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Working Group on Effects
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STATUS REPORT ON DYNAMIC MODELLING OF SOILS AND SURFACE WATERS FOR THE ASSESSMENT OF TIME DELAYS OF IMPACTS ON ECOSYSTEMS CAUSED BY CHANGES IN DEPOSITION TRENDS

Note prepared by the Coordination Center for Effects (CCE) of the International Cooperative Programme on Modelling and Mapping of Critical Levels and Loads and Air Pollution Effects, Risks and Trends, with the assistance of the secretariat

I. INTRODUCTION

1. Dynamic modelling is the logical natural extension of steady-state critical loads in support of the effect-oriented work under the Convention on Long-range Transboundary Air Pollution.

2. European databases and maps of critical loads have been used to support effects-based protocols to the Convention, such as the 1994 Protocol on Further Reduction of Sulphur Emissions and the 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone.

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3. Critical loads are based on a steady-state concept. They are the constant depositions that an ecosystem can tolerate in the long run, i.e. after it has equilibrated with these depositions. However, many ecosystems are not in equilibrium with present or projected depositions, since there are processes ("buffer mechanisms") at work that delay the reaching of an equilibrium (steady state) for years, decades or even centuries. By definition, critical loads do not provide any information on these timescales.

4. The Executive Body of the Convention at its seventeenth session in December 1999 "underlined the importance of ... dynamic modelling of recovery" (ECE/EB.AIR/68, para. 51 (b)) to enable the assessment of time delays of recovery in regions where critical loads stop being exceeded and time delays of damage in regions where critical loads continue to be exceeded.

5. Dynamic models are not new. In the past two decades scientists have been developing, testing and applying dynamic models to simulate the acidification of soils or surface waters, mostly due to the deposition of sulphur. Well known dynamic models include the Simulation Model for Acidification's Regional Trends (SMART: de Vries *et al.*, 1989; Posch *et al.*, 1993), the Soil Acidification in Forest Ecosystems model (SAFE: Warvfinge *et al.,* 1993; Alveteg and Sverdrup, 2002), the Model of Acidification of Groundwater in Catchments (MAGIC: Cosby *et al.,* 1985; 2001).

6. It is, however, a relatively new topic for the effect-oriented work under the Convention. Earlier work, e.g. under the International Cooperative Programme (ICP) on Integrated Monitoring, has applied existing dynamic models at a few sites for which a sufficient amount of input data was available. The new challenge is to develop and apply dynamic model(s) on a European scale and to integrate them as much as possible with the integrated assessment work under the Convention, in support of the review and potential revision of protocols, maybe starting as early as 2003.

7. In the framework of the effect-oriented activities under the Convention the "Very Simple Dynamic model" (VSD) (VSD: Posch and Reinds, 2002) has been developed. The VSD model is the simplest extension of the steady-state mass balance model for critical loads. It consists of basic equations which are also incorporated in SMART, SAFE and MAGIC (see Posch *et al.,* 2002).

8. A Joint Expert Group on Dynamic Modelling, consisting of experts of all ICPs under the Working Group on Effects, was established in 2000 to review dynamic modelling in the framework of the Convention. Results of its two meetings (Ystad, Sweden, 3-5 October 2000 and 6-8 November 2001) were reported to the Working Group (EB.AIR/WG.1/2001/11; EB.AIR/WG.1/2002/12).

II. DYNAMIC MODELLING IN THE CONTEXT OF THE CONVENTION

9. In the causal chain from deposition of strong acids to damage of key indicator organisms there are two major links that can give rise to delays. Biogeochemical processes can delay the chemical response in soil, and biological processes can further delay the response of indicator organisms, such as damage to trees in forest ecosystems. The static models to determine critical loads consider only the steady-state condition, in which the chemical and biological response to a change in deposition is complete. Dynamic models, on the other hand, attempt to estimate the time required for a new (steady) state to be achieved.

10. With critical loads, i.e. in the steady-state situation, only two cases can be distinguished when comparing them to deposition: (i) the deposition is below critical load(s), i.e. does not exceed critical loads; and (ii) the deposition is greater than critical load(s), i.e. there is critical load exceedance. In the first case there is no (apparent) problem, i.e. no reduction in deposition is deemed necessary. In the second case there is, by definition, an increased risk of damage to the ecosystem, and therefore the deposition should be reduced.

11. A critical load serves as a warning as long as there is exceedance, since it indicates that deposition should be reduced. However, it is often assumed that reducing deposition to (or below) critical loads immediately removes the risk of "harmful effects", i.e. the chemical parameter (e.g. the aluminium:basic cations (Al:Bc) ratio), which links the critical load to the effect(s), immediately attains a non-critical ("safe") value, and that there is immediate biological recovery as well.

12. But the reaction of soils, especially their solid phase, to changes in deposition is delayed by (finite) buffers, the most important being the cation exchange capacity. The buffer mechanisms can delay the attainment of a critical chemical parameter, and it might take decades or even centuries before an equilibrium (steady state) is reached.

