Effects Based Acidification Abatement Strategies:
Current Criteria and Proposed Approach

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1. Introduction

Within RECOVER: 2010, Work Package 7 (PROFFER) aims to Provide Relevant Output For Formulating End-user Requirements. The policy context for this work is that despite international instruments to control S and N emission being almost complete with the signing of the Multi-pollutant, Multi-effect Protocol (Gothenberg Protocol) in 1999 and the potential to consider that no further action is necessary, the instruments are <u>not ambitious</u> and reviews are already planned for 2004. There is, therefore, a need to maintain momentum and to exploit the opportunity to rectify shortfalls in the currently used instruments.

The first step in this process is to review current methods and criteria and so identify shortfalls and improvements that could be made in the future. This report documents the existing methods and criteria, reports the conclusions of the end-user meeting held in Abingdon, UK, on 22-24 May 2000 and documents the approach planned within RECOVER: 2010.

2. Current approaches and criteria

Chemical criteria for water have been defined to protect biota and humans for adverse toxic effects. These criteria are based upon the use to which the water is intended and these have formed the basis for much EU legislation relating to water. In addition, chemical criteria have been used with the framework of the UN-ECE Convention on Long Rang Transboundary Air Pollution to identify acidified and acid-sensitive waters and to underpin S and N emission reduction strategies. In this case, these chemical criteria are related to biological characteristics of the water body.

2.1 *Critical loads for freshwaters*

For the work under the LRTAP Convention a critical load has been defined as 'a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge' (Nilsson and Grennfelt 1988). Originally, critical loads were calculated for acidity and a 'sulphur fraction' was used to derive a critical load for sulphur (eg in the 1994 Oslo Protocol). For the 1999 Gothenberg Protocol, critical loads of N were also required since this was a 'multi-pollutant, multi-effect' protocol. The critical loads are defined for:

(i) the maximum critical load of sulphur as the net input of (seasalt corrected) base cation minus a critical leaching of acid neutralisation capacity (see later),

$$CL_{max}(S) = BC^{*}_{dep} - CL^{*}_{dep} + BC_{w} - BC_{u} - ANC_{de(crit)} \quad (1)$$

(ii) the minimum critical load of N, where N deposition is all consumed by sinks of N (immobilisation and uptake),

$$N_{dep} \quad N_{I} + N_{u} = CL_{min}(N) \quad (2)$$

(iii) the maximum critical load for nitrogen acidity in the case of no S deposition which accounts for N sinks and deposition-dependent denitrification,

$$CL_{max}(N) = CL_{min}(N) + CL_{max}(S)/(1 - F_{de}) \quad (3)$$

Both S and N contribute to acidification, but one equivalent of S contributes, in general, more to excess acidity than one equivalent of N. Clearly, no unique acidity critical load can be defined, but combinations of N_{dep} and S_{dep} not causing 'harmful effects' lie on the 'critical load function' of the ecosystem as defined by the three critical loads from equations (1) to (3) (Figure 1). Harmful effects, in the case of freshwaters are defined in terms of some level of $ANC_{le(crit}$ (see later).

For negotiations under the protocol, information describing critical loads is used within an integrated assessment model (RAINS model; Amann *et al*. 1999) to optimise emission reductions and lead to a closing of the gap between N and S deposition and critical loads (Posch *et al*. 1999).

The RAINS model can then be used in a 'scenario analysis' mode to estimate future trends in deposition over time (Schöpp *et al*. 2000) and this in turn can be used as input to dynamic bio-geochemical models to predict changes in soil and surface water chemistry in response to the protocol. Given suitable relationships between chemistry and biota, it is then possible to use the models to assess the timescale of recovery of the ecosystem. In addition, this process can be reversed such that ecological targets can be prescribed for a given point in time and the dynamic bio-geochemical models can estimate the deposition target required to achieve it.

