	8.0	179	125

APPENDIX 2: WATER CHEMISTRY

EHS		Sample		Alk.	Cond.	Base cations (ueq/l)					Acid anions (ueq/l)			SiO2	PO4-P	Abs.	TOC	ANC (ueq/l)	
No.	Sitecode	date	pH	ueq/l	uS/cm	Na	K	Mg	Ca	NH4	Cl	NO3	SO4	ug/l	ug/l	250nm	mg/l	Ion balance	Cantrell
33	NID23	22-Mar-00	7.05	247	101	509	20	224	307	0	596	2	63	4620	4	0.632	11.3	399	304
34	NID30	22-Mar-00	8.09	1750	191	340	7	1182	865	0	261	5	45	24340	4	0.413	7.6	2083	1788
35	NIG95	18-Mar-00	6.83	729	149	503	31	315	788	18	466	3	276	320	7	0.662	14.0	893	799
36	NIH04	17-Mar-00	4.71	-22	62	328	8	70	92	0	397	1	47	140	3	0.495	10.3	53	30
37	NIH05	18-Mar-00	4.51	-38	79	446	9	93	72	0	522	0	55	430	5	0.682	13.0	43	27
38	NIH06	17-Mar-00	5.53	10	82	514	13	128	91	0	604	1	64	270	1	0.314	6.5	77	43
39	NIH13	17-Mar-00	7.08	593	83	268	7	187	487	4	256	9	14	1450	0	0.331	7.5	670	631
40	NIH14	17-Mar-00	7.76	907	127	296	11	241	865	0	298	5	75	2100	1	0.418	8.2	1035	948
41	NIH15	16-Mar-00	7.68	3089	358	666	59	869	2882	0	653	153	214	14030	12	0.594	12.8	3456	3153
42	NIH16	17-Mar-00	7.98	4848	526	606	72	690	5142	16	652	46	272	8030	24	0.763	17.4	5540	4935
43	NIH17	17-Mar-00	6.20	31	52	354	10	92	77	0	387	1	30	1190	0	0.332	7.7	115	70
44	NIH18	17-Mar-00	4.89	-11	63	381	5	75	76	0	437	0	44	150	3	0.506	10.0	56	39
45	NIH22	17-Mar-00	6.96	256	63	276	13	86	363	0	278	4	17	1670	1	0.962	18.8	439	350
46	NIH23	17-Mar-00	7.75	3183	341	385	51	239	3524	15	448	1	121	2110	41	0.537	12.2	3629	3244
47	NIH24	16-Mar-00	7.63	1511	219	451	126	329	1723	9	542	94	152	7270	146	0.377	10.0	1841	1561
48	NIH25	16-Mar-00	7.69	782	132	359	40	153	925	6	446	13	64	2170	5	0.403	9.6	954	830
49	NIH26	17-Mar-00	6.83	185	68	320	15	135	241	0	372	4	26	3640	6	0.566	10.5	309	238
50	NIH27	17-Mar-00	7.90	1717	220	410	50	420	1637	0	497	48	110	3950	11	0.266	5.9	1862	1747
51	NIH28	17-Mar-00	7.24	484	126	476	63	214	653	8	575	21	63	8180	27	1.005	22.0	747	594
52	NIH32	16-Mar-00	7.66	2382	273	377	93	300	2586	6	459	0	244	600	20	0.469	12.6	2653	2445
53	NIH33	16-Mar-00	7.67	1551	207	356	63	236	1713	0	468	21	113	2690	15	0.477	11.8	1766	1610
54	CZ0450	17-Mar-00	7.46	673	125	341	35	231	715	5	410	49	72	330	0	0.171	5.5	791	701
55	NIH35	16-Mar-00	4.41	-42	62	282	9	73	65	0	362	2	42	290	3	0.416	9.1	23	4
56	NIH36	17-Mar-00	7.45	824	125	325	30	192	883	0	347	14	53	4030	3	0.479	10.3	1016	876
57	NIH37	17-Mar-00	6.61	104	55	301	10	106	173	0	336	2	19	2930	5	0.837	14.5	233	177
58	NIH38	18-Mar-00	7.97	3053	360	470	64	755	2842	6	580	132	224	430	23	0.315	7.5	3195	3091
59	NIH39	18-Mar-00	8.19	1749	289	449	52	704	1977	0	511	32	727	930	5	0.026	2.4	1912	1761
60	NIH42	16-Mar-00	7.74	3983	416	364	72	413	4642	4	432	6	214	4850	22	1.250	28.0	4839	4123
61	CZ0549	16-Mar-00	5.64	16	45	244	14	72	130	0	310	1	41	110	2	0.494	9.4	108	63
62	NIH44	16-Mar-00	6.51	79	52	251	8	87	186	0	310	4	46	1150	0	0.494	9.6	173	127
63	NIH45	16-Mar-00	7.18	942	141	372	33	256	980	0	388	56	67	5620	4	0.447	9.4	1130	989
64	CZ0553	20-Mar-00	7.19	1329	216	445	151	375	1472	10	541	57	141	5940	117	0.644	14.3	1704	1401

