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TRANSBOUNDARY AIR POLLUTION

Working Group on Effects

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REVIEW OF AIR POLLUTION EFFECTS

CONSOLIDATED REPORT ON AIR POLLUTION EFFECTS

Report by the Bureau of the Working Group on Effects[1,2]

INTRODUCTION

1. The Extended Bureau of the Working Group on Effects, at its meeting in February 2005, agreed to prepare a workplan for 2006 streamlined within the Working Group and with other main subsidiary bodies of the Convention. At its twenty-fourth session, the Working Group proposed, inter alia, two activities common to all International Cooperative Programmes (ICPs) and the Joint Task Force on the Health Aspects of Air Pollution (Task Force on Health) and the

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[1] This report was prepared in collaboration with the Extended Bureau of the Working Group on Effects with the assistance of a consultant and the secretariat.

[2] The present document was submitted late due to resource constraints.

Joint Expert Group on Dynamic Modelling, originally for the 2006 workplan (EB.AIR/WG.1/2005/4/Rev.1, item 3.1 (c)):

(a) Summary report of current information on dose-response functions and stock at risk;
(b) Review report of links between field observations and critical loads.

2. These common themes were based on the mandate and the long-term strategy of the Working Group, and are meant to contain the knowledge accumulated from the monitoring, modelling and other research in a harmonized form. The Extended Bureau agreed to prepare a detailed report, considering the importance of the results, for the Working Group's twenty-seventh session. The Bureau coordinated the finalization of the consolidated report and its executive summary, presented below, in close collaboration with the ICPs and the Task Force on Health and with the assistance of Mr. H.-D. Gregor and the secretariat. The results are presented as an executive summary, in accordance with the Convention's 2007 workplan (ECE/EB.AIR/WG.1/2006/4/Rev.1, item 3.1 (c)) approved by the Executive Body at its twenty-fourth session and with the 2008 workplan (ECE/EB.AIR/91/Add.2, item 3.1 (b)) approved by the Executive Body at its twenty-fifth session. The Working Group is invited to discuss the report and submit it to the twenty-sixth session of the Executive Body for its consideration.

I. BACKGROUND

3. Starting in the 1960s, growing concerns about the harmful effects of air pollutants prompted international collaboration to combat air pollutants at their sources. The Convention on Long-range Transboundary Air Pollution was adopted in 1979 and entered into force in 1983. The need for sound scientific underpinning for future decisions on controlling air pollution was recognized in the beginning. The Working Group on Effects was established in 1981 to address the effects of sulphur compounds and other major air pollutants on human health and the environment. Initially, it was to take into account the effects on health and visibility, materials, aquatic ecosystems, soil, groundwater and vegetation due to sulphur compounds and other major air pollutants. The mandate was further defined (a) to provide the scientific basis for the review of the effects, including recovery of the environment and human health following emission reductions in line with protocols;, and (b) to carry out damage and benefit evaluations. The Working Group would also alert the Convention's Executive Body to any perceived additional, or changed, threats caused by air pollution that might require policy response.

4. International Cooperative Programmes (ICPs) were established under the Working Group on Effects to carry out detailed studies and to begin long-term monitoring of affected ecosystems and materials. Today, there are six ICPs, each headed by a lead country, organized by a task force and served by an international programme centre, the Task Force on the Health Aspects of Air Pollution, , established jointly by the World Health Organization (WHO) and the Executive Body for the Convention, and a Joint Expert Group on Dynamic Modelling. Most programmes carry out monitoring (ICP Waters, ICP Forests, ICP Integrated Monitoring, ICP Vegetation and

ICP Materials), while others have no observational activity (ICP Modelling and Mapping, the Task Force on Health and the Joint Expert Group on Dynamic Modelling). The receptors and even sites are partly shared (e.g. surface waters between ICP Waters and ICP Integrated Monitoring, forest soils between ICP Forests and ICP Integrated Monitoring) or between programmes cooperating on a topic (ozone impacts on forest trees between ICP Forests and ICP Vegetation). ICP Modelling and Mapping relies on the observations provided by other programmes. Many use monitored and modelled meteorological and pollutant data from the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP).

5. The research addresses many interlinking air pollutants and the resulting environmental problems. The observational networks and results from research, modelling and mapping extend to the geographical area of UNECE and the recorded monitoring trends span over 20 years. The effects-oriented work has initiated and supported the development of several air pollutant emission reduction protocols under the Convention, some based on effects-based model calculations. The cooperation has created a unique nexus of observational networks and interdisciplinary policy-linked research.