The relationship between ANC and biology can be generated by field or laboratory experiments focusing on individual biological targets, for example, some fish species (Baker *et al*. 1987). An alternative approach is to derive empirical regression models relating biological status to chemical conditions using field survey data (eg Reckhow *et al*. 1987, Ormerod 1993, Lien *et al*. 1996; Henriksen *et al*. 1999). In general, most organisms show a graded response to ANC rather than a step change and so response curves can be fitted using logistic regression. In this way, appropriate chemical targets can be defined to protect or establish a required biological status. For example, describing the occurrence of the diatom *Achnanthes minutissima*, the macroinvertebrate *Baetis rhodani*, non-impoverished macroinvertebrate assemblages, number of mayfly species and the density of trout/salmonid populations in relation to surface water chemistry, and in particular ANC, has been collated from surveys undertaken in England, Scotland and Wales (Juggins *et al*. 1995). The results provide response curves for ANC (Figure 2) and critical ANC values for mayflies and trout (Table 1). In this example, to ensure a 0.5 probability of occurrence, the ANC should not fall below 23 $\mu eq\ l^{-1}$ for the diatom species and below 36 $\mu eq\ l^{-1}$ for *Baetis rhodani*. A more detailed survey of fish status and water chemistry has been undertaken in Norway (Lien *et al*. 1996). The results of which demonstrate the probability of a change in the status of brown trout population in relation to ANC (Figure 3). This analysis has been taken further to determine the relationship between fish status and critical load exceedance (Henriksen *et al*. 1999).

2.2 *Other EU legislation*

The Council Directive of 16 June 1975 concerned the quality required of surface water intended for the abstraction of drinking water in the Member States (75/440/EEC). This Directive classifies the quality of surface water intended for drinking into three categories (Al, A2, A3) according to the extent of the treatment required to render them fit for that use (Table 2). Only pH, NO_3 and SO_4 are considered here within the subject area of RECOVER: 2010.

The Council Directive of 18 July 1978 concerned the quality of freshwaters needing protection or improvement in order to support fish life (78/659/EEC). This directive deals with the quality of water required to support salmonid and cyprinid species of fish and lists, for each of these species, guide and mandatory values for a wide range of parameters. Within the subject area of RECOVER: 2010, pH is the only relevant parameter and this is given a mandatory range of 6 to 9 for both salmonid and cyprinid fish. This pH is based on an annual 95 percentile value for samples taken at a minimum of monthly frequency.

The proposed 'Council Directive establishing a framework for Community action in the field of water policy' (the Water Framework Directive; European Council 1999) differs significantly from the earlier mentioned Directives and others of the 1970s and 80s which were either targeted to protect particular uses of the aquatic environment (eg water for abstraction for drinking, for protection of fisheries etc) or to address specific threats to environmental quality (eg the Dangerous Substances Directive: 76/464/EEC).

The WFD provides instead a framework covering groundwater, wetlands, rivers, lakes, estuaries and coastal waters using environmental objectives which will aim to prevent further deterioration and protect and enhance the status of aquatic ecosystems. The WFD repeals seven existing Directives:

- standards for protection of drinking water (75/440/EEC and 79/869/EEC)
- freshwater fisheries (78/659/EEC)
- shellfish waters (79/923/EEC)
- groundwaters (80/68/EEC)
- control of dangerous substances (76/464/EEC)
- reporting to the Commission (77/795/EEC)

These are replaced by environmental objectives with the primary aim for surface waters and groundwaters of achieving <u>good status</u>. Good surface water status depends on a waterbody achieving at least good <u>chemical status</u> and good <u>ecological status</u>. Member states must aim to achieve these environmental objectives by 2016 (?).

<u>Good chemical status</u> is determined mainly by compliance with Environmental Quality Standards (EQS) set for priority substances, which replace the Dangerous Substances list I. None of these are relevant to RECOVER: 2010.

