UNITED
NATIONS

E

Economic and Social Council

Distr.
GENERAL

ECE/EB.AIR/WG.1/2007/14
20 June 2007

Original: ENGLISH

ECONOMIC COMMISSION FOR EUROPE

EXECUTIVE BODY FOR THE CONVENTION ON LONG-RANGE TRANSBOUNDARY AIR POLLUTION

Working Group on Effects

Twenty-sixth session
Geneva, 29–30 August 2007
Item 5 of the provisional agenda

REVIEW OF THE 1999 GOTHENBURG PROTOCOL

REVIEW REPORT OF THE WORKING GROUP ON EFFECTS

Report by the Extended Bureau of the Working Group on Effects

INTRODUCTION

1. The Working Group on Effects, at its twenty-fifth session, decided that it would prepare a document for the review of the 1999 Gothenburg Protocol. The Extended Bureau of the Working Group on Effects, comprising the Bureau of the Working Group, the Chairs of the Task Forces and the representatives of the programme centres of the International Cooperative Programmes (ICPs), agreed to prepare this document. It would extend the main findings presented in the 2004 substantive report on the review and assessment of air pollution effects and their recorded trends (see EB.AIR/WG.1/2004/14/Rev.1). The results are presented here in accordance with the Convention's 2007 workplan (item 3.1).

GE.07-23019

I. ICP FORESTS

2. On 220 forest plots mainly located in central Europe, mean bulk and throughfall sulphate (SO_4) inputs decreased from 6.7 to 4.9 and from 8.8 to 6.3 (range: 0.53–25.5) kg ha^{-1} $year^{-1}$ in 1999–2004, respectively. Mean nitrogen (N) throughfall deposition was 10 kg ha^{-1} $year^{-1}$ (range: 0.2–19.1) in 2001–2004 on 230 plots, comprising roughly equal contributions from nitrate (NO_3) and ammonium. N deposition has decreased only slightly. Sulphur (S) and N deposition decreases occurred mainly in central Europe, where loads were high in the past.

3. Critical loads for acidification were calculated using lowest critical threshold from the *Manual on Methodologies and Criteria for Modelling and Mapping Critical Loads and Levels and Air Pollution Effects, Risks and Trends*. The most sensitive critical limit was pH on two thirds of 186 level II plots. Critical loads for acidification were exceeded on 22.8% of the plots.

4. Critical loads for eutrophication were exceeded on 92% of 230 evaluated plots using critical N threshold of 0.02 eq m^{-3} in soil solution and mean total N deposition in the period from 1995–1999. Present N deposition would lead to unfavourable N concentrations in the foliage on 45% of the plots using a critical limit for foliage N of 18 g kg^{-1}, above which trees could become increasingly vulnerable to drought, frost, pests and diseases. Plant diversity in ground vegetation could be changed on 58% of the plots based on empirical data.

5. Studies in Europe (Augustin et al., 2005) and North America indicated that the exceedance of critical loads of acidity and N was related to harmful effects to various compartments of forest ecosystems, including:

(a) Decreasing soil pH and base saturation at 10–30 cm;
(b) Low carbon-nitrogen ratio (C/N) in the humus layer leading to unfavourable N concentrations in the foliage;
(c) High S concentrations in the foliage;
(d) Decreasing foliation and growth and increasing tree mortality.

6. Many of the modelled 158 plots showed an increase in acidification between 1900 and 1990, followed by a slight recovery. A dynamic model predicted that the original acidity status would not be reached again before 2050. Currently, high N concentration in soil solution would be reduced by 2010, but not on all plots.

7. High N leaching into groundwater has been related to elevated N throughfall deposition, especially at sites where the forest floor was N-enriched with low C/N ratios. At those sites, N deposition largely explained the N output variation.

8. Ozone (O_3) concentrations, monitored with passive samplers in remote forest areas of south-west Europe, were high in the southern-most areas and at high altitudes. Critical levels of 5,000 and 10,000 parts per billion times hours (ppb h) for accumulated O_3 concentrations over

the threshold of 40 ppb (AOT40) were exceeded at 95% and 69% of 100 sites, respectively, averaged over the period 2000–2002.

9. Crown condition in Europe has been related to S deposition for Norway spruce. For N and other tree species, the relationships were more complex and/or regional. Effects were also moderated by site conditions such as weather extremes and biotic factors. Crown condition dynamics for Scots pine was linked to modelled deposition on 1,313 level I plots, due to defoliation improvements in eastern Europe with former high S deposition.

10. N deposition clearly influenced ground vegetation species composition on 488 plots mostly in central Europe. N-indicating plants occurred more frequently on plots with high N deposition, but were also influenced by soil condition, climate and tree species. High S deposition affected species composition and few lichen species become dominant. The number of lichens species was also affected by N depositions. High S and N deposition decreased the number of epiphytic lichens as shown by data from 83 level II sites.

