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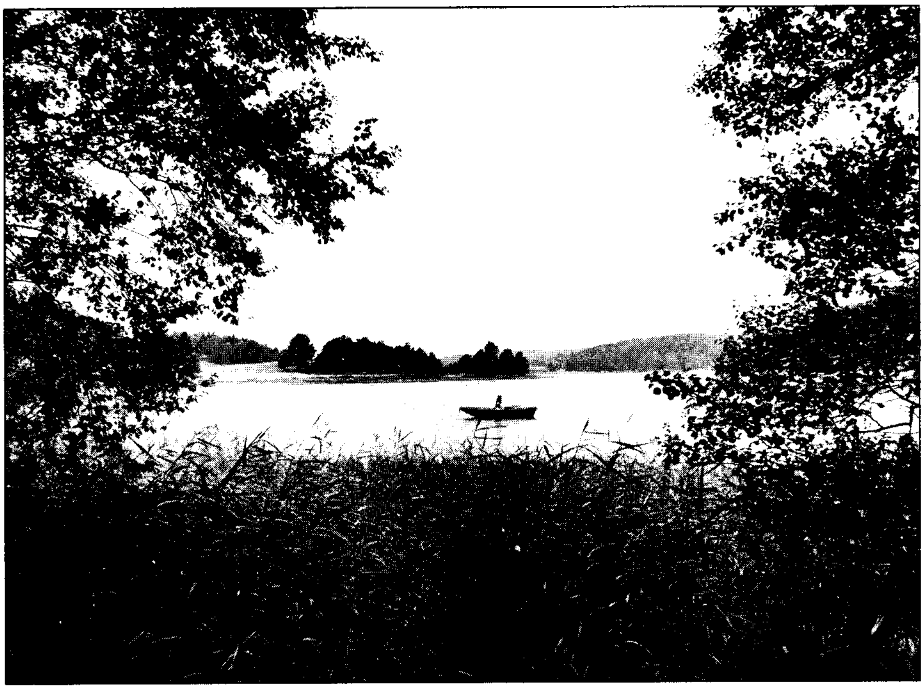

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The limits of tolerance

HOW MUCH POLLUTION can the environment take? The question is central to the debate on environmental matters, because from the answer one can see how much the emissions of pollutants will have to be reduced.

Critical loads

Various attempts have been made since the late 1970s to calculate tolerable levels for acid deposition. Such levels of exposure to pollution came later to be known as "critical loads." The following definition was coined in 1986 by an international scientific workshop on critical loads for sulphur and nitrogen: *"The highest load that will not cause chemical changes leading to long-term harmful effects on the most sensitive ecological systems"* (1).

If that is to be the definition, it can be said that in a strict sense a critical load is one that does not produce any effect on the most sensitive receptor even in the long term. By receptor may be meant and individual species, type of soil, ecosystem, etc.

Two years later the critical-load concept was adopted in the UN ECE Convention on Long Range Transboundary Air Pollution (CLRTAP) (see No.3 in this factsheet series). The concept will henceforth be basic to the development of international agreements concerning the limitation of emissions of air pollutants. As work within the Convention has proceeded, various other definitions of a critical load have been tried, the most usual being: *"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"* (2). As a definition this is however less than satisfactory, since it allows too much room for interpretation.

Target loads

In political negotiations aimed at the reduction of emissions the term "target load" also appears. While determined essentially in accordance with the critical-load concept, target loads also take other aspects into consideration, such as national environmental objectives. Target loads may therefore be higher or lower than the critical loads, depending on the manner in which the situation is judged in different cases. They may be set

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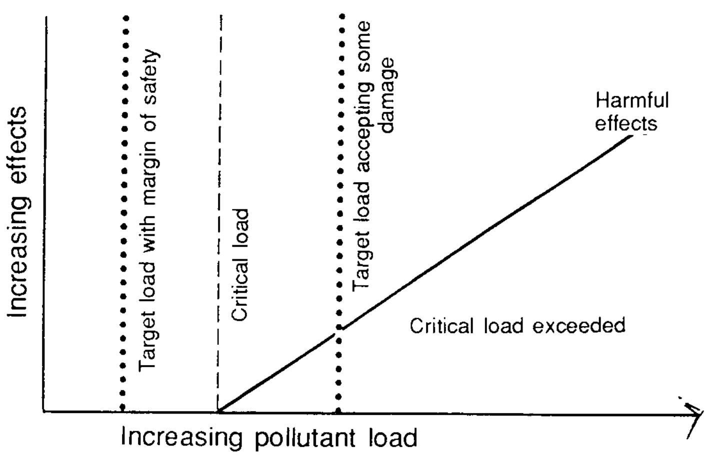
Figure 1. Critical loads and targets loads.



lower, for instance, in order to leave a margin of safety. This would simply be following a practice that is standard in the medical field. Target loads may on the other hand be allowed to be higher – meaning in effect a deliberate acceptance of a certain degree of environmental damage, or risk of damage (see Figure 1). When set higher, they may be regarded as interim targets, reflecting the need for a stepwise approach to reducing emissions. They should subsequently be progressively reduced to a level at or below the critical load.