APPENDIX 2: WATER CHEMISTRY

EHS		Sample		Alk.	Cond.	Base cations (ueq/l)					Acid anions (ueq/l)			SiO2	PO4-P	Abs.	TOC	ANC (ueq/l)	
No.	Sitecode	date	pH	ueq/l	uS/cm	Na	K	Mg	Ca	NH4	Cl	NO3	SO4	ug/l	ug/l	250nm	mg/l	Ion balance	Cantrell
65	CZH47	22-Mar-00	6.73	121	65	295	20	112	209	0	370	8	72	1320	4	0.293	6.8	186	155
66	V065403	18-Mar-00	4.41	-42	61	287	10	81	42	0	372	6	42	990	4	0.531	9.4	1	5
67	CZ0556	18-Mar-00	6.66	77	60	291	23	95	187	0	366	9	58	4970	5	0.341	7.0	163	112
68	NIH54	16-Mar-00	4.29	-57	54	227	6	52	37	0	275	10	45	330	0	0.368	8.6	-8	-14
69	NIH55	16-Mar-00	7.33	1315	179	379	88	260	1423	0	403	16	144	1930	74	0.672	14.5	1587	1388
70	NIH56	16-Mar-00	6.97	381	79	328	10	145	349	0	310	5	53	9580	5	0.316	5.7	464	410
71	NIH57	18-Mar-00	4.21	-69	62	263	11	61	24	0	326	3	43	230	0	0.698	11.0	-13	-14
72	NIH58	18-Mar-00	6.50	55	46	250	6	95	102	0	289	4	41	4550	3	0.205	4.4	120	77
73	NIH59	16-Mar-00	7.13	212	58	267	10	177	175	0	292	1	42	4070	4	0.249	5.0	294	237
74	NIH65	16-Mar-00	7.58	1346	181	357	62	285	1504	7	416	44	82	6280	26	0.572	14.1	1666	1417
75	CZH66	16-Mar-00	6.43	108	83	416	31	149	299	0	510	19	94	4840	14	0.865	18.6	272	201
76	NIH67	16-Mar-00	4.54	-29	55	256	18	67	42	0	325	3	39	750	0	0.491	9.5	16	19
77	NIH68	20-Mar-00	7.31	385	69	288	10	190	316	0	243	3	28	7120	3	0.543	10.1	531	436
78	CZH69	20-Mar-00	4.20	-71	65	261	3	60	29	0	322	1	22	350	3	0.750	14.7	8	3
79	NIH74	15-Mar-00	7.85	6275	660	587	182	751	6589	222	789	184	363	15200	5	0.173	6.3	6773	6307
80	CZ0851	16-Mar-00	7.33	487	111	314	69	179	600	4	405	11	132	3640	31	0.365	9.8	614	536
81	NIH76	16-Mar-00	7.80	1459	219	399	89	409	1577	23	442	121	143	8200	55	0.198	6.1	1768	1490
82	NIH77	16-Mar-00	6.81	195	73	333	107	101	168	0	423	1	10	170	3	0.175	5.7	275	224
83	NIH78	20-Mar-00	5.41	6	48	260	15	83	84	0	315	1	59	1930	1	0.299	6.6	67	39
84	CZH79	20-Mar-00	4.44	-40	57	257	12	61	38	0	321	1	35	200	2	0.401	9.3	11	7
85	CZH83	15-Mar-00	7.50	718	139	328	86	216	874	6	425	19	189	8780	8	0.283	7.4	871	755
86	NIH84	15-Mar-00	8.06	5885	570	533	45	1018	5033	0	560	84	256	4410	0	0.172	4.7	5729	5909
87	CZ0951	15-Mar-00	8.04	2838	360	672	183	738	2534	11	799	79	320	9110	116	0.300	8.7	2929	2882
88	NIH86	20-Mar-00	7.98	2145	300	487	122	701	2178	0	524	51	425	5120	31	0.238	8.1	2488	2186
89	NIH87	20-Mar-00	8.25	6010	643	486	71	1574	5331	0	550	274	655	8960	23	0.170	4.9	5983	6035
90	NIH88	20-Mar-00	7.49	652	113	297	24	375	566	0	325	41	97	4750	0	0.112	3.2	799	668
91	NIH89	20-Mar-00	7.57	826	118	287	15	355	703	0	287	5	73	10430	0	0.330	5.6	995	854
92	CZH91	15-Mar-00	6.91	175	78	352	21	139	255	0	393	4	108	9880	5	0.210	5.5	262	203
93	NIH92	15-Mar-00	6.91	410	136	510	43	210	559	0	615	57	143	17950	0	0.314	7.8	507	449
94	CZH93	15-Mar-00	7.84	915	186	366	113	313	1169	4	509	90	280	2000	4	0.223	6.6	1082	948
95	CZH94	15-Mar-00	7.59	2419	359	1034	74	816	2147	13	1122	1	277	4030	38	0.370	9.7	2671	2468
96	NIH95	15-Mar-00	7.33	3820	490	917	123	1753	3278	21	948	98	450	4570	240	1.741	38.0	4575	4010

