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**DYNAMIC MODELLING AT ICP INTEGRATED MONITORING SITES:
MODEL TESTING AGAINST OBSERVATIONS AND UNCERTAINTY**

Summary report presented by the Coordination Centre of the International Cooperative Programme
on Integrated Monitoring of Air Pollution Effects on Ecosystems (ICP Integrated Monitoring)

I. BACKGROUND

1. Critical loads assume a steady-state situation and only two cases can be distinguished when comparing them to deposition at a given site (or grid square): (i) deposition is below critical load(s), i.e. does not exceed critical loads; and (ii) 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. It is possible, however, that although the deposition at one point in time is below the critical load, this may not always have been the case and the ecosystem may still be damaged. In the second there is, by definition, an increased risk of damage to the ecosystem and, therefore, the deposition should be reduced.

2. A critical load serves as a warning as long as there is exceedance, since it indicates that deposition should be reduced. It is often assumed, however, that reducing deposition to (or below) critical loads immediately removes the risk of 'harmful effects'; it is assumed that the chemical parameter (e.g. the surface water acid neutralizing capacity (ANC)), which links the critical load to

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the effect(s), immediately attains a non-critical ('safe') value and that there is immediate biological recovery as well. But the reaction of soils, especially their solid phase, to changes in deposition is delayed by (finite) buffers, the most important being cation exchange capacity within the soils' exchangeable complex represented by cation exchange capacity (CEC). 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. These finite buffers are not included in the critical load formulation, since they do not influence the steady state but only the time taken to reach it. Therefore, dynamic models are needed to estimate the time taken to attain a certain chemical state in response to deposition scenarios, or the delay before the 'original' or 'acceptable' biological state is reached.

3. The link between critical loads and dynamic models is provided by demonstrating that meeting the calculated critical load through emission reductions leads to attainment of the critical chemistry over a very long timescale in the dynamic model. For further extension of the critical loads concept into dynamic modelling, it is essential to ensure such consistency between the approaches.

4. The calibration of dynamic models at a site requires a range of data describing soils and surface water, both physical and chemical characteristics, with information describing all chemical inputs and outputs to the system over time, essentially the net uptake of ions to the vegetation, the input of ions from general weathering and the input of ions from the atmosphere. Many of the ICP Integrated Monitoring sites have the data required for the model application and, in addition, now have many years of observed surface water chemistry against which the performance of the model can be assessed. ICP Integrated Monitoring has, therefore, an important role in the activities carried out by the Working Group on Effects in preparation for the future review of the Gothenburg Protocol in general, and in the further development and application of dynamic modelling in particular. The programme is expected to:

- (a) Provide for 'best' possible model calibrations using comprehensive and internally consistent data which are often not available at a regional scale;
- (b) Test the capability of the model in capturing observed chemical changes in soils and surface waters in response to observed changes in atmospheric deposition inputs;
- (c) Use these calibrations to assess the model structure and current understanding of the key processes operating to control soil and surface water chemistry;
- (d) Undertake formal model sensitivity analysis using the long-term trend data and observed variance in the 'measured' parameters; and
- (e) Strengthen confidence in regional model applications within the context of these more detailed site calibrations.

5. This report summarizes the key results and methods of calibrations of the MAGIC (Model of Acidification of Groundwater In Catchments) model to a data set from selected ICP Integrated Monitoring sites (Jenkins *et al.* 2003).

II. METHODS AND DATA

A. MAGIC model

6. MAGIC is a lumped-parameter model of intermediate complexity, developed to predict the long-term effects of acidic deposition on soils and surface water chemistry (Cosby *et al.* 1985a,b,c, 1986, 1995). The model simulates soil solution chemistry and surface water chemistry to predict the monthly and annual average concentrations of the major ions in lakes and streams. MAGIC represents the catchment with aggregated, uniform soil compartments (one or two) and a surface water compartment that can be either a lake or a stream. MAGIC consists of: (i) a section in which the concentrations of major ions are assumed to be governed by simultaneous reactions involving sulphate adsorption, cation exchange, dissolution-precipitation-speciation of aluminium and dissolution-speciation of inorganic and organic carbon; and (ii) a mass-balance section in which the flux of major ions to and from the soil is assumed to be controlled by atmospheric inputs, chemical weathering inputs, net uptake in biomass and losses to run-off. At the heart of MAGIC is the size of the pool of exchangeable base cations in the soil. As the fluxes to and from this pool change over time owing to changes in atmospheric deposition, the chemical equilibria between soil and soil solution shift to give changes in surface water chemistry. The degree and rate of change in surface water acidity thus depend both on flux factors and on the inherent characteristics of the affected soils.

B. Site applications

7. Data from six ICP Integrated Monitoring sites were used to test the MAGIC model predictions against several years of observations and to make predictions into the future (2030) assuming the agreed emission reductions under current legislation plans (essentially the 1999 Gothenburg Protocol) and the 1994 Oslo Protocol are achieved by 2010. In addition, uncertainties in data and model structures were assessed. The following sites, representing a wide range of catchment characteristics and depositions, were modelled: SE03 (Gårdsjön, Sweden), NO01 (Birkenes, Norway), FI03 (Hietajärvi, Finland), DE01 (Forellenbach, Germany), GB02 (Afon Hafren, United Kingdom) and CZ02 (Lysina, Czech Republic).

