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**ECONOMIC COMMISSION FOR EUROPE**

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

Working Group on Effects

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Item 4 of the provisional agenda

**RECENT RESULTS AND UPDATING OF SCIENTIFIC AND TECHNICAL KNOWLEDGE**

**MONITORING EFFECTS OF LONG-RANGE TRANSBOUNDARY AIR POLLUTION  
ON SURFACE WATERS IN EUROPE AND NORTH AMERICA SINCE 1985**

Report by the Programme Centre of the International Cooperative Programme on Assessment  
and Monitoring of Acidification of Rivers and Lakes

**INTRODUCTION**

1. The International Cooperative Programme on Assessment and Monitoring of Acidification of Rivers and Lakes (ICP Waters) was established under the Working Group on Effects by the Executive Body of the Convention on Long-range Transboundary Air Pollution (LRTAP) in July 1985. Since then, ICP Waters has been an important contributor documenting the effects of the implemented Protocols under the Convention. Numerous assessments, workshops, reports and publications covering the effects of long-range transported air pollution have been published over the years. This report sums up the major findings from this work, which are presented here in accordance with item 3.3 of the 2008 workplan for the

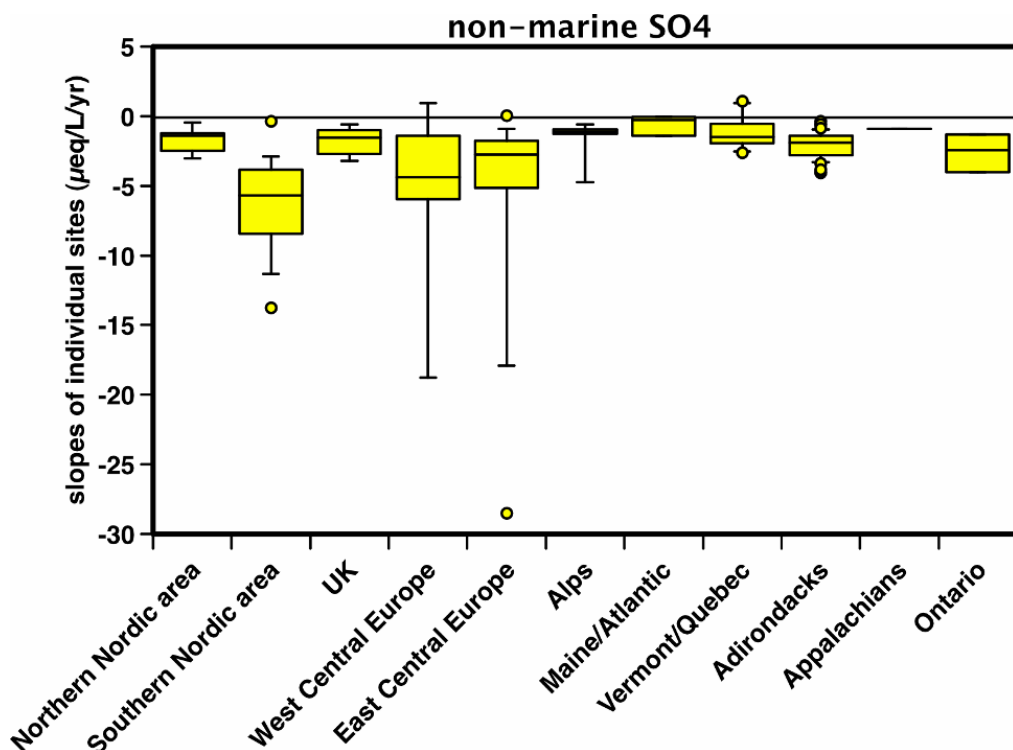
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implementation of the Convention (ECE/EB.AIR/91/Add.2) adopted by the Executive Body at its twenty-fifth session.

## I. MAJOR FINDINGS

### A. Lakes and rivers show strong signs of recovery in response to reduced acid deposition

2. Surface water quality in acid-sensitive areas has improved strongly in Europe and North America since the 1980s. The consistent pattern of chemical recovery (decreasing sulphate ( $\text{SO}_4$ ) (figure 1), and increasing pH and alkalinity) across a large number of sites is the strongest evidence that emission control programmes are having their intended effect. Monitoring data from ICP Waters document that the reductions in acid deposition are mirrored in improved water quality in most regions. In many areas, water quality is now sufficient for the return of acid-sensitive species of fish, invertebrates and mussels.