II. ICP WATERS AND ICP INTEGRATED MONITORING

A. Sulphur trends

11. The strongest evidence that emissions control programmes have achieved their intended effect comes from a consistent pattern of recovery across a large number of freshwater sites. It is expected that decreasing SO_4 in waters will result in increasing pH and alkalinity. The most recent evaluation of trends in ICP Waters data consists of chemical records for the period 1994–2004 for 179 sites (73 in Europe, 106 in North America) grouped in 12 fairly homogeneous regions with regard to deposition level and acid-sensitivity (De Wit and Skjelkvåle, in preparation). The most important finding was the widespread chemical recovery in streams and lakes in most regions in Europe and North America, despite the slightly reduced rate of decline in SO_4 as compared to the previously reported period of 1990–2001. All regions, except two, showed a significant increase in pH, and/or alkalinity, and/or acid neutralizing capacity (ANC). The regions without signs of chemical recovery were Ontario and the Blue Ridge mountains in North America.

12. Data from ICP Integrated Monitoring sites were also used in assessments for the period 1993–2003 (Kleemola and Forsius, 2006). They confirmed previously observed regional-scale decreasing trends of S in deposition, runoff and soil water.

B. Nitrogen trends

13. No universal rise or decline in NO_3 was detected at ICP Waters sites, and trends varied considerably within each region. Deposition of N in a subset of the sites (54) did not show a strong decline, and at most sites similar trends in N deposition and N runoff were found. The

monitoring data also indicated that biological recovery (fish, invertebrates) had begun in many regions, but lagged behind chemical recovery.

14. At ICP Integrated Monitoring sites, few statistically significant decreasing trends were found for N deposition. Both decreasing and increasing NO_3 trends in soil water and runoff were detected. Site characteristics largely determined the response. Long-range transported N was found important in determining the occurrence of acidophilic lichen species.

15. Environmental factors other than deposition – "confounding factors" – are expected to affect chemical and biological recovery of freshwaters and soils in response to reduced deposition inputs. Climate change, natural climate variability and insect attacks may both enhance or delay recovery depending on region and variable considered (see modelling section below).

16. Dissolved organic carbon (DOC) is an indicator of organic acidity, which may counteract the positive effects of declining SO_4. For the period 1990–2004, a widespread increase in DOC was observed at sites in formerly glaciated parts of North America and Europe. This increase was probably related to S and N deposition changes and climatic factors.

C. Budget calculations and carbon-nitrogen interactions

17. Long-term mass balances and changes in ion ratios at ICP Integrated Monitoring sites confirmed the responses to emission reductions (Forsius et al., 2005). There was a clear relationship between the net acidifying effect of N transfer processes (e.g. nitrification) and the N deposition. When N deposition increased, different N processes became important for acidification. Soils were found to release previously accumulated S at many sites, confirming similar results in Europe.

18. Typically, 90% of incoming N deposition was retained by the soil. Moderate to high level of N deposition would elevate NO_3 concentration in runoff. A critical deposition threshold for NO_3 leaching of 8–10 kg N ha^{-1} $year^{-1}$ was confirmed by the input-output calculations with ICP Integrated Monitoring data and other European data (MacDonald et al., 2002). The soil organic horizon C/N was a reasonable predictor on the annual N export flux at European forested sites, which received throughfall N deposition 30 kg N ha^{-1} $year^{-1}$. Significant relationships were observed between N input and NO_3 leaching at C/N=25 (MacDonald et al., 2002). N is usually the limiting nutrient in forest ecosystems. C sequestration and global C cycle are closely linked to N cycle and changes in N deposition. N cycle is essential in determining the long-term C source or sink in soils (Gundersen et al., 2006).

D. Dynamic acidification modelling

19. Dynamic models help to explore the temporal aspect of ecosystem protection and recovery. The critical load concept, used for defining the environmental protection levels with a

long-term perspective, does not reveal time scales of impacts and recovery. Dynamic models were used for scenario assessment at selected ICP Integrated Monitoring sites. They were applied on surface water data compiled by ICP Waters and national programmes. Modelling studies showed that the recovery from acidification of soil and water quality of the ecosystems was determined by both the amount and the time of implementation of emission reductions. The timing of emission reductions determined the state of recovery over a short time scale, up to 30 years. N emission controls contributed to the maximum recovery in response to S emission reductions. Increased N leaching could offset recovery, deteriorate pH status in freshwaters, and lead to other problems.

20. ICP Integrated Monitoring and ICP Waters studied the relative sensitivity of different climate change-related processes on acidification recovery with models (Wright et al., 2006). Several factors were of minor importance (e.g. increase in partial carbon dioxide pressure in soil, air and runoff), several were important at only few sites (e.g. sea salts) and several were important at nearly all sites (e.g. increased DOC in soil solution and runoff). Changes in forest growth and decomposition of soil organic matter were important at sites with forests or at risk of N saturation. Climate-induced changes, in particular in organic acids and N retention, should be taken into account when modelling recovery from acidification.

