Reprint of the workshop report on

CRITICAL LOADS FOR SULPHUR AND NITROGEN

Skokloster, Sweden, 1988

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Foreword

This report is a reprint of the conclusions from a workshop, held at Skokloster, Sweden, 19-24 March, 1988. A complete documentation is published in Miljörapport 1988:15 from the Nordic Council of Ministers, which includes the following background documents.

Sverdrup, H., & Warfvinge, P.G
Assessment of critical loads of acid deposition on forest soils

Sverdrup, H., & Warfvinge, P.G
Chemical weathering of minerals in the Gårdsjön catchment in relation to a model based on laboratory rate coefficients

Eriksson, E
Retention and release of sulphate in soils

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Critical loads for sulphur to lakes and streams

Wright, R.F., Kämäri, J., & Forsius, M
Critical loads for sulfur: Modelling time of response of water chemistry to changes in loading

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Introduction

At its Fifth Session in June 1986 the UNECE Working Group on Effects identified the need for a Workshop on "critical loads for the effect on soils and groundwater of long term deposition of nitrogen and sulphur compounds and to establish methods to map the geographical areas experiencing higher than critical loads with respect to the sensitivity of different soil types".

The Nordic council agreed to sponsor the Workshop on behalf of the UN ECE and the Government of Sweden agreed to host the meeting at Skokloster, 20-24 March 1988.

In view of increasing understanding of the impact of sulphur and nitrogen deposition on the natural environment, it was agreed to extend the areas of concern beyond soils and groundwaters to terrestrial systems including managed and unmanaged vegetation, excluding agricultural crops and to freshwaters. Increasing evidence of the long term accumulation of S and N in the environment has focussed attention on

(I) evaluating the possible effects of different levels of S and N deposition across the UNECE region.

(II) identifying sensitive areas on an ecosystem and/or soils basis.

(III) assessing the rates and extent of impact and recovery for a number of S and N deposition reduction scenarios.

In view of time constraints, the Workshop felt that only the first two issues could be addressed in detail at this meeting.

The conclusions and recommendations reached at this Workshop are based on the papers and data made available prior the meeting (Annex I) and on the inputs from attending experts (Annex II). The workshop accepted that other sources of information also exist which may further support or alter some of the conclusions reached.

It was recognised however that this Workshop is the first international meeting on critical loads to be held under the auspices of the UNECE and that the workshop has:-

- produced a report which has identified, as a starting point for future deliberations, critical loads for a number of air pollutants and sensitive receptors,
- reviewed in general terms the concept of critical loads as a basis for future discussions. The document will be submitted to the forthcoming UN ECE Working Group on Effects meeting to be held in Geneva in August 1988,

- formulated a number of conclusions and recommendations which suggest future courses of action and scientific activity on both national and international levels.

Definitions

The workshop experienced problems in reconciling the many definitions for critical loads given in the background documents and decided to use the definition agreed by the UNECE Working Group on Nitrogen Oxides at its Eighth Session in February 1988

"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".

It was further agreed for the purposes of this workshop and in order to provide guidance to users of the definition that the following clarifications should constitute part of the critical loads definition.

Exposure	- means deposition experienced on an area basis e.g. moles m^{2}Yrs^{-1} grams m^{2}yrs^{-1}, kg·ha^{-1}·yrs^{-1}
Pollutants	- includes sulphur and nitrogen [NO_x and NH_x] compounds
Significant Harmful Effects	- could be the consequence of short term or long term deposition. Several types of harmful effects may be defined including (a) chemical changes in soils and waters which might cause direct or indirect effects on organisms (b) changes in individual organisms, in populations and ecosystems.
Sensitive Elements	- can be part or whole of an ecosystem or of ecosystem development processes

Objectives

The objectives of the workshop were to:

- evaluate scientific information as regards critical loads for forests, soils, managed and unmanaged vegetation, excluding agricultural grops, groundwater and fresh water systems,
- define critical loads for sulphur and nitrogen, taking into account the diverse sensitivity of different ecosystems,
- discuss methods for mapping to identify areas which might exceed identified critical loads leading to the identification of areas at risks,
- provide a scientific basis on which the implications of critical levels and critical loads, their interrelationships and consequences can be evaluated,
- identify gaps in knowledge.

Structure

The workshop was organized into four different Working Groups, each covering certain aspects of the critical load concept.

The following four subjects areas were covered:

I. Critical loads for sulphur in forest soils and groundwater.

II. Critical loads for nitrogen in terrestrial ecosystems.

III. Critical loads for sulphur and nitrogen in surface water systems.

IV. Biological consequences of an excess load of nitrogen to terrestrial ecosystems.

Working group report

Each group made short summary reports which included proposed figures of critical loads for a range of ecosystems.

