Air and Air Pollution Control

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Air pollutant inputs

Deposition

Air pollutants not only have direct effects via air, they also damage ecosystems after being removed from the air (deposition). They are deposited either in gaseous form, as particles, or dissolved in precipitation and fog.

Wet deposition

Any input of airborne pollutants into ecosystems by means of precipitation (rain, snow) is called wet deposition. Its amount depends on the volume of precipitation at the testing site and the concentration of the pollutant in that precipitation.

Wet deposition is detected through measurements of pollutant concentrations in sampled precipitation. Several local, regional, and national monitoring programmes and networks take part in these measurements, resulting in a sufficiently dense and evenly distributed measurement network.

These concentration data are interpolated and multiplied with interpolated (to 1 x 1 km²) meteorological precipitation data for a given year to obtain wet deposition fields and thus enabling the production of maps.

Dry deposition

Airborne particles and gases are also deposited into soil, vegetation, and other materials without rain and snowfall. Atmospheric conditions, the concentration of the pollutant in the atmosphere, and the receptor properties determine the amount of dry deposition. Size, shape, and composition of the receptor surface are most significant. Forest canopies are very effective in filtering out particles and droplets in addition to retaining large volumes of harmful compounds in the forest ecosystem through direct absorption on and into leaves. Dry deposition in recorded regularly recorded at only a few measuring sites. Land cover specific, high-resolution data on dry deposition (1 x 1 km²) is calculated based on modelling in Germany.

Occult (fog and cloud droplet) deposition

Atmospheric pollutants dissolve in fog and cloud droplets which are deposited to ecosystems. As with dry deposition the amount of occult deposition greatly depends on receptor characteristics. High-resolution (1 x 1 km²) model results are based on land use and meteorological data as well as pollutant concentrations for forest areas above 250 mean sea level.

Total deposition

Wet deposition only accounts for about one third of total deposition, whereas dry deposition accounts for the remaining two-thirds.

Total deposition is recorded as a combination of spatially interpolated measurements of wet deposition with modelled dry and occult depositions. It is mapped in high-resolution (1 x 1 km²) and specific to land use.

Air pollutants effects in ecosystems

Air pollutants are transported through the atmosphere and deposited into ecosystems which are sometimes far away from the sources. They have various impacts on the biogeochemistry, the flora and fauna and its diversity.

Deposition of sulphur and nitrogen compounds leads to soil acidification, altering the balance between and budgets of soil nutrients. Plants and plant communities that only thrive in neutral soil conditions have no chance of survival in the long term. Such types of ecosystem then disappear, and the biodiversity of ecosystems is diminished.

Nitrogen compounds can also have eutrophication effects on semi-natural terrestrial ecosystems. Long-lasting high levels of airborne nitrogen deposition disrupts the balance between nitrogen and other nutrients such as magnesium, phosphorus and potassium in the soil and thereby affects a balanced uptake by plants. An imbalanced nutrient household in the ecosystem leads to lower tolerance of short-term interferences or stress (frost, dry periods, pests). Nitrogen deposition is a major cause of the loss of biodiversity in Europe.

If concentrations of heavy metals exceed critical limits, they are toxic to organisms and can disrupt the functioning of an ecosystem.

Ground-level ozone also is harmful to vegetation. Direct effects can lead to yield or quality loss (e.g. discolouration and death of parts of leaves). In the case of trees, long-term effects are possible (e.g. increased sensitivity to pests).

In summary, long periods of stress exerted through pollutant input lead to destabilisation of ecosystems (e.g. forest damage), which are then more vulnerable to natural stress factors and changes in climate.

The mentioned anthropogenic (i.e. caused by human activity) stress factors have local effects which vary with natural site conditions: their mutual impact can either be amplified (synergistic effects) or weakened (antagonistic effects).

The changes in ecosystems brought about or aided by air pollutant input can ultimately result in an impairment of their functions, which also means diminished ability to serve mankind, e.g. by providing clean groundwater and other resources, flood protection, acting as areas of rest and recreation, etc.