<u>Good ecological status</u> is derived from a combination of measurements of biological and physico-chemical (excluding priority substances) parameters. The most important physico-chemical parameter for upland lakes and rivers in areas subject to acidic deposition, in RECOVER: 2010, is acidification status which is to be defined in terms of pH and acid neutralisation capacity (ANC). In this respect, an EQS for ANC should be set by Member States to ensure that good biological status can be maintained. Good biological status being defined in terms of deviation from pristine (or relatively undisturbed) reference conditions. Compliance with both the EQS and good biological quality is required to achieve good ecological status. The definition of high, good and moderate status for biological and physico-chemical quality elements relevant to RECOVER: 2010 are given in Table 3.

3. Proposed approach in RECOVER: 2010

Ecological risk assessment (ERA) is a relatively new concept consisting of a formalised set of procedures by which the scientific estimation of risk of ecological damage can be integrated with the policy implications. For the RECOVER: 2010 project it provides a framework for the involvement of the end-users and to ensure that the project achieves its overall objectives.

3.1 *Ecological risk assessment*

The technique was developed in the US in the mid-1980s in conjunction with procedures for releasing new chemicals into the environment. It began with efforts to apply the concepts and rigor of human health, engineering and financial risk assessment to ecological hazards. It is now officially in use in the EU as "EC Commission regulation (EC) no 1488/94 of 28 June 1994 laying down the principles for the assessment of risks to man and the environment of existing substances in accordance with Council Regulation (EEC) No 793/93".

Suter (1995) provides a short summary of the concept of ecological risk assessment. He defines ecological risk assessment as 'the estimation of the likelihood of undesired effects of human actions or natural events and the accompanying risks to non human organisms, populations and ecosystems' ERA has the following points (Suter 1995):

- it has a standard logical procedure
- it separates assessment from management
- it has clearly defined endpoints
- it explicitly recognises the role of uncertainty in decision-making.

For the RECOVER: 2010 project, it is the separation of the assessment from the management that makes ERA particularly suitable. The technique identifies 'risk managers' and 'risk assessors'. Risk managers are the policymakers who initially define the problem and then after the risk assessors (scientists) have quantified the risks, take these results and determine the policies and counter-measures to be taken (Figure 4). This clear separation is to prevent two conflicts of interest:

- the decision-makers should not have the opportunity to manipulate the data to support a desired decision
- the scientists should not have the opportunity to introduce their own biases as to what aspects of the natural environment should be protected.

The separation of risk managers and risk assessors is fundamental. The risk managers are the designated representatives of the public. Scientists advise the risk managers, but they are not the responsible parties. For example, in the case of acid deposition and freshwater ecosystems in Norway, the first step in ERA would be a planning session at which the risk managers (in this case representatives from the Norwegian State Pollution Control Authority and the Directorate for Protection of Nature) meet with the scientists to decide which 'endpoint' or target organism is to be assessed. Is the target to be brown trout? If so, is a self-reproducing population necessary? Does reproduction have to be successful in all years? Is invertebrate community an additional endpoint? Is normal diatom community an additional endpoint? These are decisions for the policy makers or environmental managers.

Once these end points are specified, the risk assessors (scientists) will work to characterise the exposures, characterise the effects, and develop dose-response relationships. This step involves linking acid deposition to water chemistry (critical load) and water chemistry to, say, brown trout populations (critical limit) and is basically the core work of the RECOVER: 2010 project.

When the science is completed the risk managers take the scientific information on the risks (ie the risk that the brown trout population will not be self-sustaining in the year 2010 given reductions in acid deposition of the Gothenberg Protocol) and decide on policy measures (such as negotiating a new protocol) or mitigation measures (such as liming).

3.2 *Uncertainty*

The concept of risk implies some degree of uncertainty regarding the ecological effects. Acceptance of uncertainty is different from conventional science in which the experimenter is required to continue to perform studies until it can be demonstrated with high level of statistical confidence (eg 95%) that the hypothesised effect is real. ERA takes the common sense proposition that decisions must be made under conditions of significant uncertainty. There, there is often a non-trivial risk that an undesired effect will occur (Suter 1995).