"Working Groups II and IV considered terrestrial systems excluding agricultural crops. Each group identified gaps in knowledge and made recommendations including the need for mapping of sensitive areas. An attempt was made by two groups (I and II) to assess the relative combinations of S and N inputs to acidification including the implications of changes in the S:N deposition rate to total acidification".

Each Working Group presented the findings of their reports in plenary session. A number of alterations and amendents were suggested to assist better understanding of these reports. It was agreed that the chairmen and rapporteurs of each Working Group would, in consultation with the Workshop Secretariat, consider the inclusion of these points where appropriate into their final reports.

Working group I

Critical loads for sulphur in forest soils and ground water

Introduction – Forest soils

Deposition of acidifying sulphur and nitrogen compounds contributes to acidification of soil and ground water.

In forest ecosystems, acidification of soil is a natural process resulting from week acids, accumulation of cations by vegetation, humus production and nitrification. These processes are neutralized by a variety of mechanisms including, weathering of minerals, displacement of exchangeable basic cations such as calcium and magnesium, immobilisation of sulfur and nitrogen. Anthropogenic inputs of acidifying compounds from atmospheric deposition may overwhelm the natural capacity of soil to neutralize acidity. It enhances leaching of nutrient cations, increases retention of phosphorus and mobilizes aluminium and trace metals to soil solutions.

Potential deleterious effects of anthropogenic soil acidification to forest ecosystems including nutrient deficiencies, imbalances and high concentrations of aluminium and other toxic metals.

Approach

For forest soils critical loads should represent:

> the highest deposition of acidifying compounds that will not cause chemical changes in soil leading to long-term harmful effects on ecosystem structure and function.

In order to protect soil against long-term chemical change due to acidic deposition, which cannot be compensated by natural process, the reserves of exchangeable basic cations should not be depleted.

The rate of chemical weathering is the most important factor to consider when establishing critical acid loads to forest ecosystems. If inputs of basic cations from weathering and other sources such as atmospheric deposition and fertilization fail to keep pace with losses from biomass removal and drainage, depletion of basic cations from exchange sites in soil will occur. Inputs of strong acids will alter soil properties and may result in serious adverse ecological effects.

Soil minerology is a critical factor in determining weathering rates and therefore in establishing critical loads for regions. Some information is available through watershed budget studies, laboratory experiments and model calculation of weathering rates and the mineralogic conditions regulating these rates. Current information has been summarized to establish five sensitivity classes of soil on the basis of minerology that controls weathering rates (Table 1). Ranges of weathering rates were used to establish critical loads to the upper 50 cm of forest soil which approximately corresponds to the rooting zone of forest vegetation.

For example carbonate minerals readily dissolve in response to acid loading and provide a very large source of basic cations to the soil and alkalinity to the drainage water (class 5). Under these conditions the critical load of acidifying forms of sulphur is high. At the other extreme (class 1) soils dominated by minerals such as quartz and microcline provide limited neutralization against acidic inputs. Soils derived from these minerals have low base saturation and have very limited capacity to neutralize acidic inputs. Critical loads for such soil would be low.

In addition to mineralogy, several other factors influence catchment sensitivity to acidic deposition. These include climate, hydrology, biological processes, soil depth, texture type and chemical characteristics (Table 2). These factors will affect the critical load in any particular region.

Table 1. Mineralogical and petrological classification of soil material

Class	Minerals controlling weathering	Usual parent rock
1	Quartz K-feldspar	Granite Quartzite
2	Muscovite Plagioclase Biotite (< 5%)	Granite Gneiss
3	Biotite Amphibole (< 5%)	Granodiorite Greywakee Schist Gabbro
4	Pyroxene Epidote Olivine (< 5%)	Gabbro Basalt
5	Carbonates	Limestone Marlstone

Results

The critical loads for acidifying compounds of sulphur derived by above approach and based on present knowledge are summarized in Table 3.

If conditions given in Table 2 enhance sensitivity of soil then the lower limit of the range of critical loads should be used. When the conditions mitigate soil sensitivity, then the upper limit of the range of critical loads may be more appropriate.

The high critical load in class 5 may be overruled by other limiting factors such as critical levels of various pollutants.

