Critical Load Exceedance and Gap Closure Methods - A Summary

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In this Note the different methods for calculating critical load exceedances and ways of quantifying their (relative) reductions ("gap closures") - as used at various times in the integrated assessment modelling (IAM) carried out on behalf of the Working Group on Strategies - are summarized for the non-technical reader.

In the European IAM deposition of nitrogen (N) and sulfur (S) is given as single values on the ($150\times150km^2$) EMEP grid. Within a single EMEP grid cell, however, many (up to 100,000 in some cases) critical loads (CLs) for various ecosystems, mostly forest soils and surface waters, have been calculated. These CLs are sorted according to magnitude, taking into account the area of the ecosystem they represent, and the so-called cumulative distribution function (CDF) is constructed. This CDF is then compared to the single deposition values for that grid cell.

In the IAM for the 1994 Sulphur Protocol only sulfur was considered as acidifying pollutant (N deposition was fixed; it determined, together with N uptake and immobilization, the so-called sulfur factor). Furthermore, taking into account the uncertainties in the CL calculations, it was decided to use the 5-th percentile of the critical load CDF in a grid cell as the (only!) value representing the ecosystem sensitivity of that cell. And the difference between the (current) S-deposition and that 5-th percentile CL was called *the* exceedance of the critical load in that grid cell. This is illustrated in Fig.1a: Critical loads and depositions are plotted along the horizontal axis and the (relative) ecosystem area along the vertical axis. The thick solid and the thick broken lines are two examples of critical load CDFs (which have the same 5-th percentile critical load, indicated by ‘CL’). ‘D0’ indicates the (present) deposition, which is higher than the CLs for 85% of the ecosystem area. The difference between ‘D0’ and ‘CL’ is the critical load exceedance in that grid cell. Since it was impossible to reduce depositions in all European grid cells to critical loads (i.e. to reach zero exceedance), it was decided to reduce the exceedance everywhere by a fixed percentage, i.e. to "close the gap" between (present) deposition and (5-th percentile) critical load. In Fig.1a (see below) a **deposition gap closure** of 60% is shown as an example. As can be seen, a fixed deposition gap closure can result in very different improvements in ecosystem protection percentages (55% vs. 22%), depending on the shape of the CDF.

In order to take into account the complete CDF of the critical loads (and not only the 5-th percentile), it was suggested to use an **ecosystem area gap closure** instead of the deposition gap closure. This is illustrated in Fig.1b: For a given deposition ‘D0’ to a grid cell the ecosystem area unprotected, i.e. with deposition exceeding the critical loads, can be read from the vertical axis. After agreeing to a certain (percent) reduction of the unprotected area (e.g. 60%), it is easy to compute for a given CDF the required deposition reduction (see ‘D1’ and ‘D2’ in Fig.1b). Another important reason to use the ecosystem area gap closure is that it can be easily generalized to two (or more) pollutants, which is not the case for the exceedance. This generalization became necessary in the preparation for a new multi-pollutant-multi-effects protocol in the case of acidity critical loads, since both N and S are contributing to acidification. Critical load values are replaced by critical load functions (see Fig.2) and percentiles are replaced by ecosystem protection isolines. The use of the area gap closure becomes problematic, however, if only a few critical load values or functions are given for a grid cell. In such a case the CDF becomes discontinuous and (small) changes in deposition may result in either no increase in the protected area or large jumps in the area protected.

To remedy the problem with the area gap closure caused by discontinuous CDFs, a new measure, the so-called accumulated exceedance (AE) has been introduced. This required the definition of *an* exceedance in the case of two pollutants: for a given deposition of N and S the exceedance is defined as the sum of the N and S deposition reductions required to achieve non-exceedance by taking the shortest path to the critical load function (see Fig.2 below). This exceedance is multiplied by the ecosystem area; and they are summed to yield the accumulated exceedance for a grid cell. In the case of one pollutant the AE is simply given as the area under the CDF of the critical loads (see grey-shaded area in Fig.1c). In addition, the average accumulated exceedance (AAE) has been defined by dividing the AE by the total ecosystem area of the grid cell, which has thus the dimension of a deposition. Deposition reductions are now negotiated in terms of an **AE** (or **AAE**) **gap closure**, which is illustrated in Fig.1c: a 60% AE gap closure is achieved by a deposition 'D1' which reduces the total grey area by 60%, resulting in the dark grey area; also the corresponding protection percentage (61%) can be easily derived. The greatest advantage of the AE and AAE is that it varies smoothly when depositions are varied, even for highly discontinuous CDFs, thus facilitating optimization calculations in IAM.