APPENDIX 2: WATER CHEMISTRY

EHS No.	Sitecode	Sample date	pH	Alk. ueq/l	Cond. uS/cm	Base cations (ueq/l) Na	K	Mg	Ca	NH4	Acid anions (ueq/l) Cl	NO3	SO4	SiO2 ug/l	PO4-P ug/l	Abs. 250nm	TOC mg/l	ANC (ueq/l) Ion balance	Cantrell
97	NIH96	15-Mar-00	7.56	931	280	1342	75	532	1026	0	1362	1	267	10530	40	1.330	31.0	1345	1086
98	NIH97	20-Mar-00	7.12	1915	286	475	91	1059	2327	20	543	1	389	10690	260	2.651	97.0	3019	2400
99	NIH98	21-Mar-00	7.79	1709	254	493	57	747	1630	0	548	93	247	3800	8	0.241	5.7	2039	1738
100	NIH99	21-Mar-00	7.81	2400	295	591	59	723	2128	0	589	3	118	4160	0	0.355	11.6	2791	2458
101	CZJ01	15-Mar-00	7.24	294	112	421	35	215	404	0	468	101	147	11590	1	0.106	3.2	359	310
102	NIJ02	15-Mar-00	7.16	184	74	326	12	167	230	0	363	13	101	11440	0	0.142	3.6	258	202
103	NIJ03	16-Mar-00	7.69	1260	298	713	101	616	1691	0	823	510	348	8780	2	0.136	4.5	1440	1283
104	CZJ04	15-Mar-00	8.16	1135	209	451	105	589	1127	0	535	45	360	9200	40	0.210	7.0	1332	1170
105	NIJ05	15-Mar-00	7.34	3437	434	1037	108	1263	2520	0	996	52	414	2770	130	0.484	12.0	3466	3497
106	NIJ09	21-Mar-00	8.01	2490	290	559	14	1640	1544	0	546	17	122	20020	33	0.707	15.3	3072	2567
107	NIJ12	15-Mar-00	7.71	804	210	520	86	458	1070	6	572	304	318	11260	2	0.146	4.8	940	828
108	CZJ13	14-Mar-00	7.81	1220	222	537	213	433	1164	14	703	5	194	1600	250	0.403	11.0	1445	1275
109	CZJ14	15-Mar-00	8.02	1653	255	632	160	645	1454	0	745	23	153	4150	190	0.345	8.8	1970	1697
110	NIJ15	23-Mar-00	7.78	3037	428	568	101	1736	2589	19	709	362	369	3170	75	0.164	5.6	3554	3065
111	NIJ16	23-Mar-00	8.25	5450	625	817	73	2346	4619	0	819	244	577	18800	350	0.094	3.5	6215	5468
112	NIJ17	23-Mar-00	8.27	2950	370	765	83	1609	2000	0	740	100	234	18180	110	0.176	5.5	3383	2978
113	NIJ18	23-Mar-00	8.06	3527	443	655	29	2349	2424	0	703	238	386	26300	94	0.081	3.1	4130	3543
114	NIJ19	22-Mar-00	7.99	1353	213	547	50	814	1016	0	515	117	180	22480	22	0.173	4.8	1615	1377
115	NIJ21	14-Mar-00	6.89	105	64	282	10	114	177	0	325	11	88	4130	0	0.078	2.5	159	118
116	NIJ22	14-Mar-00	4.80	-16	43	216	11	59	40	2	231	21	65	3170	2	0.159	3.7	9	3
117	CZJ23	14-Mar-00	7.61	1328	301	1006	295	778	1102	14	1092	250	189	11610	110	0.868	19.0	1650	1423
118	NIJ24	15-Mar-00	7.53	661	144	369	49	298	770	0	402	147	166	8800	6	0.054	1.9	771	671
119	NIJ25	23-Mar-00	8.26	2722	372	642	82	1253	2396	0	706	196	339	14300	117	0.139	5.0	3132	2747
120	NIJ26	23-Mar-00	7.90	3610	425	721	70	1221	2877	22	805	11	475	4130	67	0.171	6.1	3598	3641
121	NIJ27	23-Mar-00	8.10	2270	239	371	10	1054	1569	0	216	3	101	15870	3	0.193	4.5	2684	2293
122	NIJ28	23-Mar-00	7.66	2588	337	547	22	1521	2119	12	525	236	321	20370	26	0.092	3.4	3127	2605
123	CZJ29	22-Mar-00	7.83	1720	218	402	24	934	1211	11	389	40	165	13000	2	0.143	4.1	1977	1741
124	NIJ32	14-Mar-00	5.15	-4	52	266	13	77	68	0	284	47	82	14880	0	0.059	1.6	11	4
125	NIJ33	14-Mar-00	7.29	753	191	563	81	334	964	13	707	137	227	1980	12	0.222	6.2	871	784
126	NIJ34	15-Mar-00	7.23	296	87	328	25	243	291	0	381	24	96	8860	1	0.191	4.3	386	318
127	NIJ35	23-Mar-00	7.39	1187	255	550	151	626	1492	18	749	195	324	3860	100	0.494	11.4	1551	1244
128	NIJ36	23-Mar-00	7.64	2009	370	854	206	976	2098	23	1279	2	410	920	37	0.266	8.4	2443	2051