Table 2. Conditions influencing critical loads to forest soil

Factor	Decreasing critical load value	Increasing critical load value
Precipitation	high	low
Vegetation	coniferous	deciduous
Elevation/slope	high	low
Soil texture	coarse-sandy	fine
Soil drainage	free	confined
Soil/till depth	shallow	thick
Soil sulfate adsorption capacity	low	high
Base cation deposition	low	high

Table 3. Critical load for forest soils (0-50 cm)

Class	Total acidity kmol $(H^+)/km^2yr$	Equivalent amount of sulphur kg/ha yr
1	< 20	< 3
2	20-50	3-8
3	50-100	8-16
4	100-200	16-32
5	> 200	> 32

Introduction – Ground water

Acidification of ground water represents a serious problem, especially, in areas with sensitive, shallow aquifers with high permeability. The acidification is in certain cases primarily related to acidic deposition from the atmoshpere, but can also be due to natural processes.

The first indications of the influence of acidity on the chemistry of ground water are increasing contents of ions i.e. Ca, Mg, SO_4, NO_3 and decreasing alkalinity in rocks and soils poor in carbonate or other buffering compounds.

Increasing ion contents including alkalinity in rocks or soils containing carbonate or other buffering compounds.

The second indication of influence of acidic deposition on ground water is a measurable decrease in pH, increasing ion contents, and also increasing concentration of aluminium in soils poor in carbonate and buffering compounds.

Acidic ground water affected by antropogenic acidification will become more corrosive to water installations, primarily copper pipes, even before pH starts to drop.

With decreasing pH increased concentrations of metals of health concern will appear in tap water, i.e. copper and lead from the piping system and aluminium from the ground water.

Approach

The long-term critical load for groundwater is established to ensure that the input of strong acid does not exceed the rate of alkalinity production by weathering in the unsaturated zone and within the aquifer.

As with forest soils, information on weathering rates are available through catchment mass balance calculations, laboratory weathering experiment and simulation model calculation.

Results

The critical load of acids to shallow ground water is closely related to the sensitivity of soil materials as presented in Table 1, and other soil characteristics summarized in Table 2. The weathering rate must be coupled with information on ground water retention time to establish critical loads for aquifers. In extreme cases, protection of ground water extracted from shallow wells (2-3 m) draining quartzitic sand and gravel, would require a critical load as low as 10-50 keq/km^2 yr. Critical loads for deeper aquifers have not been determined at present due to the hydrological complexity of such systems.

Recommendations

We recommend that the critical loads in Table 3 are adopted as preliminary until more accurate estimates are available. Lower loads may need to be set, at some future date, in accord with on-going research.

We suggest that the results of ECE's integrated monitoring programme are used for refinement of the critical load values.

Future efforts should be directed into calculating critical loads using mechanistic models that quantitatively accout for acidifying and neutralizing processes in forest soils. Existing maps of soil texture, soil type, climate and land use will have to be extended by mapping exersises of factors such as soil depth and mineralogy, in order to provide data for the calculations.

Working group II

Critical loads for nitrogen

Definitions

The assessment is based on the official definition of critical loads (Article 1, para 7, of the draft NO_x Protocol EB AIR/WG. 3/16, Annex).

- we are dealing with soil as major element of the ecosystem and as major substrate for plant and animal growth
- we considered long-term perspectives of at least one rotation period of trees
- the aim was to protect soils from long-term chemical changes with respect to base saturation.

Mode of operation

The critical loads were derived on the basis of:

- physiological and chemical considerations regarding the fate of ammonium and nitrate in ecosystems,
- existing data upon nitrate leaching from ecosystem balance studies from various parts of Europe,
- theoretical considerations of the nitrogen balance, the partitioning of nitrogen into biomass, storage and leaching, and the balance of base cations which are also partitioned into biomass and leaching, depending on the load of nitrogen and sulphate.

Criteria for defining critical loads for nitrogen

The critical loads are derived with the aim to maintain ecosystem stability by keeping the exchangeable base cation pool constant. In order to maintain a stable base cation (BC) pool (i.e. exchangable Ca, Mg, K, Na), the following equation should hold

$$BC_{leaching} \leq BC_{weathering} + BC_{deposition} - BC_{growth} \quad (1)$$

Assuming that base cations are accompanied by sulphate and nitrate only

$$Nitrate_{leaching} + Sulphate_{leaching} \leq BC_{leaching} \quad (2)$$

otherwise there will be Al leaching. Combining (1) and (2) leads to

$$\text{acceptable } Nitrate_{leaching} \leq BC_{weathering} + BC_{deposition} - BC_{growth} - Sulphate_{leaching} \quad (3)$$

In addition the nitrogen balance must be met

$$N_{input} \leq N_{growth} + N_{immmobilisation} - N_{mineralization} + N_{denitrification} - N_{fixation} + N_{leaching} \quad (4)$$

<u>Assumption 1</u>: $N_{denitrification}$ and $N_{fixation}$ are small except in situations of very wet soils (denitrification) or of nitrogen fixing trees (Alnus). Therefore, Ndenitrification and Nfixation are neglected.