Estimating uncertainty is difficult in this research area, but the key to this project is determining the uncertainties relevant to the decision and presenting these uncertainties in a comprehensive and useful manner. Thus, effects and uncertainties must be estimated independently. That is, the most likely outcome must be estimated and also the likelihood of less severe or more severe outcomes. For example, in RECOVER the goal is to estimate the most likely trout population status in the year 2010 (using predicted deposition, MAGIC and dose-response relationships), as well as the likelihood of the best case and worst case.

3.3 *End-users and RECOVER: 2010*

ERA provides the framework for involvement of the end-users in RECOVER: 2010. At the first meeting between the scientists and the end-users the task is to specify the ecological endpoints or targets. These can be related to aquatic as well as terrestrial ecosystems, depending upon the needs of the various end-users. Then the scientists undertake the risk assessment for these endpoints together with estimated uncertainties. At a final meeting, near the end of the project, the end-users will be presented with the results (estimated effects and estimated uncertainties) and these will be discussed.

4. Required targets and end-points

At the first meeting of end-users (PROFFER) in May 2000 the different biological and chemical targets were discussed and determined and the priorities are listed in Table 4.

It was also stressed that the priorities for biological and chemical targets varied regionally within Europe. For example, in Scandinavia and upland UK, brown trout were considered a key target, whereas in Cermany this was not the case and the suitability of water for meeting the drinking water abstraction guidelines was more important. The regional priorities identified are set out in Table 5.

The required information for policy-makers was determined to be:

- Status of the biological targets in 2010 (or at least how far are we from the ultimate goal).
- Status of the biological targets in 2016
- Timescale for achieving the desired targets
- Regional extent (maps) of compliance with UN-ECE targets (?) and 'good status' under the EU WFD.
- Best and worst case scenarios for all of the above.

5. References

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Table 1 *Biological status and ANC predicted from regression relationships (Juggins et al. 1995)*

ANC	No of mayfly species	Trout density (nos 100 m^{-2})
-100	0	5
-50	0	9
-20	0	12
0	0	14
20	1	17
50	2	23
100	4	37
200	19	94

Table 2 *Guide (G) and mandatory (I) concentrations of NO_3 and SO_4 and pH for three categories of water treatment (A1 = lowest level of treatment)*

Parameters	A1 G	A1 I	A2 G	A2 I	A3 G	A3 I
pH	6.5 to 8.5		5.5 to 9		5.5 to 9	
Nitrate (mg/l NO_3)	25	50 (0)		50 (0)		50 (0)
Sulphate (mg/l SO_4)	150	250	150	250 (0)	150	250 (0)

Table 3: Definitions for high, good and moderate ecological status in rivers and lakes