III. ICP MATERIALS

A. Corrosion and air pollution trends

21. Dose-response functions for corrosion have been developed for carbon steel, zinc, copper, bronze and limestone due to pH, sulphur dioxide (SO_2), O_3, nitric acid (HNO_3), particulate matter (PM) deposition and climatic parameters (temperature, relative humidity, precipitation). SO_2 and pH are important for all materials. O_3 is included only for copper and HNO_3 for zinc and limestone.

22. Decreasing corrosion trends, 50% on the average, were observed in 1987–1997 (figure 1). Corrosion trends were material dependent. In 1997–2003, a decreasing trend was evident for carbon steel, while no decrease, or even a slight increase, was observed for zinc and limestone. The most recent results in 2005–2006 indicated that the decrease for carbon steel had also ceased.

23. The sites were a mixture of urban and rural areas across Europe. In 1987–2003, annual mean SO_2 concentration had decreased by 90%, nitrogen dioxide 40% and O_3 had remained relatively constant.

Figure 1. Average trends in corrosion, as surface recession for limestone and mass loss for carbon steel and zinc, based on data from 21 urban and rural test sites. Results are normalized relative to the 1987 values.

B. Corrosion and soiling effects of particulate matter

24. PM is important for corrosion. Particles are hygroscopic and prolong wetness time of surfaces. Ionic particles also stimulate corrosion. Coarse PM (PM_{10}) is included in dose-response functions for carbon steel, bronze and limestone.

25. Soiling has been monitored with passive samplers in Athens, Rome, London, Prague and Krakow under the European Union (EU) project, Multi-Assess. Dose-response functions were derived for limestone, painted steel and white plastic (figure 2).

26. Tolerable soiling dose for PM_{10} were established based on public attitudes to soiling and a perception on acceptable degradation. A 35% loss in reflectance was found to trigger significant adverse public reaction. Tolerable soiling of 181, 200 and 223 $\mu g\ m^{-3}\ year^{-1}$ was derived for limestone, painted steel and white plastic, respectively (figure 2). For example, 200 $\mu g\ m^{-3}\ year^{-1}$ indicates that PM_{10} of 20 $\mu g\ m^{-3}\ year^{-1}$ is allowed if the material was cleaned every tenth year. An appropriate interval for cultural heritage objects is 10–15 years, resulting in tolerable PM_{10} of 12–22 $\mu g\ m^{-3}\ year^{-1}$.

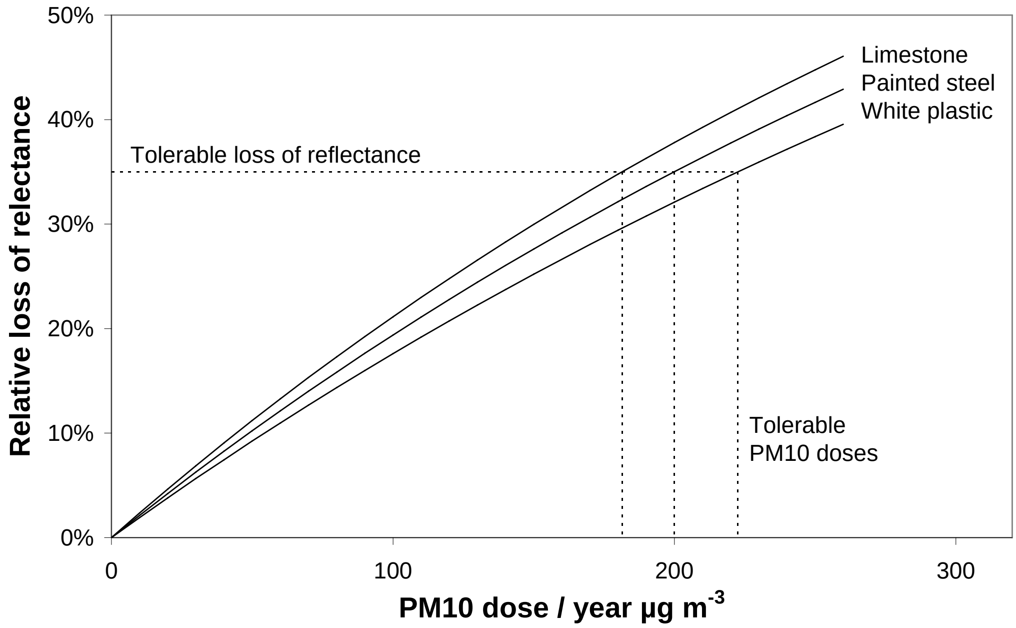


Figure 2. Dose-response functions of soiling for limestone, painted steel and white plastic. Tolerable loss of reflectance and related PM_{10} dose are indicated in the figure.