It follows from Assumption (1) and Equation (4) that

$$N_{input} \leq N_{growth} + N_{immobilization} - N_{mineralization} + \text{acceptable Nitrate leaching} \quad (5)$$

<u>Assumption 2</u>: Net immobilization, which is $N_{immobilization}$ minus Nmineralization, is only considered with respect to stable N-C-compounds in the soil. The build up of the compounds is very slow (several hundred years) and it is taken to be about 1 to 3 kg $ha^{-1}yr^{-1}$

Additional considerations

- the net accumulation in soil is dependent on the C/N ration and the number of 1 to 3 kg $ha^{-1}yr^{-1}$ was derived from known N-build up during soil development in Sweden after glaciation. The accumulation can be higher than 1 kg $ha^{-1}yr^{-1}$ on the short -term (less 1 rotation period = time span to harvesting) but it is not known whether it is stable in the long-term (> 1 rotation period). Some soil changes can be very rapid and it is not known if the stable humus changes accordingly. Aggrading forest ecosystems accumulate higher N loads.
- leaching of 1-2 kg N $ha^{-1}yr^{-1}$ is normal due to seasonal variation.
- with respect to soil chemistry and for deposition above critial loads the deposition of ammonium would be more harmful than the depostion of nitrate.
- Ecosystem studies in Europe indicate that no nitrate leaching occurs predominantly at low nitrogen loads.
- the critical loads refer to total deposition. This could be higher than N measured in bulk precipitation.

Gaps of knowledge

- complete N-cycles for different conditions, especially mineralization and immobilization of N
- representativeness of case studies
- rate of soil forming processes, weathering and carbon accumulation
- nitrification and ammonium and nitrate metabolism of non-crop species
- N_2O production
- critical markers for N-saturation and N/BC imbalance
- dry deposition and atmosphere/surface exchange of N

Critical loads

Table 1: Critical N loads for production forests (kg N $ha^{-1}yr^{-1}$)*** on well-drained sites assuming whole tree harvest

	N-accumulation in growth	Acceptable N-accumulation in soil	Leaching**	Critical N input**
Low productivity, net N immobilisation	1 - 6	1 - 3	1 - 2	3 - 11
Low productivity, net N mineralisation	1 - 6	-	-	0*
High productivity, net N immobilization	5 - 15	1 - 3	1 - 2	7 - 20
High productivity net N mineralisation	5 - 15	-	-	0*

* any N input to declining systems will delay recovery

** critical N input may approach weathering rate if Sulphur load is low. Compare Tab. 3 of WGI

*** Values can be converted into mol $m^{-2}yr^{-1}$ by dividing with 140

Table 2: Critical N loads for ecosystems varying in productivity (kg N $ha^{-1}yr^{-1}$)

Ecosystem	critical load
deciduous forests**	5 - 20*
coniferous forest**	3 - 15*
dwarf shrub vegetation	3 - 5***
grassland (e.g. mesobrometum)	3 - 10***
raised bog	3 - 5***

* in mature forests the critical load may approach 0

** declining systems should approach 0

*** without major removal of N by management

Considering a critical nitrate concentration for groundwater of 50 mg l^{-1} (EEC standard) and a precipitation surplus varying between 100 and 400 mm yr^{-1} leads to critical loads of up to 10 to 40 kg N $ha^{-1}yr^{-1}$.

