

Chapter 9.

General approach

In the context of the updating and revision of these guidelines, the ecological effects of major air pollutants were considered in more detail. This was undertaken in cooperation with the Working Group on Effects under the United Nations Economic Commission for Europe (ECE) Convention on Long-range Transboundary Air Pollution, capitalizing on the scientific work undertaken since 1988 to formulate criteria for the assessment of the effects of air pollutants on the natural environment.

The evaluation for the guidelines focused on the ecological effects of sulfur dioxide (including sulfur and total acid deposition), nitrogen dioxide (and other nitrogen compounds including ammonia) and ozone, which were thought to be currently of greatest concern across Europe. A number of other atmospheric contaminants are known to have ecological effects, but were not considered by the working groups. In the case of metals and persistent organic pollutants, levels of soil contamination or bioaccumulation leading to adverse effects have been proposed, but methods of linking these to atmospheric concentrations or depositions have not yet been developed. In the case of fluorides and particles, ecological effects are no longer of widespread concern in Europe, although air quality criteria have been proposed in the past by other bodies, and new criteria for fluorides are currently under consideration by certain national governments.

Use of the guidelines in protecting the environment

Although the main objective of the guidelines is the direct protection of human health, the WHO strategy for health for all recognizes the importance of protecting the environment in terms of benefits to human health and wellbeing. Resolution WHA42.26 of the World Health Assembly and resolutions 42/187 and 42/186 of the United Nations General Assembly recognize the interdependence of health and the environment.

Ecologically based guidelines for preventing adverse effects on terrestrial vegetation were included for the first time in the first edition of *Air quality guidelines for Europe* in 1987, and guidelines were recommended for some gaseous air pollutants. Since that time, however, significant advances have been made in the scientific understanding of the impacts of air pollutants on the environment. The realization that soils play an important role in mediating both the direct and indirect effects of air pollutants on terrestrial and freshwater ecosystems has led to the development and acceptance of the joint concepts of critical levels and critical loads within the framework of the ECE Convention on Long-range Transboundary Air Pollution.

At the ECE Workshop on Critical Loads for Sulphur and Nitrogen, held at Skokloster, Sweden (1) and at a workshop on critical levels held at Bad Harzburg, Germany (2), the following definitions were agreed on.

Critical level is the concentration of pollutants in the atmosphere above which direct adverse effects on receptors such as plants, ecosystems or materials may occur according to present knowledge.

Critical load is a quantitative estimate of an exposure, in the form of deposition, to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge.

The critical levels and loads approach is essentially a further development of the first edition of these guidelines published in 1987. There are several fundamental differences between conventional environmental objectives, critical levels and critical loads (Table 1).

Table 1. Differences between conventional environmental objectives, critical levels and critical loads

Conventional objectives	Critical levels	Critical loads
Effects are generally experienced at the organism level	Effects are experienced from organism to ecosystem levels	Effects are usually manifested at the ecosystem level
Objectives are established on the basis of laboratory tests	Objectives are established by laboratory or controlled environmental and field studies	Ecosystem studies are required to establish values
Lethality or physiological effects are the usual response used in setting objectives	Physiological, growth and ecosystem effects are caused by direct or indirect mechanisms	Ecosystem effects are caused by direct (abiotic change) or indirect (biotic interaction) mechanisms
Environmental objectives are set well below known effects to provide some margin of safety	Objectives are set as close to effect thresholds as possible	Objectives are set as close to effect thresholds as possible
No beneficial effects are likely to occur in the environment at any level	Changes may occur that are deemed beneficial (such as increased growth)	Changes may occur that are deemed beneficial (such as increased productivity)
Environmental damage from exceedances is usually observed within a short time	Environmental damage usually results from short- to medium-term exceedances	Environmental damage usually results from long-term (years, decades) exceedances and may be cumulative

Critical levels relate to direct effects on plant physiology, growth and vitality, and are expressed as atmospheric concentrations or cumulative exposures over a given averaging time. Typically, critical levels are based on effects observed over periods of from one day to several years. Critical loads relate to effects on ecosystem structure and functioning, and are expressed as annual depositions of mass or acidity. Typically, critical loads relate to the potential effects over periods of decades. In the case of sulfur and nitrogen compounds, critical levels can be directly related to critical loads when the deposition velocity for a given vegetation type is known. Nevertheless, while critical levels provide effects thresholds for relatively short-term exposures, and are not aimed at providing complete protection of all plants in all situations from adverse effects, critical loads provide the long-term deposition below which we are sure that adverse ecosystem effects will not occur.