APPENDIX 2: WATER CHEMISTRY

EHS No.	Sitecode	Sample date	pH	Alk. ueq/l	Cond. uS/cm	Base cations (ueq/l) Na	K	Mg	Ca	NH4	Acid anions (ueq/l) Cl	NO3	SO4	SiO2 ug/l	PO4-P ug/l	Abs. 250nm	TOC mg/l	ANC (ueq/l) Ion balance	Cantrell
129	NIJ38	23-Mar-00	7.78	1239	217	478	29	894	1070	0	474	195	283	14640	44	0.231	5.8	1519	1268
130	NIJ39	22-Mar-00	7.70	1440	197	347	5	1023	956	0	465	32	186	22950	4	0.270	5.5	1648	1468
131	CZ1550	15-Mar-00	7.91	1462	238	632	108	551	1393	0	711	8	242	1080	23	0.272	8.6	1723	1505
132	NIJ45	14-Mar-00	7.96	2359	363	671	110	945	2403	0	885	110	439	4870	40	0.447	12.0	2695	2419
133	NIJ46	14-Mar-00	9.00	1709	314	783	136	739	1847	0	1017	91	376	1140	60	0.394	11.0	2021	1764
134	NIJ47	14-Mar-00	7.53	1708	357	909	332	655	1906	0	1283	1	495	7880	140	0.418	14.0	2023	1778
135	NIJ49	23-Mar-00	8.42	1507	211	457	29	952	1058	0	443	19	220	2760	3	0.164	5.4	1814	1534
136	CZJ54	15-Mar-00	8.24	3570	449	782	71	1410	2894	8	998	155	271	7740	10	0.128	4.3	3733	3592
137	NIJ55	14-Mar-00	8.13	3785	546	1229	138	1579	3734	0	1501	265	464	6980	50	0.161	6.0	4450	3815
138	NIJ57	14-Mar-00	8.29	3530	607	932	92	2027	4235	0	1168	277	1781	9620	20	0.113	3.8	4060	3549
139	NIJ65	14-Mar-00	8.41	5230	681	1152	231	2319	4579	0	1428	497	707	920	110	0.212	7.0	5649	5265
140	CZJ66	14-Mar-00	7.99	2550	375	966	139	1067	2184	18	1237	3	315	3650	1	0.332	12.0	2802	2610

APPENDIX 3

FAB MODEL OUTPUTS: CRITICAL LOADS AND EXCEEDANCES

KEY

See main text for explanation of critical load terms.