8. The model applications used best available soils and water chemistry data held in the ICP Integrated Monitoring database in Helsinki. Where possible/necessary, this was augmented by data available for each site more fully described elsewhere: Birkenes (Larssen *et al.* 2002), Lysina (Krám *et al.* 1997, Hruška *et al.* 2002), Afon Hafren (Jenkins *et al.* 1997), Hietajärvi and Forellenbach (Forsius *et al.* 1998) and Gårdsjön (Moldan *et al.* 1995, Andersson and Olsson 1985).

9. For the model calibration, historical sulphur and nitrogen deposition was derived from EMEP scale assessments (Mylona 1993, Simpson *et al.* 1997). The EMEP trends were scaled to match the deposition measured at the sites at the start of monitoring, though the start year varied at each site. Thereafter, the measured/estimated annual deposition was used as input to the model until the present day (2000). This has enabled the comparison of simulated and observed data.

10. Beyond 2000, two deposition reduction scenarios were used: the current legislation plans and the Oslo Protocol. Both scenarios were provided by the Centre for Integrated Assessment Modelling (CIAM) and the Coordination Center for Effects (CCE) (Posch *et al.*, 2003). The 'Oslo Protocol scenario' is the predicted change in sulphur deposition (no change in nitrogen) to 2010 with the implementation of the Protocol. The 'current legislation scenario' approximates the Gothenburg Protocol to 2010 but also includes agreements under the National Emissions Ceilings Directive and the Large Combustion Plants Directive of the European Union.

III. RESULTS

11. In general, the model predictions matched the long-term observations at each of the sites well. The large declines in sulphate concentrations seen at many of the sites were well captured by the model, as were the observed increases in acid neutralizing capacity (ANC). At some sites, sea-salt inputs varied considerably on an annual basis causing the match between observed and simulated concentration to weaken, although the general trends were in agreement. At most sites there was a close match between observed and simulated pH but there are discrepancies between observed and simulated aluminium concentrations at several sites. The close match between observed and simulated values achieved in this rigorous test of the model, using best available site information and input-output data, demonstrates that the model captures the key controls on mean annual surface water chemistry. Results from the Lysina and Birkenes sites are here shown as examples of the model applications (figures I and II). The detailed results are in the full report of Jenkins *et al.* (2003).

12. At all sites the improvements in chemistry predicted under the current legislation scenario (Gothenburg Protocol) was clearly greater than for the Oslo Protocol scenario. This provided quantification of the benefits of the stricter emission controls. At three of the sites, the calculated critical load for acidity using the steady-state water chemistry method and estimated required load for a dynamic model run into the future (2090) with the same ANC target, were similar, thereby demonstrating consistency between the approaches.

IV. CONCLUSIONS

13. Long-term observations of input and output chemistry at intensively monitored catchments provide an important test of the performance of dynamic models. Furthermore, the soils' detailed physical and chemical data available for these sites provide for a 'best' assessment of model parameters (for example compared to survey data). This makes these model applications as representative as can be expected. In all cases, the MAGIC model was more or less capable of matching the observations of stream chemistry over a ten (or more) year time period. The ability of the model to capture observed long-term responses provided confidence in model predictions under future emission scenarios.

14. European scale dynamic modelling assessment is likely to focus on chemistry data from wide regional surveys of surface waters (Jenkins *et al.* 2002). These surveys often comprise single water samples from many sites collected many years apart. Also, detailed soil information is rarely available at this scale and so soil characteristics are derived from mapping using extrapolation techniques (Helliwell *et al.* 1998). Clearly, detailed model application to any one site in these

regions provides a 'reference' for the regional modelling. This defines the role of ICP Integrated Monitoring with respect to dynamic modelling assessment and underlines the need for strong links to relevant activities of ICP Waters and other national/regional modelling efforts.

15. Sensitivity analysis of model predictions is urgently required. In this respect the detailed, site-specific model applications are of great importance and the current effort must be maintained. There is, therefore, a clear need for continued long-term monitoring at the ICP Integrated Monitoring catchments.

16. The modelling work reported here has not been entirely carried out and/or based on data provided by the National Focal Points of ICP Integrated Monitoring. A willingness to work jointly for achieving, in a most effective way, the common objective has brought together a number of other relevant data holders and interested modellers. Experience gained with this approach should be considered when planning future national and international activities and organizing the necessary resources.