13. These finite buffers are not included in the critical load formulation since they do not influence the steady state, only the time to reach it. Therefore, dynamic models are needed to estimate the times involved in attaining a certain soil chemical state in response to deposition scenarios, e.g. the consequences of "gap closures" in emission reduction negotiations.

14. In addition to the delay in chemical recovery, there is likely to be a further delay before the "original" biological state is reached, i.e. even if the chemical criterion is met (e.g. Al:Bc<1), it will take time before full biological recovery is achieved.

15. The figure below summarizes the possible development of a (soil) chemical and biological variable in response to a "typical" temporal deposition pattern. Five stages can be distinguished:

Stage 1: Deposition was and is below the critical load and the chemical and biological variables do not violate their respective criteria. As long as deposition stays below the critical load, this is the "ideal" situation;

Stage 2: Deposition is above the critical load, but the chemical and biological variables are still below the critical value. There is no threat of "harmful effects" yet; there is a delay before the criteria are violated. Therefore, damage is not visible in this stage, despite the exceedance of the critical load. We call the time between the first exceedance of the critical load and the first violation of the biological criterion (the first occurrence of actual damage) the "Damage Delay Time" ($DDT=t_3-t_1$);

Stage 3: The deposition is above the critical load and both the chemical and biological criteria are violated. Measures have to be taken to avoid a (further) deterioration of the ecosystem;

Stage 4: Deposition is below the critical load, but the chemical and biological criteria are still violated, and thus recovery has not yet occurred. We call the time between the first non-exceedance of the critical load and the subsequent non-violation of both criteria the "Recovery Delay Time" ($RDT=t_6-t_4$);

Stage 5: This stage is similar to stage 1. Deposition is below the critical load and both criteria are no longer violated. Only at this stage can one speak of full ecosystem recovery.

16. Stages 2 and 4 can be further subdivided into two sub-stages each: (i) chemical delay times ($DDT_c=t_2-t_1$ and $RDT_c=t_5-t_4$; dark grey in fig.); and (ii) (additional) biological delay times ($DDT_b=t_3-t_2$ and $RDT_b=t_6-t_5$; light grey). For the present, due to the lack of operational biological response models, damage and recovery delay times mostly refer to chemical recovery alone and they are used as a surrogate for overall recovery.

17. A detailed explanation and motivation of the use (and constraints) of dynamic modelling can be found in Posch, *et al.* (2002). This "Manual for Dynamic Modelling of Soil Response to Atmospheric Deposition" is also downloadable from www.rivm.nl/cce.

III. THE USE OF DYNAMIC MODELLING IN INTEGRATED ASSESSMENT

18. Ultimately, within the framework of the Convention, a link has to be established between the dynamic soil models and integrated assessment (models), i.e. between the Working Group on Effects and the Task Force on Integrated Assessment Modelling. Different modes of interaction with integrated assessment models can be identified such as scenario analysis, the determination of target loads, the design and use of "recovery isolines", and the integration of a dynamic model into an integrated assessment model (e.g. RAINS).

A. Scenario analysis

19. Deposition scenario output from integrated assessment models is used as input to dynamic models to analyse their impact on (European) soils and surface waters, and the results (recovery times etc.) are reported back. At present available dynamic models are well suited for this task. The question is how to summarize the resulting information on a European scale. Also, the "turn-around time" of such an analysis is bound to be long within the work-plan of the Convention.

B. Determination of target loads

20. Dynamic models are used to determine target loads, e.g. the maximum deposition allowed to reach a certain agreed-upon goal (e.g. value of a soil variable) within a fixed time horizon. These target loads are passed on to the integrated assessment modellers to evaluate their feasibility of achievement (in terms of costs and technological abatement options available). This requires no changes to existing models per se, but some additional work, since dynamic soil models have to be run "backwards", i.e. iterative runs are needed. In addition, since both N and S contribute to acidity, it will not be possible to obtain unique deposition pairs of N and S deposition to reach a given target (compare critical load function for acidity critical loads).

C. Recovery isolines

21. Response functions (broadly comparable to protection isolines for critical loads) are derived with existing dynamic models and linked to integrated assessment models. These response functions ("recovery isolines" in the form of "look-up tables") are pre-processed model runs for a large number of plausible future deposition patterns from which the results for every (reasonable) deposition scenario can be obtained by interpolation.

D. Integrated dynamic model

22. A dynamic model is integrated into the integrated assessment models (e.g. RAINS) and used in scenario analyses and optimization runs. The widely used models, such as MAGIC, SAFE and SMART, are not easily incorporated into integrated assessment models, and they might still be too complex to be used in optimization runs. Alternatively, the VSD model could be incorporated into the integrated assessment models, capturing the essential, long-term features of dynamic soil models. This is analogous to the process that led to the simple ozone model included in RAINS, which was derived from the complex photo-oxidant model of EMEP. However, even this would require a major effort and one of the most difficult things involved would be to create a European database to run the model.

23. The further development of appropriate interfaces between dynamic modelling and integrated assessment is of ongoing concern to ICP on Modelling and Mapping of Critical Levels and Loads and Air Pollution Effects, Risks and Trends (ICP M&M), the Task Force on Integrated Assessment Modelling and the Joint Expert Group on Dynamic Modelling.