**Figure 1.** Box and whisker plot showing  $\text{SO}_4$  trend slopes (in  $\mu\text{eq l}^{-1} \text{ year}^{-1}$ ) for the period 1994–2004 in the different regions of Europe and North America. Values for non-marine  $\text{SO}_4$  are calculated by removing the trace amounts of  $\text{SO}_4$  from seasalt spray that contribute to sulphur (S) deposition. Each box shows the range of slopes (25th to 75th percentiles, with line at the median). Lines (whiskers) show the range of the data that lay within the upper (lower) quartile

plus 1.5 times the interquartile range (minus 1.5 times the interquartile range). The dots show outliers.

### **B. Biological recovery is slow and not widespread**

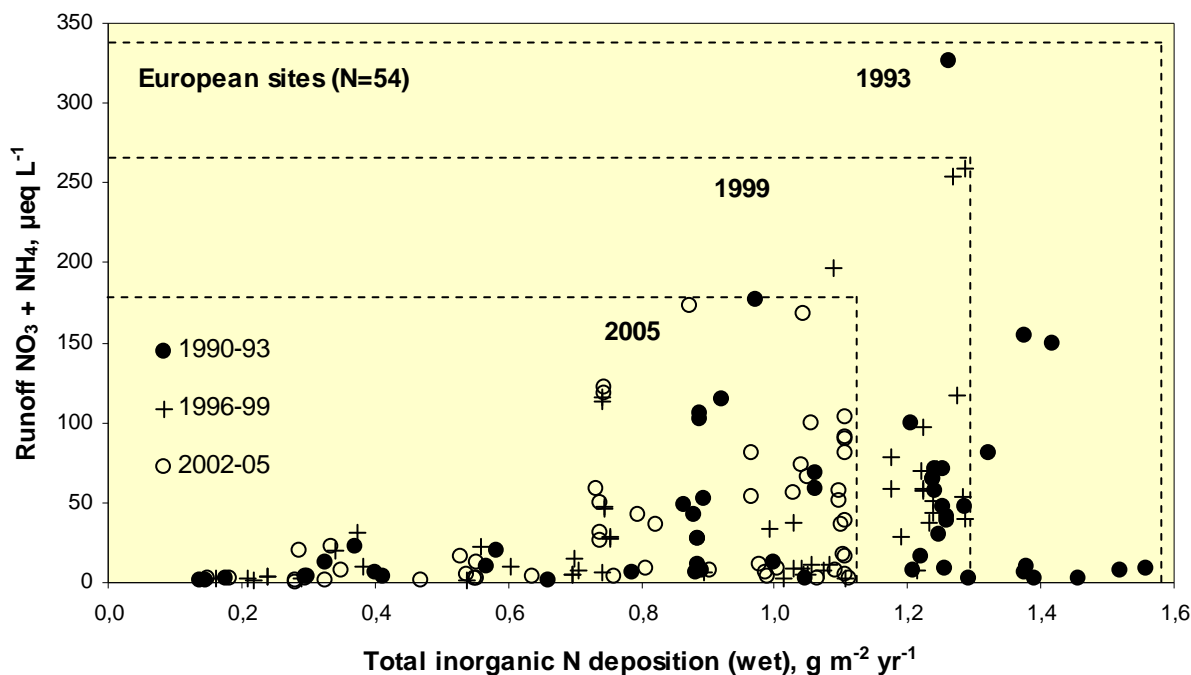
3. Biological monitoring in ICP Waters focuses on acid-sensitive invertebrate species. Improved chemical water quality has resulted in recovery of aquatic biota in Canada, the Czech Republic, the Nordic countries and the United Kingdom. In the most acidified regions in Europe signs of biological recovery are more difficult to find. This may be because the water quality has not recovered sufficiently to permit widespread biological recovery. The lack of documented examples of biological recovery is related to both the dynamic nature of biological responses, but also to a lack of appropriate long-term monitoring data.