Scientific agreement

In the spring of 1988, two major international scientific conferences were held on the subject of critical loads. One was concerned with sulphur and nitrogen deposition (3), the other with atmospheric levels of gaseous pollutants (4). There were two follow-up meetings four years later (5, 6).

The conclusions from these various meetings are set forth in the following. In considering them it should be kept in mind that the proposed critical-load figures have always tended to be set lower as research methods improve and more data becomes available. It is thus not unlikely that even today's critical loads will be revised downwards.

Acid deposition (sulphur)

The critical load for acid deposition will depend on the buffering capacity of the soil – on how quickly the minerals in the soil can be freed by weathering, thus enabling them to neutralize the acid.

Table 1 shows the critical loads for various types of soil, calculated a) for the total input of acid, and b) for a corresponding quantity of sulphur. A kiloequivalent of hydrogen ions per sq kilometre corresponds to 0.16 kg of sulphur per hectare. In any effort to protect a given area from acidification, the total acid input must be taken into account. The figures for sulphur, however, assume sulphur to be the only cause of acidification. Should nitrogen also be a cause, the soil will be able to tolerate less sulphur than indicated in the table. The limits will have to be lowered, too, if other acidifying processes, such as the removal of biomass in forestry operations, also have to be taken into consideration.

As regards forest soils, the critical load for sulphur in the most sensitive areas is maximum 3 kg per hectare per year. For surface waters and ground waters the critical loads are usually determined by the sensitivity of the surrounding soils, and so are often about the same. If the deposition is higher than the critical load, the system will suffer long-term acidification. Recent mapping has shown that critical loads for acidity are now being exceeded over three-quarters of Europe (7).

In Europe the depositions of sulphur now vary greatly from region to region. Where emissions are very great, as in parts of the Czech Republic, the deposition may reach 100 kg S/ha and year, as against 20-40 kg/ha and year in much of the rest of Central Europe. Whereas in the forest areas of southern Scandinavia the depositions may amount to 20-30 kg/ha and year, in the far north they are only about 3 kg/ha and year.

Nitrogen

Nitrogen can cause both over-fertilization (eutrophication) and acidification of ecosystems. It is this dual effect that has made critical loads more difficult to define –

Table 1. Critical loads of acid and sulphur in relation to the weathering capacity of forest soils

	Minerals controlling weathering	Usual parent rock	Acid input (keq $H^+/km^2 \cdot yr$)	Sulphur deposition kg S/ha · yr)
1.	Quartz K-feldspar	Granite Quartzite	<20	<3
2.	Muscovite Plagioclase Biotite (<5%)	Granite Gneiss	20-50	3-8
3.	Biotite Amphibole (<5%)	Granodirite Greywakee Schist, Gabbro	50-100	8-16
4.	Pyroxene Epidote Olivine (<5%)	Gabbro Basalt	100-200	16-32
5.	Carbonates	Limestone	>200	>32

than it is, say, when considering sulphur alone. Furthermore, the critical loads for nitrogen will depend on several factors, including ecosystem productivity, microorganism activity in the soil, and the composition of the vegetation.

Eutrophication is a frequent occurrence, since most terrestrial and some inshore ecosystems are N-limited and thus additional nitrogen coming into the system will be quickly taken up by organisms (plants, trees, plankton) and usually stimulate their growth. This commonly leads to ecosystem imbalances, in the form of changes in nutrition, competitive relationships, and resistance to insects, fungi, and temperature/drought stresses. These changes can almost all be regarded as adverse. Excess growth from eutrophication may also mean that more nutrients/base cations may be taken up by plants and trees, thus impoverishing and acidifying the soil still further.

Acidification occurs when most of the system is saturated with excess nitrogen which can no longer be bound or retained by biological matter. In soils, this means that nitrogen in the form of nitrate (NO_3^-) will leak from the system, taking with it nutrient (alkaline) base cations such as calcium and magnesium (Ca^{2+}, Mg^{2+}), and thus acidifying the soil. Acidification may also occur in non-saturated soils during winter when tne vegetation is not taking up nutrients.