1. RIVERS (BIOLOGICAL QUALITY ELEMENTS)			
Element	High Status	Good Status	Moderate State
Phytoplankton	The taxonomic composition of phytoplankton corresponds totally or nearly totally to undisturbed conditions. The average phytoplankton abundance is wholly consistent with the type-specific physico-chemical conditions and is not such as to significantly alter the type-specific transparency conditions. Planktonic blooms occur at a frequency and intensity which is consistent with the type-specific physico-chemical conditions	There are slight changes in the composition and abundance of planktonic taxa compared to the type-specific communities. Such changes do not indicate any accelerated growth of algae resulting in undesirable disturbances to the balance of organisms present in the water body or to the physico-chemical quality of the water or sediment. A slight increase in the frequency and intensity of the type-specific planktonic blooms may occur.	The composition of planktonic taxa differs moderately from the type-specific communities. Abundance is moderately disturbed and may be such as to produce a significant undesirable disturbance in the values of other biological and physico-chemical quality elements. A moderate increase in the frequency and intensity of planktonic blooms may occur. Persistent blooms may occur during summer months.
Macrophytes and phytobenthos	The taxonomic composition corresponds totally or nearly totally to undisturbed conditions. There are no detectable changes in the average macrophytic and the average phytobenthic abundance.	There are slight changes in the composition and abundance of macrophytic and phytobenthic taxa compared to the type-specific communities. Such changes do not indicate any accelerated growth of phytobenthos or higher forms of plant life resulting in undesirable disturbances to the balance of organisms present in the water body or to the physico-chemical quality of the water or sediment. The phytobenthic community is not adversely affected by bacterial tufts and coats present due to anthropogenic activity.	The composition of macrophytic and phytobenthic taxa differs moderately from the type-specific community and is significantly more distorted than at good status. Moderate changes in the average macrophytic and the average phytobenthic abundance are evident. The phytobenthic community may be interfered with and, in some areas, displaced by bacterial tufts and coats present as a result of anthropogenic activities.
Benthic invertebrate fauna	The taxonomic composition and abundance correspond totally or nearly totally to undisturbed conditions. The ratio of disturbance sensitive taxa to	There are slight changes in the composition and abundance of invertebrate taxa from the type-specific communities. The ratio of disturbance sensitive taxa to	The composition and abundance of invertebrate taxa differ moderately from the type-specific communities. Major taxonomic groups of the type-

	insensitive taxa shows no signs of alteration from undisturbed levels.	insensitive taxa shows slight alteration from type-specific levels. The level of diversity of invertebrate taxa shows slight signs of alteration from type-specific levels.	specific community are absent. The ratio of disturbance sensitive taxa to insensitive taxa, and the level of diversity, are substantially lower than for good status.
Fish fauna	Species composition and abundance correspond totally or nearly totally to undisturbed conditions. All the type-specific disturbance sensitive species are present. The age structures of the fish communities show little sign of anthropogenic disturbance and are not indicative of a failure in the reproduction or development of any particular species.	There are slight changes in species composition and abundance from the type-specific communities attributable to anthropogenic impacts on physico-chemical and hydromorphological quality elements. The age structures of the fish communities show signs of disturbance attributable to anthropogenic impacts on physico-chemical or hydromorphological quality elements, and, in a few instances, are indicative of a failure in the reproduction or development of a particular species, to the extent that some age classes may be missing.	The composition and abundance of fish species differ moderately from the type-specific communities attributable to anthropogenic impacts on physico-chemical or hydromorphological quality elements. The age structure of the fish communities shows major signs of anthropogenic disturbance, to the extent that a moderate proportion of the type-specific species are absent or of very low abundance.
2. RIVERS (PHYSICO-CHEMICAL QUALITY ELEMENTS)			
General conditions	The values of the physico-chemical elements correspond totally or nearly totally to undisturbed conditions. Nutrient concentrations remain within the range normally associated with undisturbed conditions. Levels of salinity, pH, oxygen balance, acid neutralising capacity and temperature do not show signs of anthropogenic disturbance and remain with the range normally associated with undisturbed conditions.	Temperature, oxygen balance, pH, acid neutralising capacity and salinity do not reach levels outside the range established so as to ensure the functioning of the type-specific ecosystem and the achievement of the values specified above for the biological quality elements. Nutrient concentrations do not exceed the levels established so as to ensure the functioning of the ecosystem and the achievement of the values specified above for the biological quality elements.	Conditions consistent with the achievement of the values specified above for the biological quality elements.
3. LAKES (BIOLOGICAL QUALITY ELEMENTS)			
Phytoplankton	The taxonomic composition of phytoplankton corresponds totally or nearly totally to undisturbed conditions.	There are slight changes in the composition and abundance of planktonic taxa compared to the type-specific communities. Such changes	The composition of planktonic taxa differs moderately from the type-specific communities.