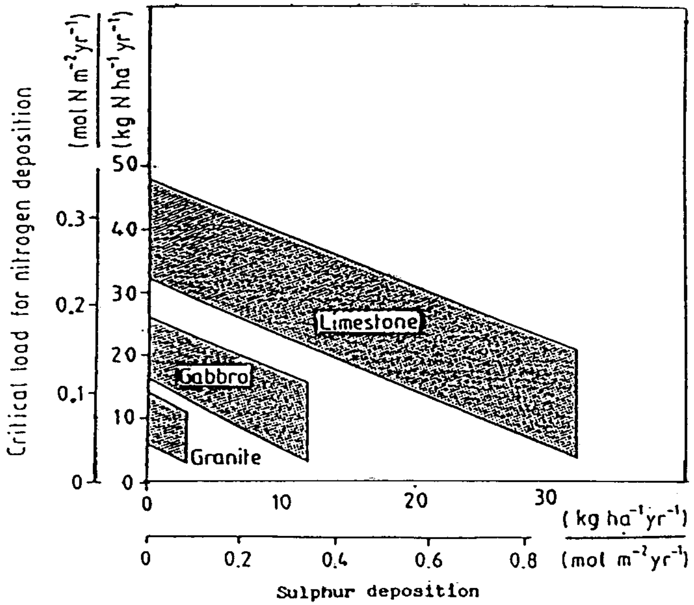

Figure 1

Critical loads for Nitrogen and Sulphur for conditions of base cation removal at the rate of weathering. The range represents biomass removal and net accumulation.

Working group III

Critical loads for aquatics

Introduction

The acidification of surface waters by acid sulphate deposition has been observed in various parts of the world. Critical loadings for acid deposition have been estimated using empirical data and chemical models based on our present understanding of the atmospheric, watershed, soil and lake processes involved.

The group reviewed existing data and discussed a number of issues, some of which have become more prominent since the 1986 critical loads meeting.

Two key background documents for this work group were prepared for the meeting by Hultberg (1988) & Henriksen (1988) and three new documents were introduced.

In particular, the work group discussed in detail:
- acceptable pH criteria
- definition of acid impact from the atmosphere
- the effect of variable hydrology
- the contribution of nitrate to acidification
- background sulphate concentrations in dilute lakes
- prediction models
- in-lake alkalinity processes
- mapping techniques
- research and monitoring needs

The critical loading summary report was reviewed. One participant submitted a revised summary report for consideration by the group.

Conclusions

The workgroup:

1) Endorsed a revised definition of critical loads as developed by the NO_x work group as follows:

> "A quantitative estimate of the loading of one or more pollutants below which significant harmful effects on specified sensitive elements of the environment are not likely to occur according to present knowledge".

2) proposed estimated critical loads based on available information from Sweden, Norway, Switzerland, United States, Canada, Netherlands, Finland and Scotland (Table 1)

3) Recommends further consideration of strengths and weakness of approaches used and the data employed in arriving at the estimates as new data become available.

4) Recognizes that critical loading estimates are regionally and site-specific because of variations in sensitivity due to differences in base cation concentrations and hydrology and in loading due to variations in precipitation amounts and relative significance of wet and dry deposition. Afforestation can affect the total loading. Critical loading estimates must be made specific to the area of application (Henriksen and Brakke 1988).

5) Used pH 5.3 as the minimum level to maintain a bicarbonate system in lakes in combination with a maximum dissolved inorganic Al concentration of 30 ug/l some protect fish species for areas with shallow soils, low sulphur adsorption and low ionic strength in runoff. Ca and organics acids can ameliorate toxic effects of H^+ and Al^{+3}. Critical loading estimates for Sweden and Norway are found in Table 2.

6) Used pH value of 6.0 as required to maintain most aquatic organisms for lakes that had original pH > 6.0 (Hultberg 1988).This is supported by the species distribution/pH tables developed by Eilers et al (1984).

7) Suggests defining the acidifying potential (AP) of precipitations as:

$AP = [SO_4^*] - [Ca^* + Mg^*]$ (Brydges and Summers 1988)

* denotes non-marine contributions

In cases where nitrate leaching from watersheds becomes significant, used the net acidifying potential given by:

$NAP = ([SO_4^*] - [Ca^* + Mg^*])$in precip. + $[NO_3]$ in runoff (Brydges and Summers, 1988).

8) Used the Henriksen nitrogen mobilization factor to evaluate the status of nitrogen leaching from watersheds.

Table 1.
Estimated critical loads for sulphur deposition. Derivations have generally been based on the most sensitive surface waters within each geographical area.

* denotes non-marine contribution.