II. CAUSE-EFFECT RELATIONSHIPS

A. Acidification

6. The monitoring of ICP Waters showed that acidifying deposition (sulphur (S) and nitrogen (N) deposition) was negatively correlated with water pH and acid neutralizing capacity (ANC) with clear trends in large regions. In Europe, S deposition correlated positively with aquatic sulphate concentrations, and high total N deposition (>15 kgN ha^{-1} a^{-1}) correlated positively with nitrate (NO_3) concentrations. These and other monitored water chemistry parameters correlated with biological responses. Data from Norway linked ANC with fish extinction. Similar relationships have been derived for invertebrates in running waters and diatoms in lakes.

7. The ICP Forests data from extensive monitoring sites (level I) in Germany showed that a low soil base saturation (BS<15%) has led to domination of acid cations in soil solution. The S content in needles was negatively correlated with BS, resulting in tree crown defoliation. In central Europe, N was the dominant source of potential soil acidification. At many intensive monitoring sites (level II) in central Europe, NO_3 concentration exceeded groundwater quality criteria for health. There were many indications of low aluminium-base cation ratio in soil solution (Al/BC<1.0), which is linked to risk of root damage. At level I and II sites, the depositions of S and N were positively correlated with the defoliation of several tree species. N deposition also enhanced the stem growth.

8. The acidity budgets at ICP Integrated Monitoring sites showed a clear relationship between N deposition and the net acidifying effect of N processes. Budgets for S indicated that

soils were releasing previously accumulated S. Background N deposition was negatively correlated with the number of acid-sensitive epiphytic lichens.

9. The main risk for effects was defined by ICP Modelling and Mapping as the total deposition exceeding critical loads. Its national focal centres (NFCs) used various effects parameters to calculate critical loads. For forest soils, they included BC/Al of 0.5–1.7 leading to root damage (1.0 was used as default for coniferous forests), Al concentration in soil solution, and pH, for which exact threshold values depended on ecosystem characteristics. For surface waters, the thresholds included ANC of 0–20 meq m^{-3}. For dynamic modelling, the critical thresholds could be chosen, inter alia, as for critical loads.

B. Eutrophication

10. Data from ICP Forests showed that at level II sites in Europe, the N throughfall deposition was positively correlated with high N leaching when the soil carbon-nitrogen ratio (C/N) was smaller than 25. At level II sites, N deposition was positively correlated with N content in foliage, nutrient imbalances in soil and foliage, and species composition. S and N deposition were negatively correlated with the number of epiphytic lichens.

11. Data from ICP Integrated Monitoring showed that observed total N deposition of 8–10 kgN ha^{-1} a^{-1} was positively correlated with increased NO_3 leaching. Other predictors included N concentration in organic matter and current year needles, N flux in litterfall and soil organic horizon C/N ratio. N deposition was found to influence the composition of the lichen flora.

12. Surveys of ICP Vegetation correlated the total modelled N deposition with the total N concentration in mosses, which is applicable as a bioindicator for N deposition. Lichens and mosses, and their species composition, were identified to be very sensitive to ammonia.

13. The main risk of total N deposition exceeding the critical load was calculated by NFCs of ICP Modelling and Mapping. For terrestrial ecosystems, they included 0.2–6.5 mgN l^{-1} in soil solution leading to various detrimental effects. In particular, N enrichment might lead to unwanted changes in biodiversity. For dynamic modelling, the critical thresholds could be chosen with similar thresholds.

C. Ozone

14. The defoliation was correlated with high long-term mean ozone (O_3) concentration for common beech at ICP Forests level II sites in Italy.

15. ICP Vegetation compiled several dose-response functions in the *Manual on Methodologies and Criteria for Modelling and Mapping Critical Loads and Levels and Air Pollution Effects, Risks and Trends* for the concentration-based evaluation. Three groups of AOT40 (accumulated concentration above a threshold of 40 parts per billion (ppb)) correlations

were identified for crops on the basis of concentration-based dose-response functions for yield reductions: (a) sensitive (including wheat); (b) moderately sensitive (including potato); and (c) resistant (including barley). For (semi-)natural vegetation there was a new AOT40 for perennials. For the flux-based approach, dose-response functions were defined for crops (wheat, potato) and trees (beech, birch (provisional)), and flux-based risk assessment methods were developed for a generic crop and two types of generic trees, including a Mediterranean evergreen.