Both critical levels and critical loads may be used to indicate the state of existing or required environmental protection, and they have been used by ECE to define air pollutant emission control strategies for the whole of Europe. They are being or may be used in a series of protocols relating to the control of sulfur dioxide, nitrogen oxides, total nitrogen (including

oxidized and reduced species) and ozone. Full use has been made in this publication of the data that underpin these protocols. The proposed guidelines cover the same range of air pollutants and are aimed at a wide range of vegetation types and ecosystems. Individual species, vegetation types and ecosystems may vary in their sensitivity to a given pollutant, and this sensitivity may also depend on other factors such as soil type or climate. When possible, therefore, different values of critical loads or levels are defined, depending on the relevant factors. When this approach is not possible, values are based on protecting the most sensitive type of vegetation or ecosystem for which good quality data are available.

There is thus a sound scientific basis for expecting that adverse ecological and economic effects may occur when the guidelines recommended below are exceeded. There is a possibility that adverse effects might also occur at exposures below these guidelines, but there is considerable uncertainty over this and it was decided to recommend values with a sound scientific basis rather than to incorporate arbitrary uncertainty factors. Critical levels and critical loads thus fulfil the primary aim of air quality guidelines in providing the best available sound scientific basis for the protection of vegetation from significant effects.

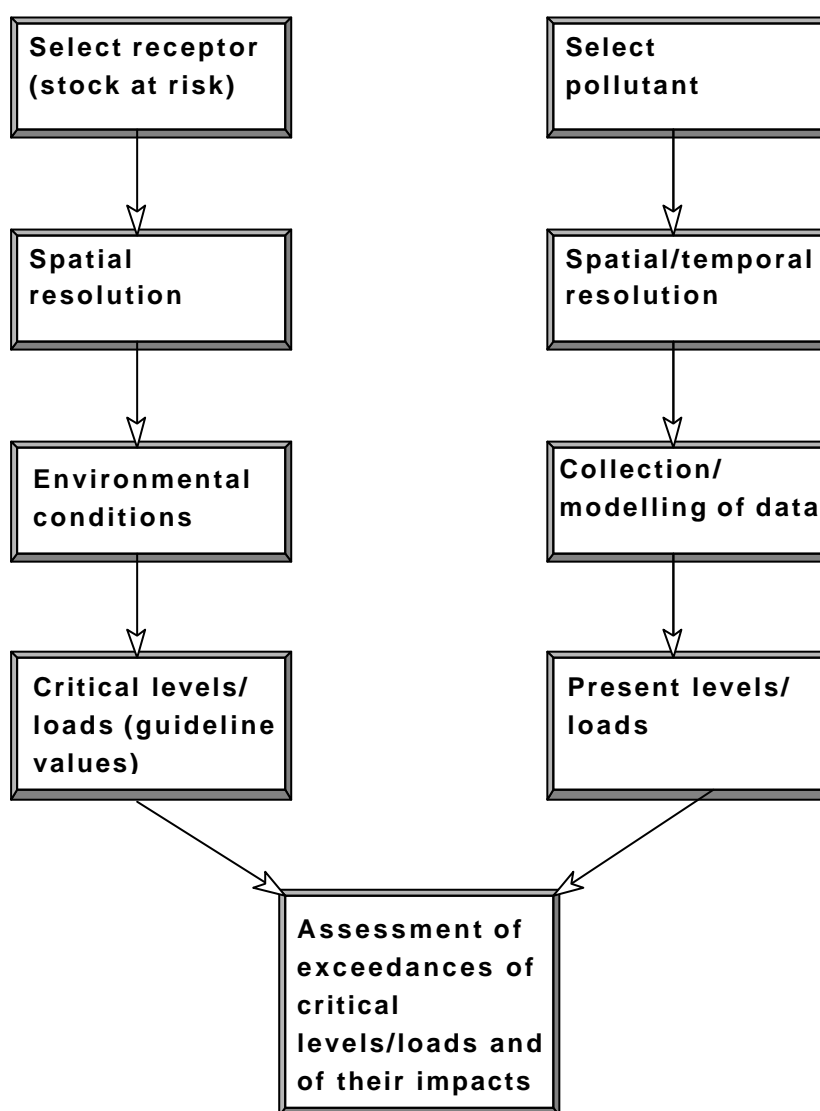
To carry out an assessment based on the guidelines, due consideration has to be given to the various problems caused by air pollution and their impact on the stock that may be at risk. The requirements for the former are often different from those needed to assess the risks to human health. Nevertheless, methodologies have been developed that can assess the risks of damage to vegetation and ecosystems.

Because of the different definition of critical loads and critical levels, the variable nature of the ecological impacts caused by different pollutants, and the different types of scientific evidence available, it is not possible to use a single methodology to derive the air quality guidelines presented in this section. For critical levels, the methods used rely on analysis either of experimental studies in the laboratory or in field chambers, or of field studies along pollution gradients. For critical loads, the methods used rely on analysis of field experiments, comparisons of sites with different deposition rates, or modelling. Where possible, data from a combination of sources are used to provide the strongest support for the proposed guidelines. Uncertainties in defining guidelines can arise (*a*) because of the limited availability of appropriate data; (*b*) because the data exist only for specific vegetation types and climates and therefore may not be representative of all areas of Europe; or (*c*) because exposure patterns in experimental chambers may not be representative of those under field conditions.