### **C. Distinct lack of chemical recovery in some regions**

4. Despite reduced SO<sub>4</sub> deposition, some regions show no reductions in SO<sub>4</sub> concentrations in surface waters and no improved water quality. Clear examples are the Blue Ridge Mountains in Virginia in the United States of America and the Harz Mountains in Germany. Deep soils with a large SO<sub>4</sub> adsorption capacity dominate and SO<sub>4</sub> concentrations in surface water are controlled by S desorption that was deposited in the past decades.

### **D. Long-term trends in nitrate in surface waters are poorly understood**

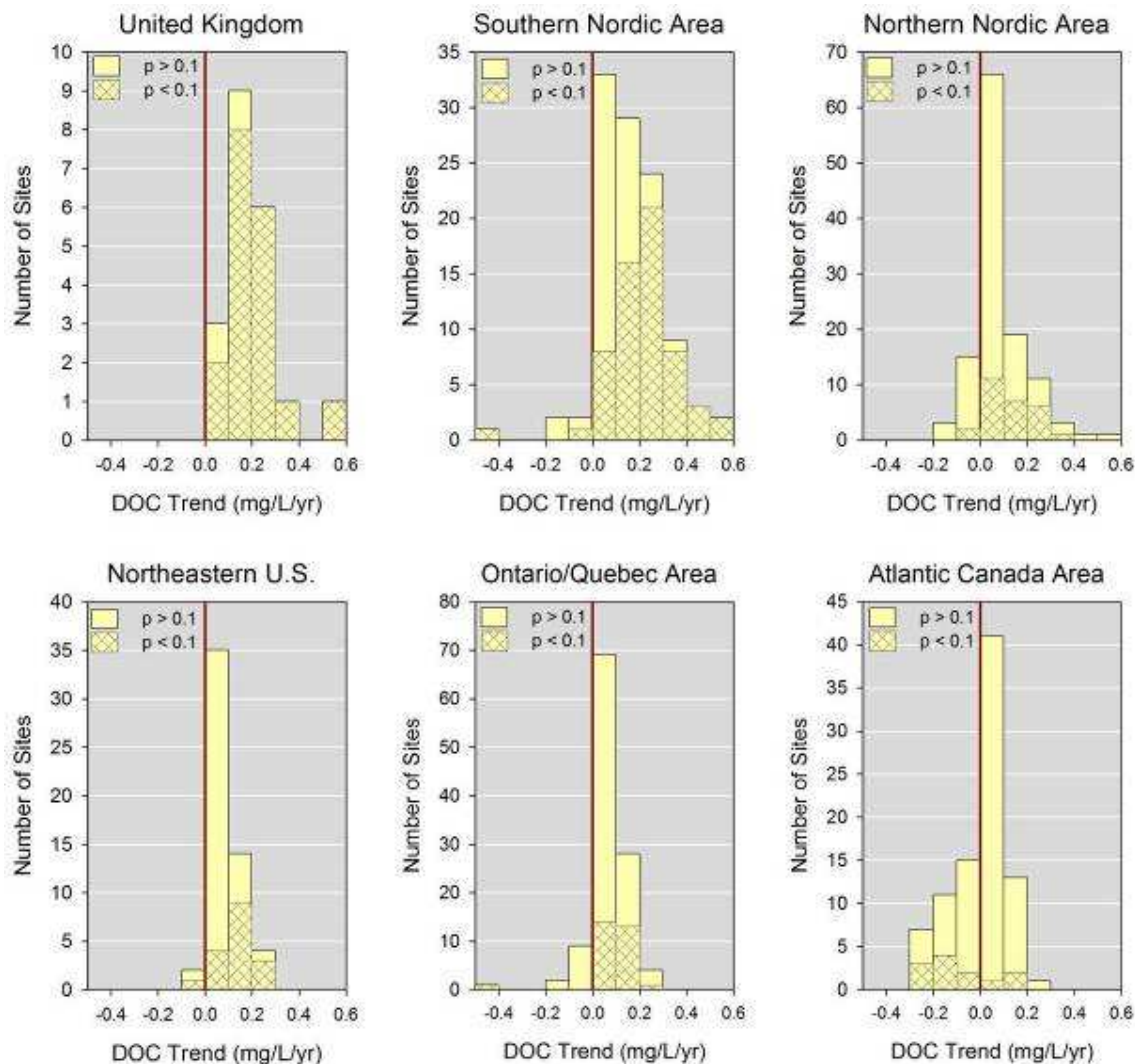
5. Nitrogen (N) deposition does not show the widespread declines that we observe in S deposition. Most deposited N is retained in soils and vegetation and is not leached. Nitrate (NO<sub>3</sub>) in surface waters exhibits positive, negative and neutral trends, unlike the decreasing SO<sub>4</sub> trends that show strong dependence on changing S deposition in most of Europe and North America. There is some evidence of reduced NO<sub>3</sub> concentrations in regions where N deposition has declined (figure 2). Elsewhere, NO<sub>3</sub> trends in surface waters are thought to be related to climate, forest growth and N saturation, or are simply not understood. Acid-sensitive ecosystems are continually enriched with N, which increases the probability of future acidification and eutrophication due to NO<sub>3</sub> leaching.