IV. OPERATIONAL PROGRESS UNDER THE MEDIUM-TERM WORK-PLAN OF THE WORKING GROUP ON EFFECTS

24. ICP M&M workshops were organized in October 2001 in Zagreb (Croatia), Bled (Slovenia) and Karzag (Hungary), to familiarize participants with dynamic modelling.

25. The Coordination Center for Effects (CCE) developed a Dynamic Modelling Manual (Posch *et al.*, 2002) and an operational version of the VSD model (Posch and Reinds, 2002). This material has been made available to National Focal Centres (NFCs) and is also downloadable from www.rivm.nl/cce.

26. CCE collaborated with the Swedish Ministry of Environment to support the Polish NFC in testing this material using its national critical load database. CCE also collaborated with the Swiss NFC to compare the VSD and SAFE models, using national data. The results were presented at the twelfth CCE workshop, held back to back with the eighteenth meeting of the Task Force on ICP M&M in Sorrento (Italy), from 15 to 19 April 2002. These and other results of the workshop can also be downloaded from www.rivm.nl/cce.

27. The twelfth CCE workshop and the eighteenth meeting of the Task Force on ICP M&M recommended to CCE the following operational actions ensuing from the medium-term work-plan of the Working Group on Effects:

(a) Autumn 2002: Issue a call (deadline: early spring 2003) for an update of the critical load database and an extension to include variables and data required for operating the VSD model. Consistency between the critical load database and its extension required for dynamic modelling is important since data used to establish critical load and exceedance maps should be consistent with data for the dynamic assessment of impacts caused by these exceedances;

(b) Spring 2003: Focus the CCE workshop (e.g. through a training session) on dynamic modelling using the response to the call for data to enhance NFC consensus on dynamic modelling and required data;

(c) Autumn 2003: Issue a call (deadline: spring 2004) for an update of the critical load database and an extension to include variables and data required for dynamic modelling for the support of the policy process in 2004.

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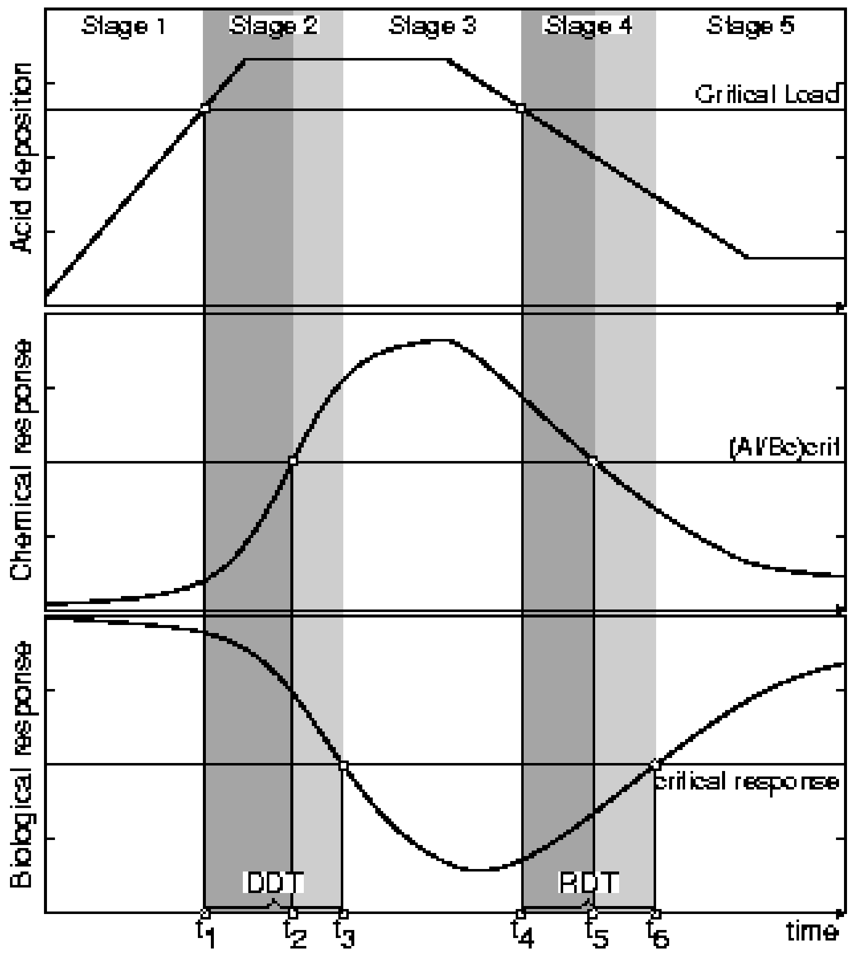

Figure. "Typical" temporal (past and future) development of the deposition (top), a soil chemical variable and the corresponding biological response. Also depicted are the critical values of those (chemical and biological) variables and the critical load derived from them. The delay between the (non-)exceedance of the critical load, the (non-)violation of the critical chemical criterion and the crossing of the critical biological response is indicated in grey shades, highlighting the Damage Delay Time (DDT) and the Recovery Delay Time (RDT) of the system.