In the field, pollutants are never present in isolation, while the same pollutant may have several impacts simultaneously (for example, exposure to sulfur dioxide can cause direct effects on leaf physiology and contribute to long-term acidification, while deposition of nitrogen can cause both acidification and eutrophication). Currently, knowledge of the impacts of pollutant combinations is inadequate to define critical loads or levels for such combined impacts, and thus the guidelines are recommended for the ecological effects of individual pollutants. When applying these guidelines in ecological risk assessment, the possibility of such combined impacts should be considered. Furthermore, when considering an area of mixed vegetation types or ecosystems, several guidelines may apply. Thus ecological risk assessment applying the critical levels and loads approach must be aimed at identifying or protecting the most sensitive element of the environment.

A simple overview of the elements of how critical levels and critical loads can be used is given in Fig. 1. The left- and right-hand pathways indicate the requirements, enabling finally the comparison of critical levels or critical loads with ambient air concentrations (present levels) or pollutant depositions (present loads) on broad spatial scales. The left-hand pathway depicts the steps needed to obtain a geographical distribution of critical levels and loads over European ecosystems.

Fig. 1. Critical levels/loads application pathway



Since critical levels and critical loads indicate the sensitivity of receptors (such as individual plant species or ecosystems) to air pollutants, an important step in the critical levels/loads application pathway consists of the geographical determination and mapping of the receptors and their sensitivities, at as fine a spatial resolution as possible.

Critical levels are in most cases formulated in such a way that a certain receptor type (such as forests or crops) has the same critical level value throughout Europe. In these cases, the

resulting sensitivity maps look uniform over large areas. More recent developments in critical levels research attempt to incorporate environmental conditions into the assessment. The incorporation of such modifying factors – such as water availability, which influences the opening of the stomata and thus the uptake of gaseous pollutants by plants – can lead to a higher degree of differentiation in the mapping of sensitivities.

Critical loads are also allocated to certain receptor types, such as forests, bogs, heathlands, grasslands or lakes, but the spatial differentiation is generally more advanced than in the case of critical levels. It is often possible to take into account environmental conditions such as soil characteristics, water conditions, precipitation amounts, land use and management practices. The result is a critical load map with a high spatial variation in sensitivities.

The right-hand pathway in Fig. 1 depicts steps to ensure comparability of present levels/loads with critical levels/loads. The comparison with present ambient air concentrations or present depositions can only be made if the spatial resolution is compatible with the mapped critical levels/loads. The regional distribution of ambient air concentrations and depositions can be modelled to reflect data measured by national and/or international monitoring networks over Europe. Subject to the spatial resolution of these modelled data, comparisons of critical levels/loads with present levels/loads can be made at finer or coarser spatial resolutions. At the European level, present levels/loads are currently modelled for grid cells with a size of 150 km × 150 km or 50 km × 50 km by the ECE Co-operative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe (EMEP). In the case of depositions, compatibility with the mapped critical loads can be achieved by establishing cumulative frequency distributions of the critical loads occurring in the grid cell. A low percentile value (such as 5) of these distributions can be chosen for comparison with the present loads. If, in the framework of effect-orientated pollutant emission reduction strategies, the present levels or loads are reduced to critical levels or a 5-percentile value of the critical loads distribution, respectively, the protection of most sensitive receptors is reliably estimated to be high (for example achieving potential protection of 95% of the ecosystems in a grid cell).

The left- and right-hand pathways of Fig. 1 finally lead to the assessment of exceedances of critical levels/loads. Exceedances of critical levels/loads are interpreted in a qualitative rather than a quantitative manner, in that the probability of damage is considered to be non-zero whenever critical levels/loads are exceeded. Thus, the exceedance of critical levels/loads implies non-sustainable stress, which can lead to damage at any point in time and to an extent depending on the amount of excess pollution. Research is continuing to determine quantitative regional relationships between the actual excess pollution and the expected damage. Exposure–response relationships for sensitive receptors, established in experimental or field studies and modified for prevailing environmental conditions, may tentatively be used to quantify the consequences of excess pollution. However, research results are considered to lack the robustness needed to allow applications to European ecosystems as a whole.

References

1. NILSSON, J. & GRENNFELT, P., ED. *Critical loads for sulphur and nitrogen*. Copenhagen, Nordic Council of Ministers, 1993 (Miljørapport No. 15).
2. *Final report of the Critical Levels Workshop, Bad Harzburg, Germany, 14–18 March 1988*. Berlin, Federal Environment Agency, 1988.