**Figure 2.** Total N (sum of  $\text{NO}_3$  and ammonium ( $\text{NH}_4$ )) concentration in runoff (in  $\mu\text{eq l}^{-1}$ ) and total inorganic wet N deposition (in  $\text{g m}^{-2} \text{ year}^{-1}$ ) for 54 European ICP Waters sites in 1990–1993, 1996–1999 and 2002–2005 (deposition data for 2002–2003 only). The dotted lines indicate the successive change in maximum total inorganic N deposition and inorganic N runoff ( $\text{NO}_3 + \text{NH}_4$ ) with time.

#### E. Increases in dissolved organic carbon (are related to reduced sulphur deposition)

6. Trends in dissolved organic carbon (DOC) have been positive in almost all the ICP Waters sites in North America and Europe, beginning in the early 1990s, especially in areas where acid deposition has been considerable. This has led to a significant browning of surface waters. The extended database compiled by ICP Waters to assess DOC trends is the largest region-wide overview (>500 lakes and rivers in northern Europe and North America) that documents the trends in DOC (figure 3). The DOC trends are related to declining atmospheric loads of  $\text{SO}_4$ . The browning of the waters is thus a sign of ecosystem recovery. In near coastal regions, seasalt deposition also affects DOC concentrations and trends.

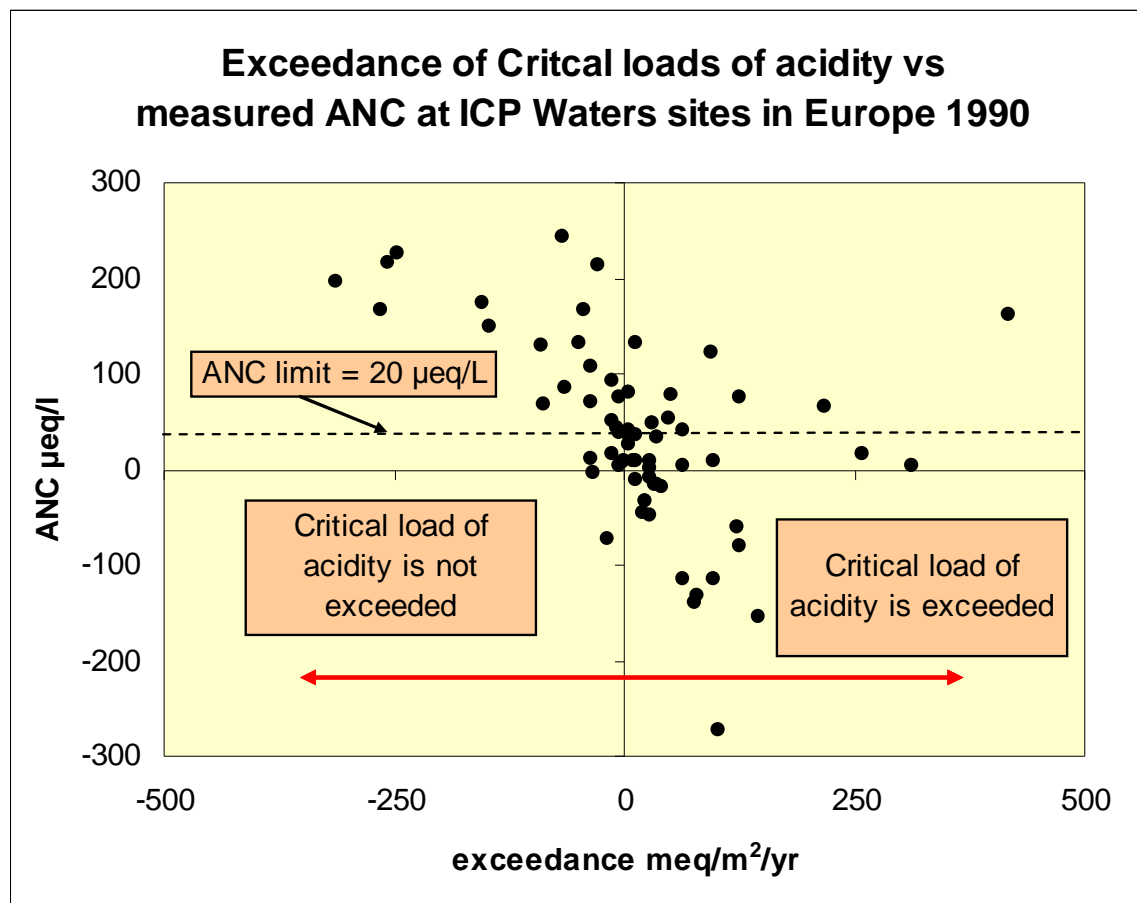


**Figure 3.** Histograms of DOC trend magnitudes (and significance) 1990-2004 for regions of Europe (upper panels) and North America (lower panels). Bars show total number of sites in each trend class; cross-hatched portions of bars represent trend slopes significant at  $p < 0.10$ . Trends in all regions except Atlantic Canada are dominated by positive slopes. In the United Kingdom, the southern Nordic area and the north-eastern United States, these trends are mostly significant.

#### **F. Modelled critical loads for surface waters are supported by the Programme's data**

7. Critical loads of acidifying components for surface waters have been modelled and reflect catchment sensitivity to acid deposition. Calculation of the difference between the critical load and actual load of S deposition results in the critical load exceedance. The exceedance is either positive (load of acid deposition is too high compared with the acid-tolerance of the water body) or negative (no exceedance). Measured lake chemistry at ICP Waters sites indicates that