D. Heavy metals

16. ICP Waters noted that heavy metal concentration in some lakes were above national critical limits for biological impacts.

17. ICP Integrated Monitoring sites showed evidence of decreasing lead (Pb) concentrations in organic layers of soils and of decreasing cadmium (Cd). Mercury (Hg) showed no sign of decrease, even in the humus layer.

18. The moss survey of ICP Vegetation provided data on the total heavy metal concentration as a biomonitor for deposition. No links between the heavy metal concentration and ecological effects had yet been established.

19. ICP Modelling and Mapping mapped the main risk as total deposition exceeding critical loads for ecosystems and health. For the total deposition of Pb, Cd and Hg, and for Hg concentration in precipitation, critical thresholds were chosen based on ecotoxicology for terrestrial (Pb, Cd, Hg) and freshwater (Pb, Cd) ecosystems. For health, they included freshwater and food quality (Hg), arable land and food quality (Cd), and terrestrial and groundwater criteria (Pb, Cd, Hg).

E. Persistent organic pollutants

20. ICP Waters found that the global distillation of persistent organic pollutants (POPs) posed risks for fish contamination in Arctic and Alpine areas, as it led to elevated concentrations of contaminants in fish from these areas.

F. Causal effects on materials

21. For pollution situations dominated by sulphur dioxide, the dry and wet S deposition were correlated with corrosion rates for all studied materials (Al, copper (Cu), bronze, limestone, sandstone, weathering steel and two types of paint coated steel). The corrosive effects were virtually certain for all materials. The dry O_3 deposition was correlated with Cu corrosion in Europe.

22. For cases with multiple pollutants in Europe, dry and wet S deposition was correlated with corrosion rates for all materials. The dry O_3 deposition, nitric acid (HNO_3) concentration and total coarse particulate matter (PM_{10}) deposition were correlated with corrosion rates for Cu (due to O_3), zinc (HNO_3), limestone (HNO_3, PM_{10}), carbon steel (PM_{10}) and bronze (PM_{10}). The corrosive effects of HNO_3 and PM_{10} were extremely likely for the specified materials.

23. PM_{10} was positively correlated with soiling of white stone, painted steel, white plastic and polycarbonate. The values of tolerable loss of reflectance were derived for PM_{10} values.

G. Causalities between air pollution and health

24. The risk level for nitrogen dioxide in the 2005 WHO *Air Quality Guidelines* was set at the annual average of 40 $\mu g\ m^{-3}$. More detailed cause-effect relationships could not be established based on the current evidence.

25. Earlier guideline value for O_3 was 120 $\mu g\ m^{-3}$ (or AOT60). The new 2005 WHO *Air Quality Guidelines* level was set at 100 $\mu g\ m^{-3}$ of daily maximum 8-hour mean, at which the mortality might be increased by 1–2%. Based on the meta-analysis of epidemiological time-series studies, the mortality increase was established at 0.3% per 10 $\mu g\ m^{-3}$ of daily maximum 8-hour mean. It was recommended that calculation of impacts be based on concentrations greater than 70 $\mu g\ m^{-3}$ (or 35 ppb).

26. The long-term studies for fine PM ($PM_{2.5}$) indicated an increase in risk of all-cause mortality by 6% per 10 $\mu g\ m^{-3}$. This linear increase in risk was detected across all ranges of $PM_{2.5}$ levels observed in epidemiological studies, i.e. between 7 and 40 $\mu g\ m^{-3}$. A wide range of non-fatal health effects was linked with exposure to fine and coarse fractions of PM. They included the incidence of chronic respiratory and cardiovascular disease, hospital admissions due to cardiovascular and respiratory disease, asthma and lower respiratory symptoms. However, the effects estimates for those outcomes were less consistent than the evidence on the effects of PM on mortality. The WHO *Air Quality Guidelines* level was set at 10 $\mu g\ m^{-3}$ of annual average $PM_{2.5}$.

27. No threshold was observed for Cd. Pb was shown to be harmful above 100 $\mu g\ l^{-1}$ in blood. For Hg, the level of 0.5 $mg\ kg^{-1}$ for freshwater and marine fish and mammals should not be exceeded to prevent food chain impacts. To avoid health effects, further inputs of Cd to the atmosphere or soil should be avoided, concentration of Hg in fish should be reduced and emission of Pb to the atmosphere should be kept as low as possible.