IV. ICP VEGETATION

A. Ozone

27. Literature reviews and monitoring conducted by ICP Vegetation have indicated that over 200 species of crops and (semi-)natural vegetation were responding to O_3 at current or recent concentrations in the UNECE region. Responses included the development of visible injury, such as small yellow or bronze spots on the leaf surface, and reductions in growth, seed production, and/or ability to over-winter (for perennial species). O_3 injury had been detected every year in the period 1990–2006 in 17 countries across the width and length of Europe. Trends in impacts reflected the spatial and temporal variation in concentrations, with no marked decline or increase evident. For example, O_3 injury was greatest in 2003, when concentrations were relatively high across most of Europe, and lowest in the cooler, wetter year of 2002, when concentrations were relatively low.

28. ICP Vegetation contributed to the update of the *Modelling and mapping manual.* A flux-based method was included for crops and trees, which relates O_3 effects to "uptake" by the plant. It provides a biologically realistic approach for estimating risk of damage, and combines the influence of climatic factors (temperature, humidity, light), soil factors (soil moisture content) and plant factors (growth stage) on the "uptake" of O_3 through the pores on the leaf surface. It then relates accumulated "uptake" (or flux) to effects such as yield and biomass reduction. In contrast, the concentration-based approach, used in the development of the Gothenburg Protocol, only related effects to the O_3 concentration in the air above the canopy, without consideration of the uptake-modifying factors included in the flux method.

29. A full flux-effect model has been developed for two crops (wheat and potato) and provisionally for two forest trees (beech and birch). Flux parameterizations were defined for a generic (simplified) crop and two generic tree species in Europe for use in integrated modelling and mapping risk of damage. Flux-based methods are currently being developed for communities of (semi-)natural vegetation. In the meantime, a new concentration-based critical level has been derived for application to communities dominated by perennials. The concentration-based critical level in the *Modelling and mapping manual* remains unchanged for agricultural crops and (semi-)natural vegetation communities dominated by annuals. A new one has been added for horticultural crops and that for forest trees has been halved.

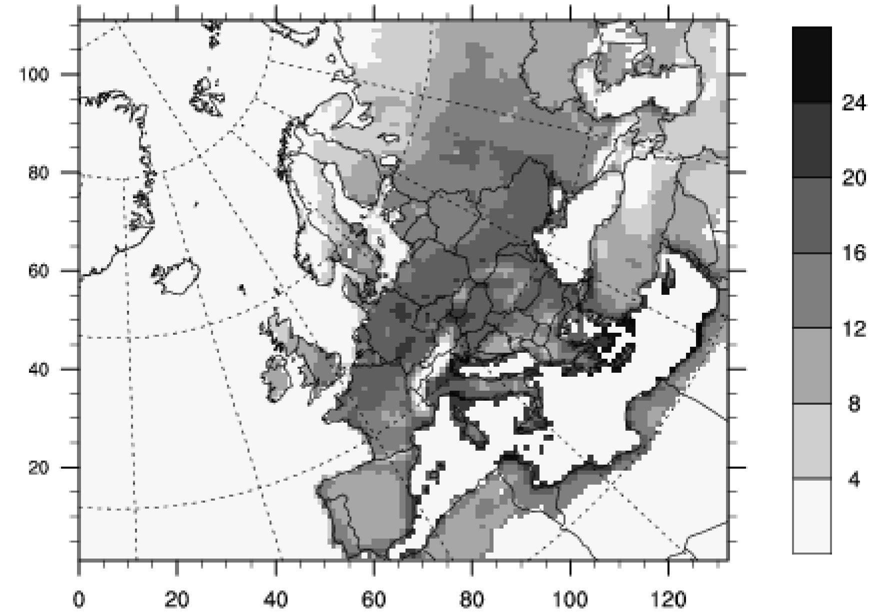
30. As a first step towards a flux-based risk assessment, the full flux model for wheat and forest trees (represented by beech and birch) was used to map areas of risk of damage resulting from exceedance of the O_3 critical level. For both receptors, exceedance was greatest in central and southern Europe. The gradient between northern and southern Europe was much lower for the O_3 flux than for the concentration-based indices (Simpson et al., 2007). Maps produced using the simplified (generic) flux models for crops and deciduous trees indicated broadly similar patterns of risk to those produced using the full flux models (figure 3). Application of the generic flux model for Mediterranean evergreen trees in southern Europe indicated a significant reduction in risk of damage compared to that indicated by application of the generic deciduous tree model or full flux model, which was due in part to better representation of summer drought-induced reductions in O_3 “uptake” in trees in these areas.

31. Dose-response functions, based on growth or yield reductions, have been determined for over 20 crops and almost 90 species of (semi-)natural vegetation. Crops such as wheat, soybean and tomato are particularly sensitive to O_3. Grasslands, heathlands, scrub and tundra, as well as mires, bogs and fens have the highest proportions of O_3-sensitive plant communities. The O_3 -induced crop yield losses for 47 European countries were estimated with the concentration-based approach to be 6.7 ± 2.5 billion Euros for the year 2000 (Holland et al., 2006), or 2% of the agricultural production, and to fall to 1.7–4.5 billion Euros in 2020, depending on the emission scenario. A flux-based economic loss estimate is not feasible yet, as dose-response functions are only available for two crops.