The critical loads for nitrogen in terrestrial ecosystems are usually defined with reference to forest soils, with the intention of preserving ecosystem stability in the long term, or at least not reducing the vitality of forest trees. Using the simple mass-balance approach the critical load has been put between 7 and 20 kg N/ha/yr, according to whether the site is low productive or high productive. These figures are however probably too high, since they indicate the critical deposition at the nitrogen saturation level. When considering longer time periods involving several periods of forest rotation, and assuming that only stems are harvested, the critical load should be in the range of 4-10 kg/ha/yr. For "natural" forests with no biomass removal, the critical load should be 2-5 kg/ha/yr.

Table 2. Critical loads for nitrogen (kg N per hectare and year) to (semi-) natural terrestrial and wetland ecosystems.

	Critical load	
Acid (managed) coniferous forests	15-20	*
Acid (managed) deciduous forests	<15-20	*
Calcareous forests	unknown	
Acidic (unmanaged) forests	unknown	
Lowland dry heathlands	15-20	**
Lowland wet heathlands	17-22	**
Species-rich lowland heaths/acid grasslands	7-20	*
Arctic and alpine heaths	5-15	(*)
Calcareous species-rich grassland	14-25	**
Neutral-acid species-rich grassland	20-30	*
Montane-subalpine grassland	10-15	(*)
Shallow soft-water bodies	5-10	**
Mesotrophic fens	20-35	*
Ombrotrophic bogs	5-10	*

** reliable, * quite reliable, (*) best guess

Critical loads for eutrophication effects on semi-natural ecosystems are based mainly on observed changes in vegetation, such as alterations in the composition of species. As can be seen in Table 2, the critical loads are either given in ranges or expressed as a "less than" figure. This is because of the variation in sensitivity within the same type of ecosystem and/or the lack of data to enable a figure to be set for the upper limit. For several types of ecosystem, critical loads for nitrogen have still to be determined.

The total deposition of nitrogen over much of Central Europe is at present 30-40 kg N/ha/yr. Over forest land in southern Sweden it amounts to 20-30 kg/ha, and in coniferous forest in the Netherlands it may locally exceed as much as 100 kilograms.

Gaseous forms

Instead of critical loads, the term critical levels is often used when speaking of gaseous pollutants. These have been defined as: *"The concentrations of pollutants in the atmosphere above which direct adverse effects on receptors, such as plants, ecosystems or materials, may occur, according to present knowledge"* (2).

Usually figures are given for one pollutant only. In fact however the air over Europe consists of a cocktail of substances, and it has long been known that in combination they can intensify each other's effect (so-called synergism). Thus if the synergistic effects are to be taken into consideration, the critical levels should be lower.

Ozone

Crops are believed to be particularly sensitive to ozone (O_3), but at present levels forest trees may also be damaged. At the 1988 conference (4) critical levels were agreed for the different kinds of pollutant, including ozone, the levels for which appear in Table 3.

At the 1992 workshop, a new concept for critical levels for ozone was developed (6). The formula is now to be: (x) ppb-hours above (y) ppb baseline (ppb=parts per billion; 1 ppb=2$\mu g/m^3$). In the course of discussion it was proposed to set the level at 300 ppb-hours above a 40 ppb baseline. These figures are still a matter of debate, however, and it has been suggested that the baseline figure would need to be as low as 20 ppb, if the earlier critical levels are to be replaced by this new concept.

Ozone is formed in the troposphere as a result of reactions be-

Table 3. Critical levels for the protection of sensitive plants, plant communities, and ecosystems against ozone as a single pollutant.

Exposure duration (hours)	Ozone concentration (ppb)
0.5	150
1.0	75
2.0	55
4.0	40
8.0	30
Vegetation period*	25

* Average of 7-hour mean/day 09.00-16.00 during vegetation period.

tween nitrogen oxides and volatile organic compounds (VOCs) in the presence of sunlight. Monitoring data shows that the critical levels agreed in 1988 are being exceeded over almost the whole of Europe. For example, in the period 1985-87, the one-hour critical level of 150 micrograms per cubic metre ($\mu g/m^3$) was exceeded at about 75 per cent of the measuring stations in western Europe. The eight-hour and the seasonal mean critical levels were exceeded at 100 per cent of the stations (8). Computer modelling has shown that a reduction of at least 75 per cent of the emissions of both nitrogen oxides and VOCs will be needed if critical concentrations are not to be exceeded.