Acidification

Inputs of sulphur and nitrogen compounds cause more acid soil conditions (lowered pH value) and a loss of nutrients. As a result, the amounts and composition of nutrients available to vegetation is changed. Long periods of acid stress lead to an imbalanced nutrient uptake and reduced vitality of plants (e.g. trees), and to limited resistance to natural stress factors. Many ecosystem functions are then limited, especially water filtration. Thus, forest damage is in fact damage not to trees only but to forest ecosystems.

Furthermore, pollutant deposition lead to wide-ranging degradation of soil conditions to unfavourable acidified levels. Since plants and plants communities that only thrive in neutral soil conditions are displaced by competing species and communities that do thrive in acidic environments (e.g. wavy hairgrass), acid inputs lead to a decrease in the diversity of vegetation. As many animal species are entirely dependent on certain plant species, the continuous decline in plant species diversity which has been observed in Germany also affects the diversity of animal species. Fauna must also bear the immediate consequences of acidification: for instance, earthworms that inhabit mineral soils can not exist in acidified soil (lower than pH 4), as aluminium, which has a toxic effect on them, is dissolved in this range. However, there is no ”ecological substitute” for earthworms. This is another example of geochemical changes having ecological and functional effects.

Inputs of acidifying sulphur compounds have declined in recent years, although no such positive trend can be detected for acidifying nitrogen inputs. The critical loads for sulphur inputs continue to be exceeded on 85% of the surface of sensitive ecosystems in Germany: these areas continue to acidify. Recovery of ecosystems to pre-industrial era levels can, depending on soil and ecosystem, take several hundred years' time even if critical loads are not exceeded.

Sulphur deposits and their role in acidification

Up until the mid-1990s inputs of acidifying substances were highest in the forest areas of the Central German Uplands. High deposition rates of sulphur compound as a consequence of industrial combustion processes were a main cause, particularly in the 1970s and 1980s, of massive exceedance of critical loads.

These exceedances have been reduced thanks to the success achieved by international treaties to reduce transboundary air pollution. In the *Laender* of former West Germany, clean air policy measures such as the Federal Immission Control Act (*BImSchG)* or the Technical Instructions on Air Quality (*TALuft*) led to significant abatement of inputs as of the mid-1980s. It was only after 1990 that this process was emulated in the new *Laender* of reunified Germany.

Nevertheless, the extensive inputs of the past have long-term effects: the soils in areas with previously high levels of sulphur deposition will remain acidified for a long time. Lime has been spread at many sites to compensate for acid deposition.

Nitrogen is currently European ecosystems' most significant acidifier

The excessive input of nitrogen compounds (mainly $(H)NO_3$ and ammonium (NH_4+) from nitrogen oxides (transport) and ammonia from agricultural sources, animal husbandry in particular), leads to soil acidification. Constant levels of nitrogen inputs from the atmosphere during the last 15 years have turned nitrogen into the most significant acidifier and therefore main cause of continued acidification of semi-natural ecosystems. The nitrogen input is converted to nitrate (NO_3-) in the soil, which can be leached from the soil together with nutrients of basic reaction (magnesium, calcium, potassium). This results in imbalanced nutrient composition of soils and plants, elevated nitrate concentrations in soil leachate and groundwater, as well as widespread leveling of soil conditions to adverse acidified levels.

Critical loads of acidification

"Critical load" is a term used to denote atmospheric loads of particular air pollutants. It indicates the amount of a given substance per defined unit of area and time which, can be introduced into an ecosystem without bringing about environmental damage in the long-term, according to present knowledge.

Critical loads of acidification relate to for airborne nitrogen and sulphur inputs. If they are not exceeded, neither acute nor to long-term deleterious effects on sensitive ecosystems such as woods, heathlands and marshlands and contiguous systems (e.g. groundwater) will occur. Conversely, if critical loads of acidification are indeed exceeded by atmospheric loads, the affected area will then be subject to the risk of deleterious environmental effects.

The level of deposition which can be tolerated in any individual case is determined solely by the characteristics of the ecosystem under consideration. Critical loads are, accordingly, ecosystem-specific. The basic method of critical load calculation is to generate a mass balance, which compares and contrasts the rates of nitrogen and sulphur input to the rates of those processes which can buffer or immobilise these substance inputs or remove them from the system.