28. Harmful exposures were defined for several selected POPs. The hazardousness for human health for these substances was confirmed. The quantification of risk for some substances was based on the extrapolation from animal toxicological studies.

III. STOCK AT RISK

29. Fish stocks were quantitatively estimated for lakes in Norway, Sweden and Finland. Fish stocks were estimated to be present in 103,715 lakes (82% of a total 126,482 lakes). More than 10,000 stocks of brown trout, roach, perch and Arctic char were lost due to acidification. There were additional losses of anadromous species, in particular salmon, which is present in more than 200 rivers in northern Europe.

30. ICP Forests addresses the degree of defoliation as percentage of leaf or needle loss for selected main tree species. Total forest area assessed in 37 countries is 175 million ha. Out of the total 130,000 sample trees, Norway spruce accounts for 19.9%, common beech 8.3%, European and sessile oak 6.5%, holm oak 3.6% and maritime pine 2.1%.

31. The ICP Integrated Monitoring sites represent natural terrestrial and surface water ecosystems. They are located mainly in protected areas, in many cases the Natura 2000 areas of the European Union (EU). These sites represent special values for the society, and the spatial area covered is often limited.

32. ICP Vegetation has assessed O_3 effects for crops using the database of the Stockholm Environment Institute for agricultural crops in the 50 km × 50 km grid over Europe. O_3-induced yield losses for crops amounted to 2% of the agricultural production in Europe in 2000. For semi-natural vegetation 54 communities of EUNIS level 4 were identified as potentially sensitive to O_3.

33. ICP Modelling and Mapping and its Coordination Centre for Effects (CCE) manages data related to calculated and empirical critical thresholds and receptor characteristics in 37 countries, mostly in Europe, in EUNIS classes in various resolutions aggregated to the 50 km × 50 km grid. It also holds combined data sets of NFCs and a CCE background database, which cover other countries, including those in Eastern Europe, Caucasus and Central Asia (EECCA). The area covered in Europe is 4,226,443 km^2. The forest soil and freshwater ecosystems for dynamic modelling cover 683,000 km^2. Heavy metals are mapped for 18 countries.

34. ICP Materials has mapped stock at risk for selected countries: the Czech Republic, France, Germany, Italy and Switzerland. In some of them, corrosion costs per km^2 were also included. No Europe-wide assessment has yet been performed. The programme was involved in several stock-at-risk studies, including the recent inventory at a site from the UNESCO World Heritage list in central Paris.

35. The work of the Task Force on Health addresses all European population to be subject to the impacts of air pollution. This amounts to approximately 700 million people in the EMEP model domain.

IV. LINKS BETWEEN OBSERVATIONS AND CRITICAL LOADS

A. Acidification

36. ICP Waters showed a generally good agreement between the exceedance of critical loads for acidity and measured ANC in surface waters. ANC is a good indicator of biological effects. Sites with significant time delays between changes in S and N deposition and response in water chemistry were exceptions.

37. The data from ICP Forests level I sites in Germany showed that the exceedance of critical loads for acidification were negatively correlated with pH and BS. It was also linked to S content in foliage and subsequently with defoliation.

B. Eutrophication

38. Several ICPs had initiated studies on pathways and processes linked to nutrient N. The results from ICP Modelling and Mapping indicated that in large parts of the UNECE region, the critical loads for eutrophication were exceeded, with risks to the diversity of plant species.

C. Ozone

39. ICP Vegetation carried out an O_3 damage evidence study, which comprised over 500 records in 16 countries in Europe. It concluded that visible symptoms had occurred with over 30 crops and 80 (semi-)natural vegetation species. The generic stomatal flux index for crops was better at predicting the widespread occurrence of O_3 damage on crops than the concentration-based index of AOT40, which underestimated the impacts across Europe.

D. Heavy metals

40. Level I sites of ICP Forests in Europe showed that the critical loads for heavy metals in humus and mineral soils were exceeded in 2–15% of the plots. The Cu concentration in foliage exceeded the critical limit for common beech at 8% of the sites.

41. Budgets at ICP Integrated Monitoring sites showed that deposition of Cd, Pb and Hg led to accumulation in soils and catchments.

42. The moss survey of ICP Vegetation showed that high heavy metal concentration in mosses coincided with areas where critical loads, based on ecotoxicological and health effects, were exceeded.