B. Nutrient nitrogen

32. Since the Gothenburg Protocol, ICP Vegetation has applied a method of indicating the spatial distribution of enhanced N deposition to natural vegetation in the ECE region. The total N concentration in naturally occurring mosses correlated well with atmospheric N deposition in selected countries (Harmens et al., 2005). Highest N concentrations were found in central Europe (Germany) and lowest concentrations in Scandinavia (Finland, Norway and Sweden).

(a)



(b)

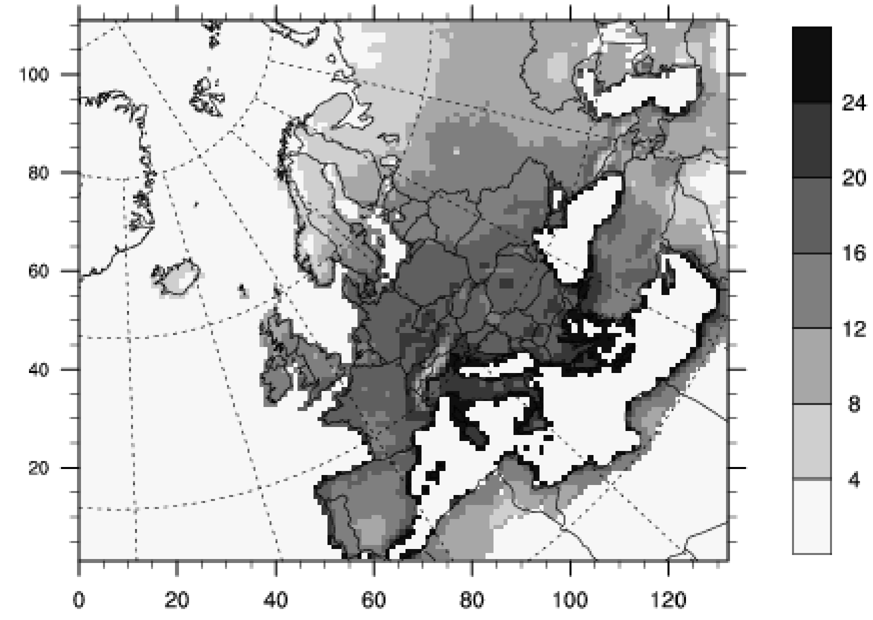


Figure 3. Modelled O_3 fluxes to (a) generic crops and (b) generic deciduous forests in 2004. The thresholds were accumulated stomatal flux of 3 and 1.6 mmol m^{-2}, respectively. Calculations were made for all grid squares with vegetation, but not taking into account the actual distribution of relevant species.

V. ICP Modelling and Mapping

33. The European critical loads database, held at the Coordination Centre for Effects (CCE), consists of data submitted by 26 Parties. The latest, 2006, update includes submissions from 18 Parties.

34. Using these data and modelled deposition by EMEP[1], the total area at risk of acidification, i.e. where critical loads for acidification are exceeded, would decrease from about 12% in 2000 to about 8% in 2010 assuming the current legislation scenario. The total area at risk of eutrophication by nutrient N would remain unchanged at about 46 % in the EMEP modelling domain.

35. Data for dynamic acidification modelling are available from 14 Parties. Preliminary results in the CCE 2005 status report indicated that 29% of the area at risk in 2010 could recover in the future, i.e. about 20% before 2030, and 7% would recover only after 2100. The CCE database also includes target loads that describe recovery of 95% of the area which is not safe from acidification in 2010 if acid deposition is sufficiently reduced in the implementation year 2020.

36. Dynamic modelling of eutrophication is data-intensive and needs further testing at regional scale before Europe-wide applications. The information in the report “Developments in deriving critical limits and modelling critical loads of N for terrestrial ecosystems in Europe” can be used for applications of a range of critical thresholds in calculated critical loads and for exploring dynamic eutrophication modelling applications

37. The harmonized pan-European land cover database has recently become available for use in work under the Convention. The same map is being used to calculate critical loads and levels for terrestrial and aquatic ecosystems, and to calculate ecosystem-specific S and N deposition as well as O_3 fluxes to vegetation. A Party can request data for its territory from CCE.

38. CCE, in cooperation with the Centre for Integrated Assessment Modelling (CIAM), has developed linearized impact coefficients relating emissions to critical load exceedance for easier use of critical loads in the optimization module of integrated assessment models.

39. ICP Modelling and Mapping concluded that closing the gap between deposition and critical loads should remain anchored in sustainable endpoints for human health and the environment. They should – in line with the original approach chosen for the Gothenburg Protocol – focus on the regional distribution of the sensitivity of ecosystems rather than on the geographical deposition distribution. Closing the gap to deposition levels derived from emission

[1] Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants.

scenarios, instead of critical loads, could be useful as an interim goal. Structural changes and control technique improvements should be considered in abatement strategies.