	The average phytoplankton abundance is wholly consistent with the type-specific physico-chemical conditions and is not such as to significantly alter the type-specific transparency conditions. Planktonic blooms occur at a frequency and intensity which is consistent with the type-specific physico-chemical conditions	do not indicate any accelerated growth of algae resulting in undesirable disturbances to the balance of organisms present in the water body or to the physico-chemical quality of the water or sediment. A slight increase in the frequency and intensity of the type-specific planktonic blooms may occur.	Abundance is moderately disturbed and may be such as to produce a significant undesirable disturbance in the values of other biological and physico-chemical quality elements. A moderate increase in the frequency and intensity of planktonic blooms may occur. Persistent blooms may occur during summer months.
Macrophytes and phytobenthos	The taxonomic composition corresponds totally or nearly totally to undisturbed conditions. There are no detectable changes in the average macrophytic and the average phytobenthic abundance	There are slight changes in the composition and abundance of macrophytic and phytobenthic taxa compared to the type-specific communities. Such changes do not indicate any accelerated growth of phytobenthos or higher forms of plant life resulting in undesirable disturbances to the balance of organisms present in the water body or to the physico-chemical quality of the water or sediment. The phytobenthic community is not adversely affected by bacterial tufts and coats present due to anthropogenic activity.	The composition of macrophytic and phytobenthic taxa differs moderately from the type-specific community and is significantly more distorted than at good status. Moderate changes in the average macrophytic and the average phytobenthic abundance are evident. The phytobenthic community may be interfered with and, in some areas, displaced by bacterial tufts and coats present as a result of anthropogenic activities.
Benthic invertebrate fauna	The taxonomic composition and abundance correspond totally or nearly totally to undisturbed conditions. The ratio of disturbance sensitive taxa to insensitive taxa shows no signs of alteration from undisturbed levels.	There are slight changes in the composition and abundance of invertebrate taxa from the type-specific communities. The ratio of disturbance sensitive taxa to insensitive taxa shows slight alteration from type-specific levels. The level of diversity of invertebrate taxa shows slight signs of alteration from type-specific levels.	The composition and abundance of invertebrate taxa differ moderately from the type-specific communities. Major taxonomic groups of the type-specific community are absent. The ratio of disturbance sensitive taxa to insensitive taxa, and the level of diversity, are substantially lower than for good status.
Fish fauna	Species composition and abundance correspond totally or nearly totally to undisturbed	There are slight changes in species composition and abundance from the type-specific	The composition and abundance of fish species differ moderately from the type-

	conditions. All the type-specific disturbance sensitive species are present. The age structures of the fish communities show little sign of anthropogenic disturbance and are not indicative of a failure in the reproduction or development of any particular species.	communities attributable to anthropogenic impacts on physico-chemical and hydromorphological quality elements. The age structures of the fish communities show signs of disturbance attributable to anthropogenic impacts on physico-chemical or hydromorphological quality elements, and, in a few instances, are indicative of a failure in the reproduction or development of a particular species, to the extent that some age classes may be missing.	specific communities attributable to anthropogenic impacts on physico-chemical or hydromorphological quality elements. The age structure of the fish communities shows major signs of anthropogenic disturbance, to the extent that a moderate proportion of the type-specific species are absent or of very low abundance.
4. LAKES (PHYSICO-CHEMICAL QUALITY ELEMENTS)			
General conditions	The values of physico-chemical elements correspond totally or nearly totally to undisturbed conditions. Nutrient concentrations remain within the range normally associated with undisturbed conditions. Levels of salinity, pH, oxygen balance, acid neutralising capacity, transparency and temperature do not show signs of anthropogenic disturbance and remain within the range normally associated with undisturbed conditions.	Temperature, oxygen balance, pH, acid neutralising capacity, transparency and salinity do not reach levels outside the range established so as to ensure the functioning of the ecosystem and the achievement of the values specified above for the biological quality elements. Nutrient concentrations do not exceed the levels established so as to ensure the functioning of the ecosystem and the achievement of the values specified above for the biological quality elements.	Conditions consistent with the achievement of the values specified above for the biological quality elements.