Sites showing critical load exceedance are shaded.

FAB Exceedance Class:
0 Not exceeded
1 Reduce S only
2 Reduce S, then S or N
3 Reduce both S and N
4 Reduce N, then S or N
5 Reduce either S or N (or a combination of both)

APPENDIX 3: FAB MODEL OUTPUTS

EHS Number	Sitecode	CLminN keq/ha/yr	CLmaxN keq/ha/yr	CLmaxS keq/ha/yr	Exceedance 1995-97 keq/ha/yr	Exceedance 1995-97 Class	Exceedance 2010 keq/ha/yr	Exceedance 2010 Class
1	NIC30	0.29	9.85	9.56	-8.83	0	-9.21	0
2	NIC40	0.18	15.69	15.51	-14.31	0	-14.71	0
3	NIC41	0.24	3.73	3.49	-2.39	0	-2.77	0
4	NIC50	0.28	7.15	5.06	-3.96	0	-4.27	0
5	NIC51	0.31	12.94	12.63	-11.67	0	-11.90	0
6	NIC60	0.29	4.79	4.50	-2.62	0	-3.17	0
7	CZC61	0.58	2.45	1.33	-0.83	0	-1.02	0
8	NIC62	0.28	6.71	6.44	-5.87	0	-6.08	0
9	CZ0859	0.17	2.40	0.89	-0.28	0	-0.46	0
10	CZC70	0.45	2.65	1.95	-0.33	0	-0.87	0
11	NIC71	0.26	8.50	8.24	-6.97	0	-7.23	0
12	NIC72	0.35	11.62	11.26	-10.32	0	-10.57	0
13	NIC73	0.29	11.42	11.13	-10.26	0	-10.52	0
14	NIC80	0.29	13.38	13.09	-11.76	0	-12.13	0
15	NIC81	0.33	12.37	12.04	-11.07	0	-11.32	0
16	NIC82	0.30	19.95	19.65	-18.80	0	-19.07	0
17	CZ1059	0.27	16.94	13.66	-12.66	0	-12.93	0
18	NIC90	0.30	13.40	13.11	-12.04	0	-12.30	0
19	NIC91	0.21	13.98	9.55	-8.26	0	-8.49	0
20	NIC92	0.34	12.00	11.66	-10.84	0	-11.13	0
21	NIC93	0.27	13.79	13.52	-12.43	0	-12.73	0
22	NID00	0.14	8.84	6.65	-5.28	0	-5.58	0
23	CZ1157	0.21	1.33	0.60	0.36	5	0.10	5
24	NID02	0.34	4.64	4.29	-2.11	0	-2.65	0
25	NID03	0.33	12.45	12.12	-10.22	0	-10.68	0
26	NID10	0.34	18.51	18.17	-16.92	0	-17.35	0
27	CZD11	0.29	4.14	3.70	-1.55	0	-2.07	0
28	NID12	0.46	8.66	8.20	-6.13	0	-6.71	0
29	BEAH	0.28	1.89	1.61	0.64	5	0.06	5
30	NID20	0.30	36.32	36.02	-34.10	0	-34.65	0
31	CZD21	0.23	4.96	2.79	-0.90	0	-1.46	0
32	CZD22	0.25	3.13	1.98	-0.82	0	-1.17	0
33	NID23	0.27	3.75	3.49	-2.38	0	-2.71	0
34	NID30	0.31	18.45	18.14	-15.77	0	-16.37	0
35	NIG95	0.29	12.51	7.79	-6.73	0	-7.11	0
36	NIH04	0.39	1.20	0.66	0.23	5	-0.03	0
37	NIH05	0.41	0.99	0.41	0.24	2	-0.02	0
38	NIH06	0.31	0.96	0.53	0.20	5	-0.06	0
39	NIH13	0.29	9.12	8.83	-8.01	0	-8.33	0
40	NIH14	0.31	12.33	12.02	-11.37	0	-11.55	0
41	NIH15	0.30	19.68	19.38	-18.68	0	-18.92	0
42	NIH16	0.29	37.02	36.72	-36.08	0	-36.31	0
43	NIH17	0.33	1.28	0.95	-0.04	0	-0.40	0
44	NIH18	0.52	1.45	0.61	0.11	5	-0.18	0
45	NIH22	0.21	4.98	4.76	-4.04	0	-4.28	0
46	NIH23	0.32	28.67	21.72	-20.41	0	-20.60	0
47	NIH24	0.23	15.57	12.21	-11.30	0	-11.45	0
48	NIH25	0.30	9.46	6.38	-5.58	0	-5.75	0
49	NIH26	0.32	2.82	2.50	-1.58	0	-1.93	0
50	NIH27	0.25	19.76	19.51	-18.53	0	-18.75	0