40. N is one of the key drivers in biodiversity loss in Europe. The exceedance of critical loads of nutrient N indicated risk to biodiversity.

VI. TASK FORCE ON HEALTH

41. The Task Force on Health has no practical possibility to monitor health effects of air pollution in populations, in contrast to the monitoring of many ICPs. The Task Force evaluates health effects based on the risk assessment paradigm. The exposure-response functions (or their approximations ambient concentration-response function) are combined with exposure information to calculate the proportion of the illness to health that could be attributed to the exposure. The number of cases attributed to the exposure can be estimated with data on the frequency of disease in a given population. The work focuses on identification of relevant concentration-exposure functions based on accumulated world-wide scientific research. Air quality information is gathered in collaboration with EMEP and other groups to assure best data are available. The analyses also include the assessment of the contribution of the pollution from long-range transport of air pollutants to population exposure, which is the ultimate determinant of the health effects.

A. Ozone

42. Recent studies have revealed associations between daily mortality and O_3 levels below the previously identified World Health Organization (WHO) guideline of 120 µg m^{-3} (or AOT60), but without clear evidence of an effects threshold. Chamber and field studies indicate considerable individual variation in response to O_3, which led to a new WHO guideline level of 100 µg m^{-3} (daily maximum 8-hour mean). Health effects could occur below this guideline level in some sensitive individuals. Based on time-series studies, the increase in the number of attributable deaths was estimated 1–2% on days with 100 µg m^{-3} compared to 70 µg m^{-3} (8-hour mean). The Task Force on Health proposed a new exposure indicator SOMO35 (sum of means over 35 ppb), which is proportional to the magnitude of health effects. It is relatively easy to estimate with available atmospheric models and simple to calculate from monitoring data.

43. O_3 levels above 70 µg/m^3 would amount to 21,000 premature deaths in 25 EU Member States (EU25) and a large number of hospital admissions, days with disability and other indicators of acute morbidity. The effects were based on a risk coefficient estimated by WHO meta-analysis of time series studies and SOMO35 calculated by the EMEP Eulerian model. The analysis carried out in the RAINS model did not indicate a significant reduction of these impacts in the next decade by the implementation of the current policies.

B. Particulate matter

44. Airborne PM causes adverse health effects at current exposure levels for urban populations in both developed and developing countries. The effects are predominantly related to respiratory and cardiovascular systems. Susceptibility to the pollution may vary with health or age. The health relevance of various components of PM, especially long-range transported secondary PM, is being researched. PM from major mobile and stationary combustion sources is associated with serious health effects, including increased illness (morbidity) and death (mortality) from cardiovascular and respiratory diseases. Although secondary inorganic aerosols have less toxic activity in laboratory conditions, epidemiological studies have shown the impacts of SO_4 and NO_3 on various health outcomes. Particles of different size, source and composition are considered equally hazardous to health.

45. The updated WHO *Air Quality Guidelines* recommend using mass concentrations for fine PM ($PM_{2.5}$) and PM_{10} as health risk indicators. Interim targets were also proposed for PM and O_3, encouraging stepwise reductions in severely polluted areas. Though the *Air Quality Guidelines* do not have a direct impact on the Convention, the health-based exposure targets provide an important objective for the policies.

46. The risk increases with exposure and only a little evidence suggests any threshold below which no adverse health effects would occur. The low end of effects is near background concentrations of 3–5 $\mu g\ m^{-3}$ for $PM_{2.5}$. The *Air Quality Guidelines* recommend annual averages of 10 and 20 $\mu g\ m^{-3}$ for $PM_{2.5}$ and PM_{10}, respectively.

47. The impacts of the pollution have been estimated to reduce life expectancy by 8.6 months on average in the EU25. Annually, 348,000 premature deaths are attributed to PM, which also increases the risk of less severe health effects such as exacerbation of respiratory or cardiovascular symptoms. If current policies to reduce primary and secondary PM were successfully implemented in the next decade, these impacts would decrease by only one third.

VII. JOINT EXPERT GROUP ON DYNAMIC MODELLING

48. Dynamic models have been developed, tested and applied both within the framework of the Convention and as part of ongoing national and international research programmes. They relate changes in pollutant load or critical load exceedance to observed harmful chemical and biological change. Chemical and biological time delays in both damage and recovery are estimated under different emissions and land use scenarios.

49. The ecosystem area for which dynamic modelling has been carried out by CCE covers about 670,000 km^2, comprising predominantly forest soils in areas where critical loads of acidity are still exceeded. This European dynamic modelling framework, developed within the Convention, is a major step forward and is available for review and possible revision of the Gothenburg Protocol.

A. <u>Acidification</u>

50. Dynamic models represent the key processes operating to link S and N depositions to surface water chemistry and their outputs have been found to match closely the observed trends in water chemistry. They have also been demonstrated to be consistent with critical loads (Wright et al., 2005).