In the mass balance for the calculation of the critical load for the input of acidifiers the most important acid-generating soil processes are compared and contrasted to those processes which either consume or buffer the acid. Thereby specific soil chemistry indicators of relevance to the effects generated (e.g. defined concentrations or ion ratios in the soil solution) should not be exceeded, nor should the values fall below them, respectively, in the long-term. The ecosystem-specific calculation and the cartographic representation of the spatial distribution of the critical loads and their exceedance are effectuated using a geographical information system (GIS).

A proportion of the input nitrogen can unlike sulphur be immobilised in the ecosystem. Accordingly, the critical load and its exceedance depends on the ratio of sulphur to nitrogen flows. Critical loads of acidification are therefore depicted as a critical load function. In this way the range in which the ecosystem has long-term protection from acidification is limited in each case by a combination of sulphur and nitrogen depositions. The exceedance of the critical load can thus equally be stated and represented for combinations of sulphur and nitrogen depositions.

The risk indicated by critical load exceedance does not necessarily mean that, in the year in question, harmful chemical values were obtained or that biological effects became apparent. It can take decades for ecosystems to react to critical load exceedance. This long delay before the effects of pollutants become discernable depends on substance input rates, meteorological and other ancillary conditions, and the characteristics of the ecosystem in question. Conversely, the slow reaction of ecosystems is the reason why the recovery to pre-industrial conditions can take several centuries, even if the deposition subsequently falls below critical loads. It is for this reason that absolute damage prognoses made by means of critical load exceedances are in principle impossible.

To this end, dynamic mass balance models become necessary which, in contradistinction to the above steady-state mass balance models, incorporate temporally variable ancillary conditions, as well as delay and feedback effects. They can therefore be used to prognosticate the development over time of further acidification as well as the recovery of the location in question in the light of different pollution scenarios. Dynamic models can be used to calculate substance input rates at which safe conditions will be achieved in the ecosystem in question by a defined point in time (e.g. 2030, 2050) and maintained thereafter. These input rates are known as target loads and are by definition lower than the critical loads.

Critical loads as basis for evaluation

As air pollutants and the harm they cause are no respecters of international borders, what is needed to find an effective and equitable solution are international agreements on emissions reduction.

One of the long-term goals of the EU National Emission Ceilings (NEC) Directive and the Multipollutant Protocol to the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) is to ensure that deposition falls permanently and completely below the critical loads of eutrophication and acidification. In the short term the spatially differentiated comparison of the sensitivity of ecosystems with the current level of air pollutant inputs will serve as an effects-based foundation for the development of measures – in other words, the need to reduce emissions will be determined according to the risks of deleterious effects. This political approach is known as the ”effects-based” approach.

An interim goal was formulated for 2010 in the abovementioned agreements. It stipulates a reduction throughout Europe of at least 50% of the ecosystem area in which the critical loads are exceeded compared to the year 1990. Whereas this target was a basis for the emissions reduction negotiations, the emission ceilings agreed upon as a result of the negotiations do not meet this objective. The UNECE Protocol, signed in 1999, sets out the following national emissions reduction targets for 2010 in respect of 1990 levels:

- Ammonia (NH_3): -28 %,
- Nitrous oxides (NO_x): -60 %,
- Sulphur dioxide (SO_2): -90 %.

It may well be that the targets for NH3 and NOx will not be met by measures already in force. For this reason Germany has defined further measures in the context of a national programme for compliance to the national emission ceilings.

Acidification will remain problem a problem for ecosystems and biodiversity long after 2010. In 2004 the critical loads for acidification in Germany were still being exceeded in 85% by area of all sensitive ecosystems (graphic). These regions are becoming further acidified; the others will recover in the course of the next decades and centuries. The ”Thematic Strategy on Air Pollution” of the EU Commission therefore proposes amongst other things a reworking of the NEC Directive with reduced emission ceilings by the year 2020, the observance of which will require the introduction of additional measures.