EHS Number	Sitecode	CLminN keq/ha/yr	CLmaxN keq/ha/yr	CLmaxS keq/ha/yr	Exceedance 1995-97 keq/ha/yr	Exceedance 1995-97 Class	Exceedance 2010 keq/ha/yr	Exceedance 2010 Class
51	NIH28	0.31	6.61	6.31	-5.33	0	-5.57	0
52	NIH32	0.33	13.85	13.34	-12.56	0	-12.94	0
53	NIH33	0.34	12.08	9.92	-9.01	0	-9.29	0
54	CZ0450	0.13	10.85	5.62	-4.55	0	-4.74	0
55	NIH35	0.27	0.64	0.26	0.48	3	0.21	4
56	NIH36	0.36	10.01	9.65	-8.68	0	-9.05	0
57	NIH37	0.29	1.88	1.59	-0.77	0	-1.07	0
58	NIH38	0.25	18.34	18.10	-17.20	0	-17.46	0
59	NIH39	0.11	39.60	14.30	-10.92	0	-11.18	0
60	NIH42	0.31	29.03	21.63	-20.29	0	-20.59	0
61	CZ0549	0.17	2.37	1.05	-0.04	0	-0.38	0
62	NIH44	0.29	3.38	1.44	-0.39	0	-0.72	0
63	NIH45	0.30	9.18	8.87	-7.83	0	-8.17	0
64	CZ0553	0.17	30.57	12.72	-10.15	0	-10.41	0
65	CZH47	0.33	2.10	1.74	-0.34	0	-0.68	0
66	V065403	0.27	0.49	0.17	1.24	3	0.91	3
67	CZ0556	0.21	3.35	1.53	-0.62	0	-0.84	0
68	NIH54	0.25	0.39	0.09	1.01	3	0.62	3
69	NIH55	0.36	13.74	10.46	-9.36	0	-9.67	0
70	NIH56	0.29	3.62	3.33	-2.09	0	-2.47	0
71	NIH57	0.27	0.26	-0.01	1.07	3	0.79	3
72	NIH58	0.27	1.35	1.08	0.43	5	0.14	5
73	NIH59	0.30	3.42	3.12	-1.77	0	-2.11	0
74	NIH65	0.33	9.45	9.12	-8.30	0	-8.61	0
75	CZH66	0.43	2.83	2.29	-1.03	0	-1.41	0
76	NIH67	0.26	0.57	0.20	0.88	3	0.58	3
77	NIH68	0.29	5.67	5.39	-3.61	0	-4.00	0
78	CZH69	0.37	0.37	0.00	1.27	3	0.87	3
79	NIH74	0.36	21.37	21.01	-20.32	0	-20.67	0
80	CZ0851	0.28	7.97	3.85	-2.85	0	-3.11	0
81	NIH76	0.29	10.99	10.70	-9.62	0	-9.93	0
82	NIH77	0.24	3.65	1.71	-0.73	0	-1.01	0
83	NIH78	0.30	1.25	0.75	0.83	4	0.54	4
84	CZH79	0.23	0.53	0.17	1.03	3	0.61	3
85	CZH83	0.32	10.84	6.56	-4.89	0	-5.36	0
86	NIH84	0.31	15.41	15.10	-14.15	0	-14.61	0
87	CZ0951	0.29	22.36	10.56	-8.71	0	-8.98	0
88	NIH86	0.25	19.57	9.38	-7.51	0	-7.76	0
89	NIH87	0.28	25.94	25.66	-24.60	0	-24.91	0
90	NIH88	0.31	7.14	6.83	-5.27	0	-5.57	0
91	NIH89	0.35	10.35	10.01	-8.75	0	-9.12	0
92	CZH91	0.13	2.83	1.64	-0.58	0	-0.98	0
93	NIH92	0.21	3.50	3.07	-1.78	0	-2.22	0
94	CZH93	0.26	11.57	7.78	-6.46	0	-6.81	0
95	CZH94	0.23	28.18	14.41	-12.17	0	-12.48	0
96	NIH95	0.34	10.19	9.86	-8.95	0	-9.29	0
97	NIH96	0.22	23.58	5.24	-2.82	0	-3.00	0
98	NIH97	0.27	21.30	9.95	-8.05	0	-8.31	0
99	NIH98	0.28	30.44	8.84	-6.05	0	-6.26	0
100	NIH99	0.20	17.08	10.66	-8.98	0	-9.30	0