51. Soils and surface waters would continue to recover after 2010 assuming the emission targets of the Gothenburg Protocol in areas where deposition is below critical loads. There will be major time delays (many decades) in chemical recovery at acidified sites with low weathering systems or where deposition is only marginally below critical loads.

52. Model outputs of the EU project Recover indicated that acidification would continue to be a significant problem after 2016 in 12 acid-sensitive surface water regions in Europe even after full implementation of current legislation, including the Gothenburg Protocol. More than 5% of the ecosystems in each region would not meet the ANC limit value for protecting sensitive aquatic organisms (Jenkins et al., 2003). S deposition reductions would be sufficient to stop the decrease in soil base saturation but insufficient for recovery (Wright et al., 2005). The Sufor (Sustainable Forestry in Southern Sweden) programme indicated that following full implementation of the Gothenburg Protocol, 60% of forest soils in Sweden would recover within the next 100 years and 40% would remain acidified for the foreseeable future (Sverdrup and Stjernquist 2002).

53. Recovery in biological receptors will be further delayed (up to 10 years) after chemical recovery, but some systems may never return to their original status. Results from a Norwegian lake demonstrated that when the appropriate chemical threshold (ANC=25) was reached, the salmon population recovered in seven to ten years (Raddum et al., 2004).

B. <u>Nutrient nitrogen</u>

54. Dynamic models describing carbon and N cycles and air pollution impacts for terrestrial and aquatic systems were available for scenario assessment. They were capable of linking atmospheric deposition, land management and climate change with impacts on terrestrial biodiversity, but required further development and testing. Models have been developed and tested to assess changes in biodiversity. Clear definitions of “biodiversity damage”, unwanted changes in biodiversity, were lacking

55. Many terrestrial ecosystems were currently N-enriched, with observed impacts on biodiversity. Model outputs indicated that ecosystems would continue to accumulate N after 2010 assuming emissions compliant with the Gothenburg Protocol, leading to further changes in biodiversity. Changes in terrestrial ecosystems have been observed even in low deposition areas (<10 kg N ha^{-1} $year^{-1}$). Chemical and biological recovery would take many decades assuming emissions from the Gothenburg Protocol. Ecosystems might already be irreversibly changed.

VIII. OVERALL CONCLUSIONS

56. As shown by monitoring data from ICPs, the Gothenburg Protocol has led to a significant decrease in S deposition and consequent impacts on ecosystems. Aquatic and forest ecosystems have become less acidified and building materials corrode less. Both observations and modelling have concluded biological recovery lags behind chemical recovery. Healthy ecosystems may not be reached for decades, even with a full implementation of the Gothenburg Protocol.

57. N deposition has remained unchanged, slowing down recovery from acidification and causing widespread eutrophication in Europe. N continues to accumulate in ecosystems and might surpass S as the main acidifying compound. N emissions also contribute to increased PM and O_3 concentrations.

58. O_3 impacts prevail in Europe. Improved methods, models and data have become available for O_3 assessment.

59. Climate change is known to affect many processes related to air pollution effects. Its overall influence on recovery is currently complex and difficult to evaluate.

60. The Gothenburg Protocol has been effective. Threats related to acidification, eutrophication, O_3, and PM have been reduced throughout the UNECE region to a varying degrees. Nevertheless, some problems will remain:

(a) Acidification. Some ecosystems are very sensitive to acidification. Steady-state and dynamic models predict that the Gothenburg Protocol measures will not be sufficient to fully protect them.

(b) Eutrophication. Exceedances of critical loads are significant and widely occurring in Europe. The Gothenburg Protocol has been insufficient to significantly reduce the risks from N, including forest nutrition imbalances and degradation of biodiversity.

(c) Ozone and particulate matter. Precursors of O_3 and PM would most likely not be reduced enough to prevent damage to vegetation, corrosion and soiling of materials as well as significant numbers of morbidity and mortality cases in the population of Europe.

61. An ongoing commitment to long-term monitoring is required to assess effects of air pollution abatement. Uncertainties could be reduced in several areas, inter alia:

(a) Biological recovery from acidification;
(b) N cycle;
(c) Additional health effects of O_3 and PM, in particular its components;
(d) Combined effects of multiple pollutants;
(e) Appropriate metrics for biodiversity;
(f) Interaction between air pollutants and climate change.

62. Closing the gap of critical load and level exceedance in integrated assessment models should remain anchored in sustainable health and environmental endpoints. It should focus on the geographical distribution of ecosystem sensitivity.

LITERATURE

Augustin S, Bolte A, Holzhausen M, Wolff B (2005) Exceedance of critical loads of nitrogen and sulphur and ist relation to forest conditions. *Eur J Forest Research* (124) 4 pp. 289-300.

De Wit H, Skjelkvåle BL (in preparation) Trends in surface water chemistry and biota: the importance of confounding factors. ICP Waters Report, Norwegian Institute for Water Research, Oslo, Norway.