The advantages and disadvantages (shortcomings) of the three gap closure methods described above are summarized in the following table:

	Advantages	**Disadvantages/Shortcomings**
Deposition gap closure (used for 1994 UN/ECE Sulphur Protocol)	• Easy to use even for discontinuous CDFs (e.g. grid cells with only one CL)	• Takes only one CL value (e.g. 5-th percentile) into account • May result in no increase in protected area • Difficult to define for two pollutants
Ecosystem area gap closure (used for the EU Acidification Strategy)	• In line with the goals of CL use (maximum ecosystem protection) • Easy to apply to any number of pollutants	• Difficult (or even impossible) to define a gap closure for discontinuous CDFs (e.g. grid cells with only one CL)
Accumulated Exceedance (AE) gap closure (used for the UN/ECE multi-pollutant multi-effects protocol)	• AE (and AAE) is a smooth and convex function of depositions even for discontinuous CDFs	• AE stretches the limits of the critical load definition (linear damage function!) • Exceedance definition not unique for 2 or more pollutants

Further information and the (mathematical) definitions of the various terms (CDF, percentiles, CL function, protection isoline, AE and AAE etc.) can be found in the CCE Status Reports (Posch *et al.* 1995, 1997, 1999) and the Mapping Manual (UBA 1996).

References

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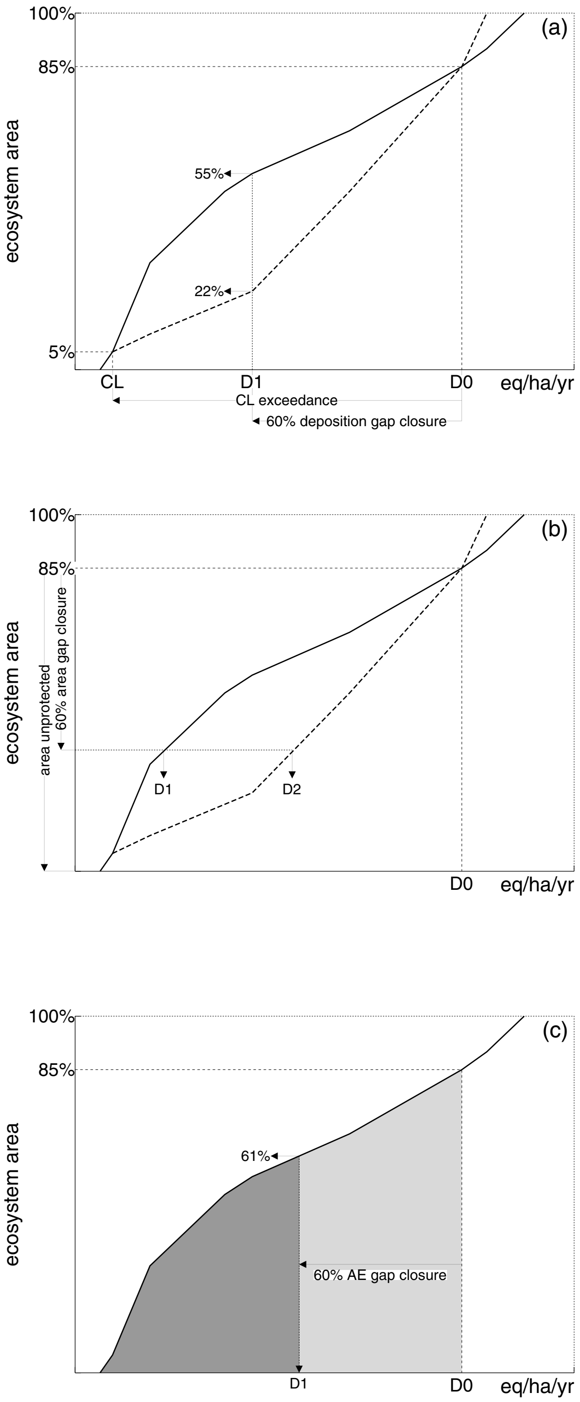