the acid-neutralizing capacity (ANC) of the lakes is consistent with the calculated critical load exceedance (figure 4). In lakes with no exceedance, ANC was mostly above the critical lower limit. Conversely, in those lakes where critical loads were exceeded, ANC was mostly below the critical lower limit. The agreement between empirical lake chemistry and modelled critical loads indicates that critical load assessments for surface waters are based on a solid empirical foundation.



**Figure 4.** Exceedance of critical load of acidity (in  $\text{meq m}^{-2} \text{ year}^{-1}$ ) and ANC (in  $\mu\text{eq l}^{-1}$ ) in 1990 at ICP Waters sites in Europe. Sites in the lower right quadrant have positive critical loads exceedance and have ANC below  $\text{ANC}_{\text{limit}}$ . Critical loads are not exceeded at sites in the upper left quadrant, and ANC is above  $\text{ANC}_{\text{limit}}$ . Sites in both these quadrants are positioned as expected with respect to critical load, exceedance and response of water chemistry. Sites in the upper right quadrant show exceedance but have ANC above  $\text{ANC}_{\text{limit}}$ . These sites may show delayed response to S deposition.

#### G. Many sites in of Europe will remain acidified after 2010

8. Chemical recovery of many ICP Waters sites will not be sufficient to sustain biological recovery by 2010, according to predictions from dynamic acidification models. Calculation of

critical loads for acidifying components is a central activity in work under the Convention. Dynamic models provide an extension to steady-state critical load models by predicting the timescale of chemical recovery related to emission reductions. Dynamic models can also be used to determine deposition levels required to achieve a prescribed target chemistry in surface waters in a given time frame, and are thus directly used to determine what further emission reductions will be necessary to protect aquatic ecosystems. ICP Waters will use the expertise within its network to support the modelling work under the Convention and assess the possibilities for using dynamic modelling for surface waters in Europe and North America.

