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Climate and Lake Impacts in Europe (CLIME)

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Abstract:

If present trends continue, limnologists believe that the projected changes in the climate will have a major effect on the dynamics of lakes throughout Europe. The methods currently used to monitor and model lakes take very little account of the changes expected in a warmer world. Most are based on a deterministic rather than a probabilistic approach and do not properly represent the 'cascade of uncertainty' associated with current climate projections. In CLIME, scientists from ten countries have collaborated to assess the direct and indirect effects of the projected changes in the climate on the dynamics of lakes. The primary objective of the project was to develop a suite of models that could be used to simulate the responses of lakes to future as well as past changes in the weather. The secondary objective was to describe the patterns of change observed in lakes distributed throughout Northern, Western and Central Europe and relate these to global-scale variations in the atmosphere and the ocean. The project was organized into four Thematic Programmes sub-divided into eleven Workpackages.

In the first Thematic Programme **(Regional Forcing),** the climatologists used Regional Climate Models and Monte Carlo simulations to produce the 'downscaled' daily variations required to drive the lake and catchment models. All the analytical and modelling work in CLIME was based on the outputs from two Regional Climate Models: the RCAO model produced by the Rossby Centre in Sweden and the HadRM3p model developed by the Hadley Centre in the UK.

In the second Thematic Programme **(Integrated Catchment-Lake Modelling)** the limnologists used long-term observations at a number of sites to validate the water quality models for the lakes and catchments. The lake models included formulations that simulated the formation and break-up of ice, thermal stratification, wind-induced mixing, the recycling of nutrients and the growth of phytoplankton. The catchment models simulated the seasonal variations in the supply of phosphorus, nitrogen and dissolved organic carbon. All the models used the same graphic interface so key processes were easily modified to match the characteristics of the individual sites. The results of the P and N modelling demonstrated that sustained increases in the flux of nutrients can be expected at all sites with the most pronounced increases being predicted for the northern lakes during the winter. The results of the DOC modelling demonstrated that significant increases in DOC can be expected at most sites with the largest increases being recorded Ireland and Finland. The results of the lake modelling showed that the most pronounced physical changes are to be expected in Central Europe where the summer temperatures could be 4-5^{o}C higher than they are today. In all three regions, there was a significant increase in the summer stability of the lakes and an associated reduction in the amount of heat the transferred into deep water. The PROTECH model used to simulate the growth of phytoplankton suggested that there would

be a general increase in the summer biomass and more localized increases in the frequency and severity of cyanobacterial blooms.

In the third Thematic Programme **(Regional Coherence)** a variety of methods were used to quantify the geographical variation in the climatic sensitivity of the lakes. These included a study of factors influencing the synchronous behaviour of lakes and an assessment of the impact of extreme weather events on their seasonal dynamics. The results showed that lakes located in different parts of Europe respond in different ways to climatic forcing and that some of these responses were mediated by the size of the lakes. In Northern Europe, the most important effects were those associated with the change in the freeze-thaw dates of the lakes and the extension of the growing period. In Western Europe, the key factors were the flushing effects of heavy rain and the stabilizing effects of summer reductions in the wind speed. The factors influencing the observed variations in Central Europe were more diverse. Lakes located at high altitude were strongly influenced by the recent reductions in ice cover whilst lakes at lower altitudes were more sensitive to the seasonal variation in the intensity of wind-mixing.

In the fourth Thematic Programme (**Regional Impact Assessments**) the socio-economists and systems analysts produced reports that addressed some of the practical consequences of the predicted changes. The reports included: a cost-benefit analysis of the management options for Lake Malaren (Sweden), a study of the public perception of change in Lake Balaton (Hungary) and an analysis of the public's 'willingness to pay' for remedial measures in the UK. The most important component of this Thematic Programme was the Decision Support System (CLIME-DSS). This is an interactive web-application that allows the end-user to visualize the projected changes in the climate and study their effect on a selected range of water quality attributes. The CLIME-DSS is based on a Bayesian network that assimilates the outputs from several thousand model simulations to generate the required Conditional Probability Tables. The system has a simple map-based Graphic User Interface which allows the user to visualize the projected changes in the climate on a European scale and display their potential effect on the quality of lake water.

A variety of methods have been used to disseminate the results of CLIME. These included web pages, leaflets, posters, presentation and papers published in scientific journals. More than eighty papers have already appeared in peer reviewed journals and a number of others submitted for publication. From a scientific point of view, the most important deliverable will be the Synthesis Volume that Springer plan to publish in 2007. This book will include twenty four multi-authored chapters and will provide an overview of all the historical and modelling work completed in CLIME.