Table 4 *Priorities for biological and chemical targets*

Priorities:	
Fish – salmonids	ANC 0 20 50
Invertebrates	Presence/absence
Macrophytes	? – require some water quality indices
Diatoms	pH
Human health	nitrate, pH, metals etc
Forest health	Ca/Al, base cation/Al etc

Table 5 *Regional priorities for chemical/biological targets*

Region	Key	Next priority	Less important
UK	Brown trout	Invertebrates	Diatoms, macrophytes
Scandinavia	Brown trout		
Southern Germany	Drinking Water		
Tatras	Drinking Water		
Alps			

Figure 1 *Example of a critical load function for S and acidifying N. Every point of the shaded area represents depositions of N and S which do not lead to the exceedance of the critical load*

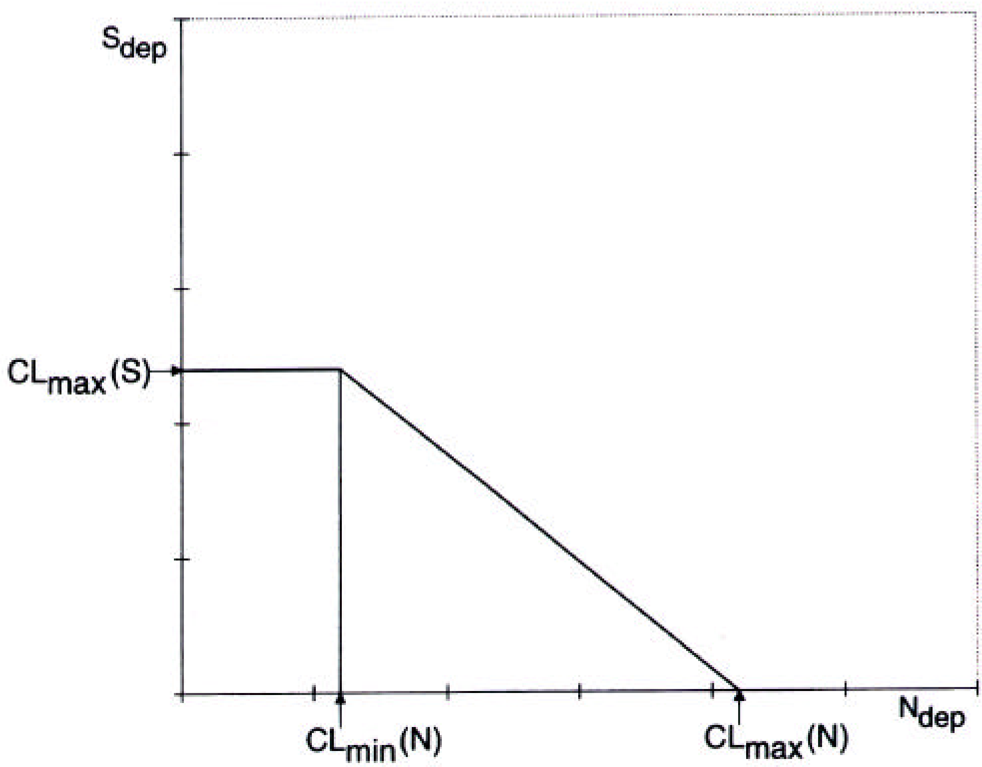

Figure 2 *Response curves derived using logistic regression and showing the relationship between ANC and the probability of occurrence of (a) A.minutissima, (b) B.rhodani and (c) non-impoverished macroinvertebrate assemblage. Ticks show original data and dotted lines represent 95% confidence limits for predicted probability (after Juggins et al. 1995)*