#### **H. Climate change will affect acidification and recovery**

9. Future trends in recovery from acidification may be influenced by a number of factors that are independent of emissions of acidifying components. In particular, climate change may significantly influence the behaviour of both terrestrial and aquatic ecosystems in the form of increasing drought frequency and higher precipitation extremes, more frequent storms (and consequently more seasalt deposition) and higher temperatures. Long-term data series show seasalt episodes setting back biological recovery several years. The extent of N retention in a warmer climate, and consequently the future influence of N on surface water acidification, represents a key uncertainty in recovery from acidification.

#### **I. Heavy metals and persistent organic pollutants are found in fish, sediments and waters in remote areas**

10. In general, the concentrations of heavy metals in ICP Waters sites not influenced by local pollution sources are low. However, a number of its sites have concentrations of heavy metals above the critical limit, based on national (e.g. Swedish) guidelines on assumed effects on aquatic biota. The number of ICP Waters sites does not allow a geographically comprehensive evaluation of heavy metal levels in surface waters in Europe and North America.

11. The results from an assessment of persistent organic pollutants (POPs) in the aquatic environment confirm previous studies indicating that global distillation processes (also called the grasshopper effect) leads to elevated concentrations of contaminants in fish from arctic and alpine areas. There are very few sites with trend data, but they generally show decreasing levels of legacy POPs (i.e. all POPs covered by the Stockholm Convention on POPs and the LRTAP Convention). Levels of some newly studied substances, such as brominated flame retardants (pentabromodiphenylether, PBDE) and perfluorooctane sulfonate (PFOS) are probably rising.

#### **J. High-quality database with long-term data from 200 surface water sites in 16 countries**

12. Surface waters are much more responsive than either soils or terrestrial vegetation to changes in long-range transported acid deposition. Lakes and rivers also have the advantage in that they integrate responses over the entire catchment area. The ICP Waters network is

geographically extensive and includes long-term data series (10–20 years) for more than 200 sites. The network is thus well poised to document changes that result from implementation of the protocols. The long-term comprehensive data sets from background sites in (semi-)natural ecosystems collected by ICP Waters are also valuable for detecting impacts of climate and global change. The data are and will be used to develop acidification and recovery models for both chemistry and biology.

#### **K. Harmonized methods and quality control**

13. Each country contributes data from national monitoring programmes. Between-laboratory quality control is necessary to assure clear identification and control of the bias between analyses carried out by individual participants of ICP Waters. Such biases may arise from use of different analytical methods, errors in the laboratory calibration solutions, or through inadequate within-laboratory quality control. The number of participating laboratories in the chemical intercomparison has increased from 9 in 1987 to 72 laboratories in 28 countries in the twenty-first chemical intercomparison in 2007. The intercomparison confirms that the results are generally comparable between laboratories. The purpose of the annual biological intercalibration is to evaluate the quality of taxonomic identification. The eleventh intercalibration was conducted in 2007. Twelve laboratories participate on a regular basis.

#### **L. Monitoring is ground truth**

14. Long-term monitoring data are the basis for all activity in ICP Waters. Monitoring data provide the ground truth upon which all modelling work such as modelling of critical loads relies. Continuation of the national programmes that monitor ecosystem effects is imperative in order to reliably document the effects of air pollution reduction measures.

### **II. FUTURE CHALLENGES**

15. For over two decades, ICP Waters has contributed solid empirical evidence and high-quality research for the scientific underpinning of policy to reduce emissions of acidifying pollutants. ICP Waters has been active in reviews of several protocols under the Convention, in particular the two protocols on S reductions in 1985 <sup>1</sup> and 1994 <sup>2</sup> and the 1999 Gothenburg Protocol <sup>3</sup>. The programme has also contributed to the review of the 1998 Protocol for Heavy Metals. The future of ICP Waters is closely linked to the need for information to document the effects of implemented protocols and to develop new protocols, including the ongoing revision of the Gothenburg Protocol. This information falls into several classes.

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<sup>1</sup> The 1984 Protocol on the Reduction of Sulphur Emissions or their Transboundary Fluxes by at least 30 per cent.