	Ca+Mg (μeq L^{-1})	Estimated Critical loads for sulphur a) b) keq$\cdot$km$^{-2}\cdot$yr^{-1}	
1. Dickson (1986), Sweden			
- shallow, soils, low ionic strength		15	
- glacial till, medium ionic strength		40	
2. Henriksen, et al. (1986), Henriksen and Brakke (1988) Norway			
- precipitation, 2 000 mm, 20-50 μeq L^{-1} Ca* + Mg*		40	
- precipitation, 1 000 mm 20-50 μeq L^{-1} Ca* + Mg*		20	
3. Schnoor and Stumm (1987) Switzerland		20-50	
4. Gorham (1984), Eastern N. America		30	c)
5. Schuurkes (1986), Netherlands		25	
6. U.S.- Canada Memorandum of intent, (1983),Eastern Canada and Eastern U.S.		40	c) d) but not b)
7. Henriksen and Brakke (1988), Eastern U.S. - most sensitive (minimum Ca+Mg) lakes e)			
Adirondacks, New York	34	34	
Catskills/Poconos	60	60	
Southern New England	35	35	
Central New England	57	57	
Maine	38	38	
Northwestern Minnesota	77	62	
Upper Peninsula of Michigan	24	20	
Upper Great Lakes area	39	31	
8. Wright, et al (1988)			
- White Oak, Run, Virginia, USA		75	
- Norwegian and Swedish lakes and catchments		20	
- Finnish lakes		20-130	
9. Schindler (1988) Eastern N. America and Sweden		18-28	
10. Harriman (pers. comm.) 30-60 μeq$\cdot L^{-1}$, Scotland		20-40	

a) These critical loads are for lake(s) or areas within the country identified.
b) Estimates based on effective acidic sulphate loading does not include completely or partically neutralized sulphate deposition. Total loads could therefore be higher.
c) Wet deposition only,
d) U.S. members of Work Group I concluded that "based on (the) status of the scientific knowledge ..... it is not now possible to derive quantitative loading/effects relationships".
e)These estimates are based on F=0.0 (F= ΔCa*+Mg*/ Δ SO_4*). F=0.0 yields over estimates of loads; for areas where sulphate has increased. F is variable and >0.0.At Ca+Mg>200μeq L^{-1}, F=1.0.

$$T\ N_F = \frac{C_{N}\,w\ .\ C_{SO_4}\,p}{C_{SO_4}\,w\ .\ C_{N}\,p}$$

where $C_N\,w$ = conc. NO_3 in runoff
$C_N\,p$ = conc. NO_3+NH_4 in prep
$C_{SO_4}\,w$ = conc. SO_4 in runoff
$C_{SO_4}\,p$ = conc. SO_4 in prep

9) Observed that:

- In areas where sulpahte deposition has decreased, surface water sulphate has also decreased.
- In some of these areas surface water acidity has decreased (Scotland (Battarbee et al. 1988) Sudbury, (Dillon et al. 1986), Algoma, (Kelso & Jeffries, 1988)

Results from Norwegian RAIN-project (Wright 1987) indicate that reducing sulphate deposition reduces sulphate concentrations, acidity and inorganic aluminium and increases in acid neutralizing capacity (ANC) in the runoff.

Table 2

Critical total sulphur deposition loads for aquatic ecosystems in Norway and Sweden (Hultberg 1988) a) b)

Water and catchment characteristics Norway and Sweden	Critical combination of pH/dissolved inorganic Al $\mu g/L^-$	Critical total S-loads in $keq \cdot km^{-2} \cdot yr^{-1}$ When non-marine base cation deposition is:	
		<10	30
Ca* + Mg* <50 $ueq.L^{-1}$ shallow soils, low ionic strength, low S-adsorption	5.3/30	20	40
Ca* +Mg*=60-160 $ueq{-}L^{-1}$	6.0/50 1)	30	50
Ca* +Mg*=200-260 $\mu eq \cdot L^{-1}$	6.0/100 1)	40	60

a) Situations where non-equilibrium conditions between pH and dissolved inorganic Al can occur in lakes and rivers where acid water high in labile Al mixes with less acid waters. The water in the mixing zone may show oversaturated concentrations of dissolved inorganic Al and the water quality will therefore be toxic to fish and other aquatic organisms at high pH.

b) These estimates are based on fish species distributions and Ca^{+2} concentrations found in Norway and Sweden.

Recommendations from group III

The following research needs have been identified to improve dose-response analyses and develop better loading estimates:

- **Long-term monitoring programs need to be expanded and continued where present, in order to establish further changes in water chemistry and document recovery.**
- Evaluate factors that control variations in NO_3- mobility, among systems and among seasons, to improve evaluations of potential short and long-term effects of NO_3- deposition on surface water chemistry. Conduct watershed manipulations to evaluate the mobility of NO_3- in areas where NO_3- increases have been observed. Such experiments are planned for southernmost Norway.
- Verify conceptual models of surface water response to acid deposition, specifically the importance of hydrology, mobile anions, soil SAC, ion exchange and % BS, weathering rates and land use. Include evaluation of nitrate mobility and organic anions. Whole-system field manipulations and long-term monitoring under different loading regimes should be continued.
- Continue development and application of process-oriented models, including sensitivity analyses that reflect uncertainties assosiated with key model parameters or processes. Future analyses and estimates could incorporate results from detailed mechanistic models, such as ILWAS.
- Evaluate possible changes in organic carbon as a function of loading by analysis of existing survey data a new watershed experiments, such as proposed at Føde, Norway.
- Quantify the regional extent of factors (e.g. SAC, % BS) and conditions (e.g. shallow, acidic soils) that influence surface water sensitivity to acid deposition, to improve estimates of numbers and types of sensitive systems.
- Quantify weathering rates and changes in weathering rates with increased atmospheric inputs.
- Continue experiments on sulfate additions and removals at RAIN project sites in Norway.
- Estimate values for Henriksen's F-factor (change in basic cation concentration per unit change in "excess" SO_4^{2-}) across a diversity of watershed types. Also, consider potential changes in the F-factor through time with increased deposition or depletion of readily available basic cations.
- Quantify dry deposition to improve evaluation of the potential influence of dry deposition on aquatic response.

- Conduct long-term laboratory and field experiments to establish the relative influence of concentration vs. loading rate on leachate chemistry for deposition of base cation concentrations and SO_4^{2-} (Gårdsjön, Sweden).

- For loading estimates proposed to date, quantify uncertainties, conduct sensitivity analyses for parameter estimation, and carefully review and screen data and information used for model development and analyses.

- Further evaluate and quantify responsiveness of fish species and other aquatic biota to changes in pH.

Working group IV

Critical loads of nitrogen – biological consequences

Modus operandi

1. Considered situations where the critical load is known to have been exceeded, i.e. biological/ecological consequences have been recorded. The methods used to detect changes included experiments under controlled conditions, chemical analysis and comparisons of floristic and faunistic composition with time and space under field conditions. Some estimates of critical load may contain an area of uncertainty due to lag time.

2. Following definition of critical load was used:

   A quantitive estimate of an exposure to deposition of N as NH_x and/or NO_x below which empirical detectable changes in ecosystem structure and function do not occur according to present knowledge. In general, the ecosystem changes may range from episodic responses to processes occuring over centuries.

Conclusions

1. Summary of biological consequences and critical loads:

System	Criteria	Estim.critic.load kg N/ha*yr	Ref.
Littoral communities	Shallow soft water communities sensitive to NH_4 when NO_3 is low, critic.load as NH_4	3 - 7	NL
Raised bogs	Sphagnum very sensitive to NO_3 (but less sensitive to NH_4).Response in a very short time due to toxicity, 5 - 10 kg during less than 1 yr	-	NL,GB
	Possible changes in flora, eg. increased growth of bushes and trees but other nutrients, eg. K, limit growth rather soon.	5 - 10	SW,GB BRD
Heathlands	Reduced frost resistance of Calluna	5 - 20	NL
	Changes in species comp., depends on weathering capacity. Low buffering soils	7 - 10	NL
	Heath to grassland conversion (complete change)	> 20	NL
	With intensive management (grazing + cyclical burning + topsoil removal), Calluna and Erica can be maintained	< 40	NL

Coniferous forests	Nutrients imbalances due to high nitrogen input depends on Mg and Ca conc. and nitrification rate. Most sensitive systems	10 - 12	NL
	Changes in herbaceous flora towards nitrophilic species but crit.load depends on uptake by trees and saturation	> 20	NL
	Pine stands with management; positive growth response during 15 years with an annual fertilizer appl. as NH_4NO_3 up to 30 kg, but changes in ground flora		SW
Deciduous forests	Changes in herbaceous flora towards nitrophilic species	< 15	SW

2. Critical load depends on

   - type of ecosystem
   - management past and present, i.e. rate of removal of N or application of other nutrients
   - soil conditions, eg. nitrification potential of the soil.

3. Important impact on organisms and systems of excess nitrogen are due to:

   - toxicity to individuals
   - changed competitive relations between populations of organisms
   - changed physical structure of the bioceonoses and increased homogeneity of the environment

4. In central Europe 65% to over 80% of the threatened vascular plants (Red Data List) can only compete on nitrogen poor soils. Most of these species are not as sensitive to acidification.

5. There are many ecosystems for which no estimate of critical load can be made. The following may be sensitive : high elevation systems, pastures and old unfertilized meadows in the agricultural landscape, lichen dominated systems, dunes.