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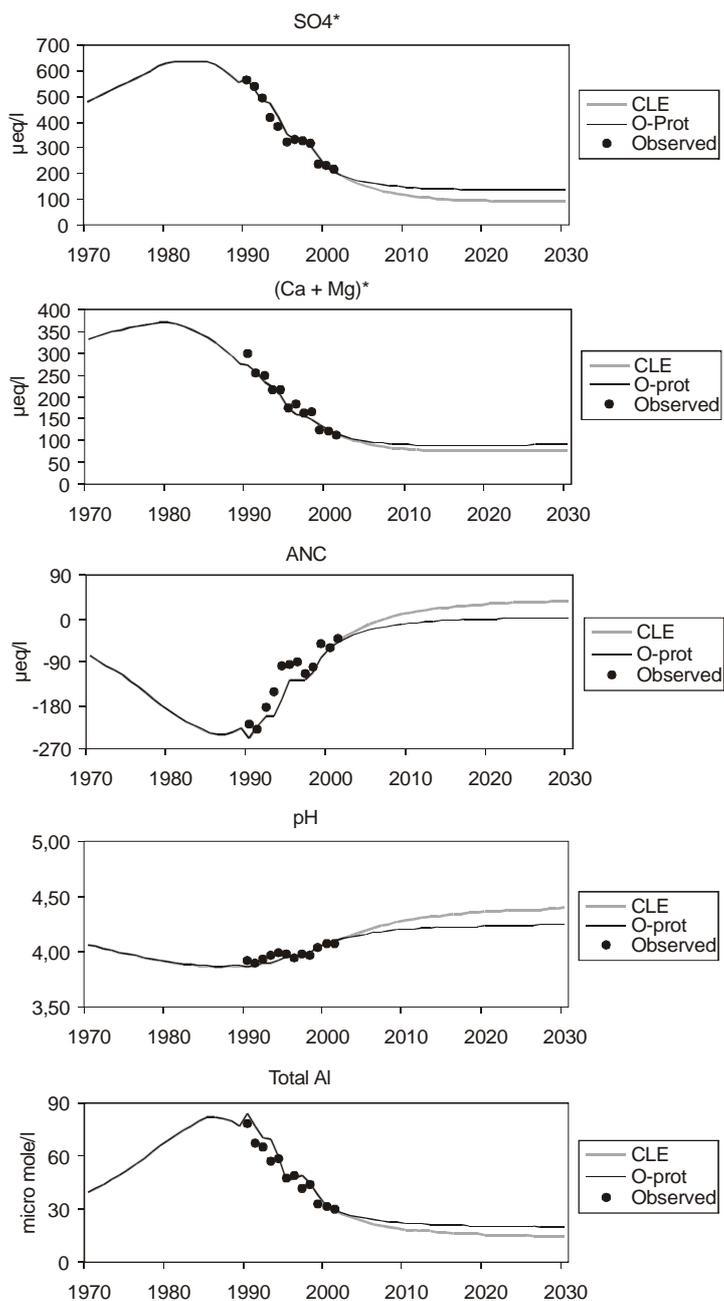


Figure I. Simulated and observed surface water chemistry and predictions under the 'current legislation' (CLE) and the Oslo Protocol (O-prot) scenarios at the Lysina catchment (Czech Republic).

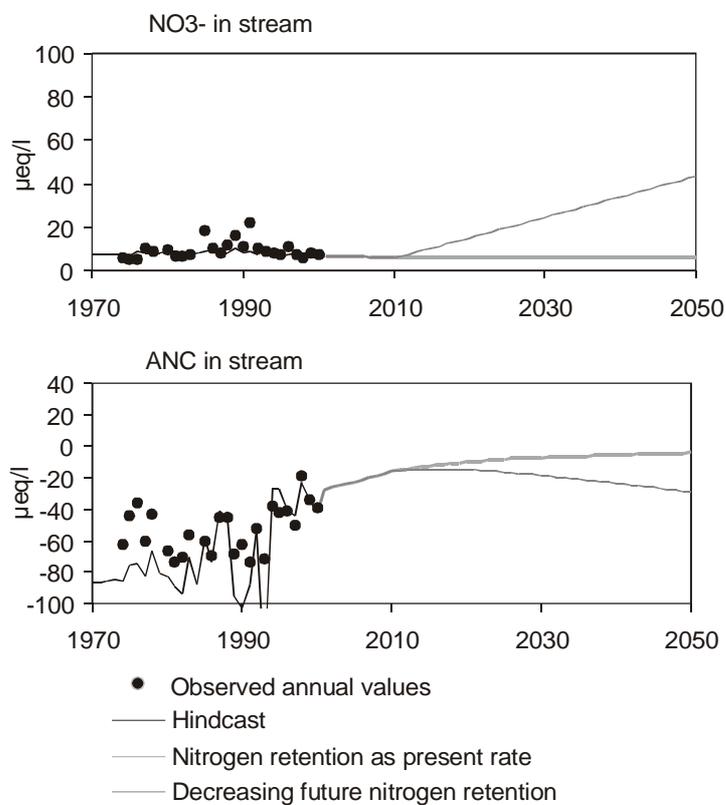


Figure II. Illustration of the impact of future changes in the catchment nitrogen retention for surface water at the Birkenes catchment (Norway), assuming nitrogen leakage increasing linearly from the present level to full leakage between 2010 and 2090.