Figure 1: Cumulative distribution function (CDF; solid thick line) of critical loads (CLs) and the different methods of gap closure: (a) deposition gap closure, (b) ecosystem gap closure, and (c) accumulated exceedance (AE) gap closure. The dashed thick line in (a) and (b) depict another CDF, illustrating how very different ecosystem protection result from the same deposition gap closure (a), or how different deposition reductions are required to achieve the same protection level.

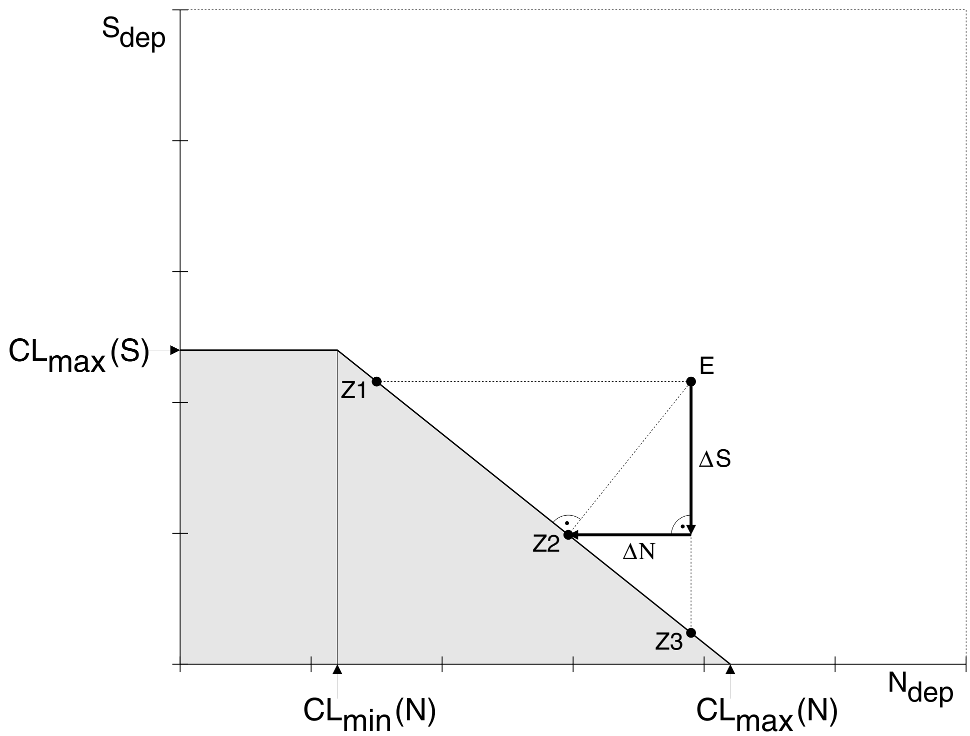

Figure 2: Example of a critical load function for S and acidifying N defined by the quantities $CL_{max}(S)$, $CL_{min}(N)$ and $CL_{max}(N)$. It shows that no unique exceedance can be defined: Let the point E denote the current deposition of N and S. Reducing N_{dep} substantially one reaches point Z1 and thus non-exceedance without reducing S_{dep}; on the other hand one can reach non exceedance by reducing S_{dep} only (by a smaller amount) until reaching Z3. For the purpose of the protocol negotiations, an exceedance has been *defined* as the sum of N_{dep} and S_{dep} reductions ($\Delta N+\Delta S$) which are needed to reach the critical load function on the shortest path (point Z2).