6. Important interactions of excess nitrogen are between:

   - other pollutants in air and soil
   - climate; drought, frost, winter-desiccation, wind.
   - canopy architecture because it influences total nitrogen input
   - excess nitrogen is known to influence the impact of pathogens and phylloplane organisms
   - excess nitrogen changes the canopy architecture with a consequent influence on microclimate, N deposition, and plant and animal populations. Chemical changes in leaves may also alter populations of herbivores which brings about further changes in the system. These may affect soil development.

Recommendations – Gaps in knowledge

1. More knowledge and understanding about changes from a broader range of ecosystems and countries, i.e. more retrospective studies, historical records (museum specimen etc.). Information from diverse sources needs to be collated into an integrated database.

2. Ecological monitoring needs to be included into the UNECE Integrated Monitoring Programme and similar networks.

3. Better, and standardized, methods for determining total nitrogen (separating NH_x and NO_x), especially dry deposition (including spatial and temporal variation).

4. More effort should be made to model the chain of consequences that may occur in ecosystems subjected, including soil micro flora and fauna to excess nitrogen.

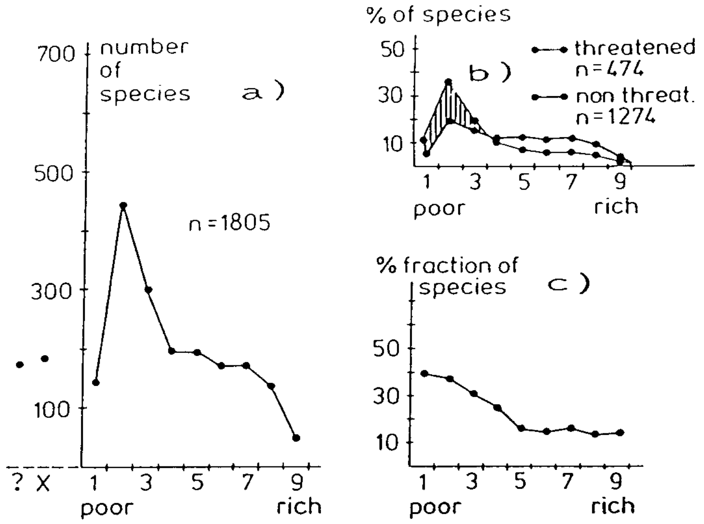

Figure 1
Distribution of 2164 Central European Plant Species in the gradient of nitrogen indicator values (re-drafted from ELLENBERG jun. 1985)

a) "?" not known; "x" indifferent
"1" most pronounced nitrogen deficiency
"3" poor in nitrogen
"5" just sufficient in nitrogen
"7" more often found at places rich in N
"8" nitrogen indicator
"9" surplus nitrogen to polluted with N

"2", "4", "6" intermediate

b) most of the threatened species can only compete on nitrogen - deficient stands (57 "potentially threatened" species not regarded).

c) the fraction of threatened species within the total of species in a given class of nitrogen indicator value is deminishing with better nitrogen supply. It remains constant from value "5" upwards (see above).

Overall recommendations

1) The Workshop evaluated the concept of critical loads on a Scientific basis and found it useful when applied to terrestrial and aquatic systems. It recommends continuing support for the development of the critical load concept.

2) The concept of critical loads calls for specific data requirements in relation to both deposition and exposure. The Working Group recommended that early discussions should be undertaken between the Steering Body of EMEP and the Working Group on Effects to identify the new data requirements likely to arise from the adoption of the critical level/load concept.

3) The Workshop recognised the need for improved research cooperation to fill in the gaps in knowledge identified by the four individual working groups. The Workshop would like to draw the attention of the UNECE Working Group On Effects to the identified need for better data exchange and coordination of research activities between individual countries on this issue.

4) The workshop was unable to address the issue of assessing the rates and extent of the impact and recovery for a number of S and N deposition scenarios. As a way of promoting discussion in this area, the Working Group invites a number of interested countries to carry out quantitative S and N deposition scenarios relating to their own national situations.

5) Thoughout its deliberations, the Workshop continually referred to the importance of integrated monitoring in evaluating critical levels/loads. The meeting endorsed the work being undertaken by the UNECE Task Force on Integrated Monitoring and recommends that the requirements relating to e.g. deposition, mapping and the need to identify sensitive areas should be borne in mind when decisions relating to siting and operation under the UNECE Integrated Monitoring Programme are taken.

6) The Workshop endorsed the need for mapping identified by the UNECE Working Group of Effects at its Fifth Session in Geneva in 1986. It also noted the recommendations made at the Critical Levels meeting at Bad Harzburg, March 1988 on the need for a workshop to address the specific issue of establishing methods for mapping geographical areas experiencing higher than critical levels /loads with respect to different types of soils and ecosystems.