E. Persistent organic pollutants

43. No information on the excess amount of POPs was available for ecosystem receptors.

F. Materials

44. ICP Materials employed its test site network on exposing materials to derive dose-response relationships. Tolerable levels were established for carbon steel (20 µm year^{-1}), zinc (1.1 µm year^{-1}) and limestone (8 µm year^{-1}). Exceedance of these levels was frequent in urban areas. Background, tolerable and maximum observed corrosion rates were defined for three materials of cultural heritage (carbon steel, zinc and limestone). The monitoring sites were classified in three groups, depending on whether one or more of the three materials were exceeded.

G. Assessment of impacts on health

45. Estimates of health effects are based on modelling and/or measurements of the body burden of pollutants. Exposure-response functions from epidemiological or toxicological studies are also used.

46. Peaks of O_3 have reduced in Europe. However, approximately 21,000 premature deaths per year are attributed to O_3 exposure in the EU. Effects are not expected to decline in the next decade.

47. The health effects of PM are described as loss of life expectancy. The loss of life expectancy for the EU was estimated to be 8.6 months on the average, with country means ranging from 3.1 to 13.6 months.

48. In spite of the decreasing Cd emissions, accumulation continued and no decrease of Cd body burdens was observed. A major decrease in body burdens was noted for Pb, mainly due to the phase-out of Pb in gasoline. Air concentrations of Pb had decreased, but there were still risks mainly due to local sources. The effects occur via soils and plants or due to direct deposition on crops. Hg deposition had decreased but the concentrations in fish had not.

49. A number of POPs, such as dichlorodiphenyltrichloroethane (DDT), hexachlorocyclohexanes (HCH), hexachlorobenzene (HCB) and polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/PCDFs) via long-range transport, may continue to lead to human exposure and consequent health implications.

V. CONCLUSIONS

50. Since early 1980s, the Working Group on Effects has provided a unique framework for comprehensive air pollution effects monitoring and research that is science-based and policy-relevant. This research, based largely on observational evidence, has documented widespread causal effects of air pollution of a variety of receptors in Europe and North America. Literature

surveys have been employed to identify potential impacts and evaluate risks when monitoring and modelling was unfeasible due to high costs, undeveloped methodologies or other constraints.

51. The modelling of the effects and risks has become an important tool, with strong links to integrated assessment modelling. In particular, the risk assessment based on critical loads would further benefit from quantified links to observed effects. Sophisticated models, model systems and methods have become available to assess several pollutants and effects simultaneously and to address the temporal development of effects.

VI. CHALLENGES

52. The monitoring of multiple receptors at a variety of sites has produced valuable long-term knowledge of the adverse effects of air pollution. Continued efforts are required to convey the main results from monitoring and modelling to integrated assessment modelling. Effects studies are the only means to address the effectiveness and sufficiency of emission abatement policies. Therefore, periodical reporting on the extent, degree and trends of air pollution effects should continue.

53. The monitoring has demonstrated and verified various adverse effects. The cause-effect relationships would need to be confirmed for all monitored and modelled areas. In particular, the risks of eutrophication would require improvements in assessing the key N processes and links to observed effects.

54. The effects-oriented activities have addressed the most relevant stock at risk. Further improvement of inventories is needed, including in specific areas of interest in the UNECE region.

55. Some detrimental effects of air pollution can be rather immediate, such as the acute health impacts of O_3, or can take decades to develop, such as species changes due to long-term excess N deposition. The work on assessing the extent and degree of effects should increasingly address the links between air pollutants and calculated or empirical critical loads and their exceedance, including temporal dynamics.

56. The collection and analysis of monitored data always includes some uncertainty, as does the construction and use of models. Some pollutant loading has been reduced. Therefore, the robustness, or the certainty, of the research conclusions is increasingly important. Effects-oriented programmes should continue to cooperate with integrated assessment modelling activities to deliver quantified information on the robustness of air pollution effects.

57. Further assessment of the technical details of the monitoring and modelling activities may help to harmonize them, thus ensuring the provision of the information and knowledge to the Convention. The draft guidelines for the reporting on the monitoring and modelling of air

pollution effects, now in preparation, could help to improve the monitoring of the effects-oriented activities.

58. A large share of the Convention’s effects-oriented activities has taken place in the industrialized member States of UNECE. Improved collaboration will be needed due to the increasing importance of the long-range transport of air pollutants as well as to address the priority need of reducing impacts in countries in EECCA and South-Eastern Europe (SEE). The participation of all Parties in meetings under the Convention should be further encouraged, as should the submission of data on air pollution effects by EECCA and SEE countries.