APPENDIX 3: FAB MODEL OUTPUTS

EHS Number	Sitecode	CLminN keq/ha/yr	CLmaxN keq/ha/yr	CLmaxS keq/ha/yr	Exceedance 1995-97 keq/ha/yr	Exceedance 1995-97 Class	Exceedance 2010 keq/ha/yr	Exceedance 2010 Class
101	CZJ01	0.15	3.95	2.29	-1.12	0	-1.54	0
102	NIJ02	0.17	2.33	2.16	-0.72	0	-1.19	0
103	NIJ03	0.28	8.99	8.71	-7.65	0	-8.00	0
104	CZJ04	0.33	10.19	4.93	-3.73	0	-4.04	0
105	NIJ05	0.36	8.45	8.09	-7.15	0	-7.63	0
106	NIJ09	0.33	12.86	12.53	-11.67	0	-11.98	0
107	NIJ12	0.24	10.35	5.76	-4.28	0	-4.70	0
108	CZJ13	0.31	11.07	7.32	-5.81	0	-6.20	0
109	CZJ14	0.28	7.23	6.65	-5.44	0	-5.88	0
110	NIJ15	0.23	10.65	9.98	-8.87	0	-9.30	0
111	NIJ16	0.30	17.74	17.44	-16.17	0	-16.65	0
112	NIJ17	0.34	14.51	14.17	-12.91	0	-13.43	0
113	NIJ18	0.35	18.87	18.52	-17.52	0	-17.96	0
114	NIJ19	0.29	10.35	10.06	-8.75	0	-9.20	0
115	NIJ21	0.15	1.97	1.82	0.37	5	-0.39	0
116	NIJ22	0.24	1.10	0.56	1.54	3	0.76	4
117	CZJ23	0.33	13.18	7.26	-5.65	0	-5.99	0
118	NIJ24	0.16	5.52	5.36	-3.67	0	-4.22	0
119	NIJ25	0.34	11.80	11.46	-10.00	0	-10.54	0
120	NIJ26	0.18	22.95	14.40	-12.17	0	-12.71	0
121	NIJ27	0.35	19.87	19.52	-17.76	0	-18.58	0
122	NIJ28	0.28	17.00	16.73	-15.51	0	-15.95	0
123	CZJ29	0.28	18.49	14.35	-12.43	0	-12.87	0
124	NIJ32	0.28	1.07	0.72	1.16	3	0.53	4
125	NIJ33	0.27	19.98	7.94	-5.50	0	-5.91	0
126	NIJ34	0.15	3.30	3.15	-1.17	0	-1.72	0
127	NIJ35	0.18	8.88	7.87	-6.24	0	-6.70	0
128	NIJ36	0.18	22.31	11.53	-8.87	0	-9.58	0
129	NIJ38	0.41	14.84	10.94	-9.21	0	-9.84	0
130	NIJ39	0.62	15.16	14.54	-12.76	0	-13.29	0
131	CZ1550	0.20	16.15	7.58	-5.72	0	-6.12	0
132	NIJ45	0.21	13.10	8.78	-7.35	0	-7.78	0
133	NIJ46	0.26	8.35	7.06	-5.89	0	-6.35	0
134	NIJ47	0.13	19.85	10.62	-8.43	0	-9.05	0
135	NIJ49	0.24	24.35	14.05	-11.79	0	-12.35	0
136	CZJ54	0.18	15.63	10.23	-8.80	0	-9.21	0
137	NIJ55	0.14	24.33	12.45	-10.41	0	-10.77	0
138	NIJ57	0.26	13.08	12.81	-11.82	0	-12.31	0
139	NIJ65	0.18	16.16	14.06	-12.94	0	-13.33	0
140	CZJ66	0.21	19.85	7.84	-5.93	0	-6.26	0