Sulphur dioxide

The atmospheric concentrations of sulphur dioxide (SO_2) that are critical for forest ecosystems and natural vegetation are put at 15-20 $\mu g/m^3$ both as an annual mean and a half-year (October-March) mean. For agricultural crops the critical level is set at 30 $\mu g/m^3$ both for annual and half-year means. Sensitive lichens may be damaged at annual means as low as 10 $\mu g/m^3$.

In some parts of Europe, particularly in the east and centre, these critical levels are being greatly exceeded.

Nitrogen oxides

Nitrogen oxides (NO_x) are generally regarded as less toxic to plants than sulphur dioxide and ozone. Because of its relatively low toxicity, no critical levels have been set for NO_x alone, but only in combination with O_3 and SO_2, assuming that the concentrations of the two latter pollutants are each below the critical levels noted above. The aim of the critical levels defined for NO_x is to protect the structure and functioning of the plant community. The maximum annual mean for NO_x (NO and NO_2 added, expressed as NO_2) would then be 30 $\mu g/m^3$ and the peak level 95 $\mu g/m^3$ (average 4-hour exposure).

Ammonia

Direct damage from ammonia occurs primarily in farming areas with intensive stock-keeping. The yearly, monthly, 24-hour, and hourly mean values for critical concentrations are 8, 23, 270 and 3300 $\mu g/m^3$.

Required reductions

A drastic reduction in emissions of air pollutants is urgently needed if the environment is not to be further damaged. In order to stop the ongoing deterioration of the environment, concentrations and depositions of air pollutants must be reduced to below the critical loads.

More than twenty European environmentalist organizations have, on the basis of up-to-date and internationally agreed scientific data on critical loads, jointly decided on the following objectives in regard to the overall emissions of air pollutants in Europe (9):

- ☐ At least a 90 per cent reduction in emissions of sulphur dioxide.
- ☐ At least a 90 per cent reduction in emissions of nitrogen oxides.
- ☐ At least a 75 per cent reduction in emissions of volatile organic compounds.
- ☐ At least a 75 per cent reduction in emissions of ammonia.
- ☐ At least a 75 per cent reduction in the concentrations of tropospheric ozone, to be achieved by meeting the objectives for NO_x and VOCs, as above.

The reductions are based on the emission levels in the early 1980s and refer to western and eastern Europe, including the European part of Russia.

These are minimum demands, but they do not necessarily imply that every country or region must achieve equal reductions. In areas with very high emissions, greater reductions will be necessary, while in some other areas the needed reductions may be lower.

References

1. Nilsson, J. (1986) (Ed): **Critical loads for nitrogen and sulphur** – report from a Nordic working group. The Nordic Council of Ministers. Report 1986:11, Copenhagen, Denmark.

2. UN ECE (1988): **Conclusions and draft recommendations of the workshops on critical levels for forests, crops and materials and on critical loads for sulphur and nitrogen.** EB.AIR/R.30.

3. Grennfelt, P. & Nilsson, J. (1988) (Ed): **Critical loads for sulphur and nitrogen** – report from a workshop held at Skokloster, Sweden, March 19-24, 1988. The Nordic Council of Ministers. Report 1988:15, Copenhagen, Denmark. ISBN 87-7303-248-4.

4. UN ECE (1988): **Report from ECE critical levels workshop,** held in Bad Harzburg, F.R.G., March 14-18, 1988. Umweltbundesamt, Berlin, Germany.

5. Grennfelt, P. & Thörnelöf, E. (1992) (Ed): **Critical loads for nitrogen** – report from a UN ECE workshop, held at Lökeberg, Sweden, April 6-10, 1992. The Nordic Council of Ministers. Report 1992:41, Copenhagen, Denmark. ISBN 92-9120-121-9.

6. (-) **Workshop on critical levels,** held in Egham, the United Kingdom, March 23-26, 1992. A UN ECE workshop. Background documents and results from working groups. (Not yet published).

7. Hettelingh, J-P., Downing, R., & de Smet, P. (1991) (Ed): **Mapping critical loads for Europe.** CCE technical report No. 1. National institute of public health and environmental protection, Bilthoven, The Netherlands. ISBN 90-6960-011-0.

8. Derwent, R., Grennfelt, P., & Hov, Ö. (1991): **Photochemical oxidants in the atmosphere.** The Nordic Council of Ministers. Report 1991:7, Copenhagen, Denmark. ISBN 87-7303-540-8.

9. Ågren, C. & Elvingson, P. (1992) (Ed): **Critical loads for air pollutants** – report from the third international NGO strategy seminar on air pollution, held in Göteborg, Sweden, April 10-12, 1992. The Swedish NGO Secretariat on Acid Rain, Göteborg, Sweden. ISBN 91-558-7751-6.