Fischer R, Dobbertin M, Granke O, Karoles K, Köhl M, Kraft P, Meyer P, Mues V, Lorenz M, Nagel H-D, Seidling W (2006) The condition of forests in Europe; 2006 Executive report. Hamburg, Germany. ISSN 1020-587X http://www.icp-forests.org

Forsius M, Kleemola S, Starr M (2005) Proton budgets for a monitoring network of European forested catchments: impacts of nitrogen and sulphur deposition. *Ecological Indicators* 5: 73-83.

Gundersen P, Berg B, Currie WS, Dise NB, Emmett BA, Gauci V, Holmberg M, Kjønaas OJ, Mol-Dijkstra J, van der Salm C, Schmidt IK, Tietema A, Wessel WW, Vestgardem LS, Akselsson C, Van der Vries W, Forsius M, Kros H, Matzner E, Moldan F, Nadelhoffer KJ, Nilsson L-O, Reinds GJ, Rosengren U, Stuanes AO, Wright RF (2006) Carbon-nitrogen interactions in forest ecosystems: final report. Hørsholm, Danish Centre for Forest, Landscape and Planning. 61 pp. ISBN 87-7903-287-7978-7903-287-3 http://en.sl.life.ku.dk/

Harmens H, Mills G, Hayes F, Williams P, De Temmerman L. and the participants of ICP Vegetation (2005) Air pollution and vegetation; ICP Vegetation annual report 2004/2005. ISBN 1 870393 80 5. http://icpvegetation.ceh.ac.uk

Hettelingh J-P, Posch M, Slootweg J, Reinds GJ, Spranger T, Tarrason L (2007) Critical loads and dynamic modelling to assess European areas at risk of acidification and eutrophication. *Water, Air and Soil Pollution: Focus* 7:379-384.

Holland M, Kinghorn S, Emberson L, Cinderby S, Ashmore M, Mills G, Harmens H (2006) Development of a framework for probabilistic assessment of the economic losses caused by ozone damage to crops in Europe. Defra contract EPG 1/3/205. http://icpvegetation.ceh.ac.uk

Jenkins A, Camerero L, Cosby BJ, Ferrier RC, Forsius M, Helliwell RC, Kopacek J, Majer V, Moldan F, Posch M, Rogora M, Schopp W, Wright RF (2003) A modelling assessment of acidification and recovery of European surface waters. *Hydrology and Earth System Sciences* 7, 447-456.

Kleemola S, Forsius M (2006) Trend assessment of bulk deposition, throughfall and runoff water chemistry at ICP IM sites. In: Kleemola S, Forsius M (editors) 15th Annual report 2006; ICP Integrated Monitoring. The Finnish Environment 30/2006: 22-48. ISBN 952-11-2256-0, 952-11-2325-7 (pdf).

Lorenz M, Fischer R, Becher G, Mues V, Seidling W, Kraft P, Nagel H-D (2006) Forest condition in Europe; 2006 Technical report of ICP Forests. Arbeitsbericht des Instituts für Weltforstwirtschaft 2006/1.

MacDonald JA, Dise NB, Matzner E, Armbruster M, Gundersen P, Forsius M (2002) Nitrogen input together with ecosystem nitrogen enrichment predict nitrate leaching from European forests. *Global Change Biology* 8: 1028-1033.

Seppälä J, Posch M, Johansson M, Hettelingh J-P (2006) Country-dependent characterisation factors for acidification and terrestrial eutrophication based on accumulated exceedance as an impact category indicator. *Int J LCA* 6:403-416.

Simpson D, Ashmore MR, Emberson L, Tuovinen J-P (2007) A comparison of two different approaches for mapping potential ozone damage to vegetation. A model study. *Environmental Pollution* 146, 715-725.

Slootweg J, Hettelingh J-P, Posch M, Schütze G, Spranger T, De vries W, Reinds GJ, Van 't Zelfde M, Dutchak S, Ilyin I (2007) European critical loads of cadmium, lead and mercury and their exceedances. *Water, Air and Soil Pollution: Focus* 7:371-377.

Sverdrup H, Stjernquist I (editors) (2002) Developing principles and models for sustainable forestry in Sweden. Kluwer Academic Publishers, Dordrecht, 441 pp.

Wright RF, Larssen, Camarero L, Cosby BJ, Ferrier RC, Helliwell R, Forsius M, Jenkins A, Kopáček J, Majer V, Moldan F, Posch M, Rogora M, Schöpp W (2005) Recovery of acidified European surface waters. *Environ. Sci. Technol.* Feb. 1, 2005, 64-.

Wright RF, Aherne J, Bishop K, Camarero L, Cosby BJ, Erlandsson M, Evans CD, Forsius M, Hardekopf D, Helliwell R, Hruska J, Jenkins A, Moldan F, Posch M, Rogora M (2006) Modelling the effect of climate change on recovery of acidified freshwaters: relative sensitivity of individual processes in the MAGIC model. *Science of the Total Environment* 365: 154-166.

Note: The references have been reproduced as received by the secretariat.