<sup>2</sup> The 1994 Protocol on Further Reduction of Sulphur Emissions.

<sup>3</sup> The 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone.



#### **A. Future acidification of surface waters**

16. At present, further large emission reductions in Europe can be expected for N but not for S. In North America, emissions reductions will continue, but the magnitude of future decreases is likely to be smaller than in the past decades. Importantly, many lakes and rivers in southern Norway, southern Sweden, the Tatra Mountains in Slovakia, the Italian Alps, and the Southern Pennines in the United Kingdom as well as in areas in the eastern part of the United States and Canada still suffer from surface water acidification that is severe enough to inflict damage on biota. Dynamic acidification modelling suggests that these areas will continue to acidify in the future. It is important for ICP Waters to maintain awareness of the acidification problems in these areas.

17. The impacts of N deposition will continue to be of concern. Current difficulties in predicting N retention, and the multiple confounding factors (acidification, climate, natural variability) that affect the N cycle, mean that N will continue to be a key uncertainty in future recovery from surface water acidification. Much of the work that ICP Waters has done with N-based effects has focused on acidification. Because nitrogen is also a nutrient, elevated N deposition can also disturb aquatic biological communities in oligotrophic (nutrient-poor) lakes. This problem ICP Waters will address in the near future.

#### **B. Biological response**

18. Future work should also include studies of dynamic biological responses in the recovery process. The widespread improvement in surface water quality during the past 15–20 years should give rise to biological recovery. Yet there are relatively few documented examples of biological recovery. The explanation may be found in the dynamic nature of biological response but also a lack of appropriate long-term monitoring data. ICP Waters will continue to work on developing biological response models for use in assessing recovery from acidification. In this work, the continuation of biological and chemical monitoring at the same sites is essential.

#### **C. Dynamic modelling and critical loads**

19. Mapping critical loads for acidifying components is a key activity within the Convention work. Dynamic models provide an extension to critical loads by predicting the timescale of chemical recovery to emission reductions. Dynamic models can also be used to determine the deposition levels required to achieve prescribed target chemistry within a given timescale, and so have direct utility in the formulation of further emission reductions. ICP Waters can use the expertise within its network to support the modelling work under the Convention, and to assess the possibilities for using dynamic modelling for surface waters in Europe and North America. ICP Waters also holds much of the necessary data for calibration of such models.

#### **D. Heavy metals and POPs**

20. Heavy metals (in particular lead, cadmium and mercury) and POPs from long-range transport have not received the same attention in monitoring programmes as acidifying components. In the future, ICP Waters plans to make recommendations for monitoring and the development of appropriate dose-response relationships, and to participate in work on effects-based approaches for POPs and heavy metals.

#### **E. Effects of climate change and other unknowns**

21. Future trends in recovery from acidification may be influenced by a number of confounding factors. Climate is widely believed to be undergoing long-term change, and the direction and degree of this change may significantly influence the behaviour of both terrestrial and aquatic ecosystems. Future monitoring, in particular and in combination with the use of dynamic models, is important to understand the effects of climate change and other unknowns for acidification, as well as for heavy metals and POPs.

#### **F. Contribution to other environmental policies**

22. The work of ICP Waters, the ongoing monitoring of waters and the long and extensive databases, provide participating countries with important environmental information that can be used in conjunction with other national and international environmental policies. For example, within the European Economic Region, policies such as the European Union's Water Framework Directive, Biodiversity Directive and Habitats Directive all can profit from ICP Waters. ICP Waters can also play a role within work under the United Nations Framework Convention on Climate Change and its Kyoto Protocol.

#### **G. Success factors**

23. The future success of ICP Waters is related to the factors that led to its success in the past: (a) the combination of collecting and presenting high quality data from many countries; (b) close contact with policymakers and other ICPs; and (c) good scientific collaboration within the programme, with other international projects, and with other monitoring networks. The ICP Waters Programme Centre has experienced that the success in running our programme is based on a scientifically sound and active Task Force, focused aims, consistent programme management, frequent assessment of data, a detailed programme manual and frequent intercomparison exercises.

24. Continuation of the national monitoring programmes that submit their data to ICP Waters and the yearly chemical and biological intercalibration exercises are crucial, and are the most important key activities in its future work.

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