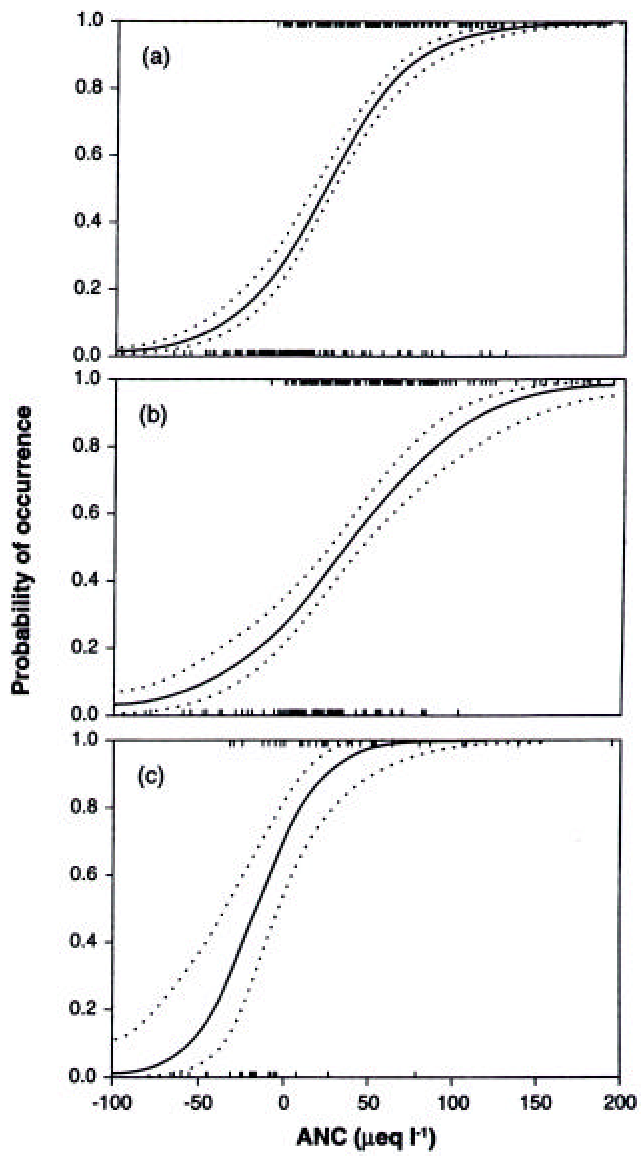

Figure 3 *Brown trout population status in relation to surface water ANC for 827 lakes in Norway (after Lien et al. 1996)*

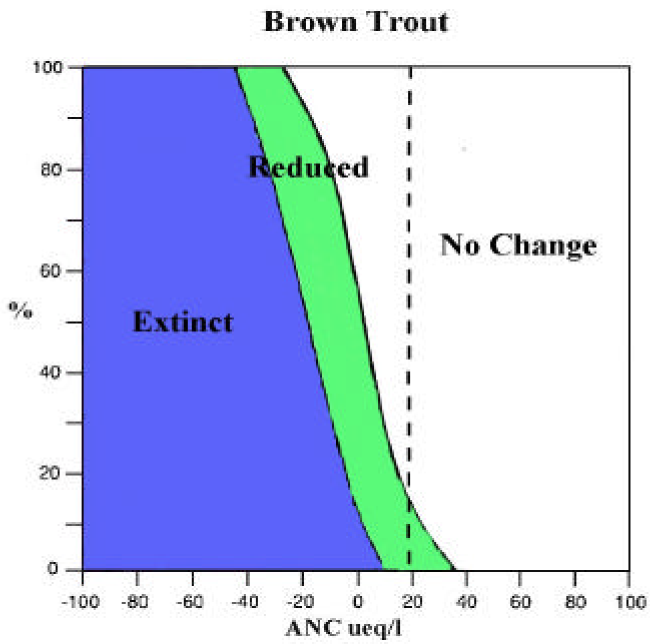

Figure 4 *Schematic flow chart for ecological risk assessment. The section in black is the risk assessment conducted by the scientists (essentially most of the work to be conducted in the case of RECOVER: 2010). Modified from Suter (1995).*

Ecological risk assessment