

## Modelling impacts of climate and environmental change on freshwater ecosystems

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### INTRODUCTION

The 2007 Conference of the Parties to the United Nations Framework Convention on Climate Change, in Bali, and the latest IPCC Report (IPCC 2007) confirmed the consensus amongst scientists and policy makers that human-induced global climate change is now occurring. However, there is less certainty about the magnitude of future temperature changes and how these will drive precipitation, evaporation and hydrology at regional scales. Moreover, how these changes will affect water quality in rivers, lakes and wetlands is extremely difficult to assess because of the non-linear nature of all interactions that can occur. As part of a Pan-European initiative to unravel some of these complexities, the Euro-limpacs Project ([www.eurolimpacs.ucl.ac.uk](http://www.eurolimpacs.ucl.ac.uk)) was established and funded by the EU Sixth Framework Programme.

Euro-limpacs has been a multi-partner, €20-million research project investigating impacts on rivers, lakes and wetlands across Europe (Battarbee *et al.* 2008). A wide range of laboratory and field experiments, data analysis and process-based modelling have been undertaken to evaluate potential impacts of climate and environmental change. This research has raised many questions including:

- How will climate change affect river flows and alter the flushing of diffuse pollutants and the dilution of point sources of effluents?
- In what ways might more intense rainfall affect nutrients and sediments loads in rivers, lakes and wetlands?
- How might rising temperatures combined with water quality changes affect freshwater ecosystems?

- How might the carbon balance and recovery of acidification be affected in upland catchments?
- How will changing land use and development across Europe affect rivers, lakes and wetland systems?

In order to answer these questions and many others (Whitehead *et al.* 2009c), a spectrum of models have been developed or applied with the Euro-limpacs project. This special issue complements another special issue that has been published as part of the project, reporting earlier model developments and applications (Wade 2006).

### SPECIAL ISSUE PAPERS

The papers in this special issue cover the development of new climate change research procedures and models, and the application of the models to a broad spectrum of hydrological and water quality problems. Chun *et al.* (2009) describe a methodology for downscaling climate change information from Global Climate Change models to six rivers systems in the UK. The authors suggest that the new framework may be particularly useful in ecological studies, where higher resolution of stream flows in low flow conditions is required and where flow threshold statistics might be useful. Whitehead *et al.* (2009b) also assess the potential impacts of climate change on six UK rivers but using the INCA (Integrated Catchment) suite of water quality models to assess how changes in flow and temperature may alter nitrogen, ammonia, phosphorus,

sediments and ecology in rivers. It is shown that the responses are complex and will vary from upland to lowland reaches of river systems. A wide variety of responses from the different rivers are obtained underlining the importance of considering each river system individually. Shifts in ecology predicted by the INCA model are interesting and speculative but the theory behind this is evaluated by [Martí \*et al.\* \(2009\)](#), who propose a methodology applicable for European wide changes in ecology using a space for time substitution technique. Variations in water quality are also explored by [Cox and Whitehead \(2009\)](#) in relation to dissolved oxygen (DO) in large river systems. In the River Thames, temperature changes due to climate change will have a direct impact, reducing DO concentrations. The changes are not large in themselves but could be significant if coupled with increased algal blooms that create significant diurnal variations in DO.

The theme of climate change impacts on water quality and nutrients, and in particular nitrogen, are assessed in a set of papers applying INCA and MAGIC (Model of Acidification in Groundwaters) to a wide range of catchments in Scotland ([Futter \*et al.\* 2009a](#)), Finland ([Bärlund \*et al.\* 2009](#); [Rankinen \*et al.\* 2009](#)), Sweden ([Futter \*et al.\* 2009c](#)) and Norway ([Sjøeng \*et al.\* 2009a,b](#)). The general consensus seems to be that there will be significant changes to nitrogen in catchments. This is due to the fact that soil nitrogen processes are both temperature and soil moisture dependent and will be affected by climate induced change. Also, processes in rivers and lakes such as nitrification and denitrification are also temperature, velocity, flow and residence time dependent. Again, these instream processes will be affected by climate change. The downstream effects of changing nutrient fluxes into lakes is also important, especially given the likely changes in temperatures which will affect ice cover and thermoclines in lakes. This has been evaluated by [Saloranta \*et al.\* \(2009\)](#) and in this study an interesting application of Bayesian Statistics is used to approach the problem of model parameter uncertainty. This is a key question in most modelling studies and especially those that try to account for the processes in environmental systems and the inevitable interactions between process variables. The Bayesian approach offers a potential solution to this complex problem. The question of model uncertainty is also addressed by [MacDougall \*et al.\* \(2009\)](#) and [Tominaga \*et al.\* \(2009\)](#) who

evaluate a range of acidification models and parameter estimation procedures respectively. The potential impacts of climate change on acidification are also evaluated in these papers and this is important because of the long term recovery of acidified rivers and lakes. Climate change may well alter this recovery process and require changes to the long term trans-boundary air pollution protocols.

Another area of concern is that of carbon balances in upland wetlands, lakes and river systems. Papers by [O'Connor \*et al.\* \(2009\)](#) and [Futter \*et al.\* \(2009b\)](#) assess the transformations of carbon in the upland environment, as evidenced by the varying flux of Dissolved Organic Carbon (DOC). The processes controlling DOC release are evaluated from both an experimental and a modelling framework using a new version of INCA for carbon.

Finally, it should be emphasised that climate change is just one problem potentially threatening aquatic ecosystems across Europe. Environmental pollution is still a major issue, especially in Eastern Europe where a massive legacy of polluted rivers exists. The problems of how to deal with this is a major issue for many countries and in the papers by [Chapra & Whitehead \(2009\)](#) and [Whitehead \*et al.\* \(2009a\)](#), Romanian rivers in Transylvania have been investigated. The particular problem is the legacy of old mines leaching toxic metals into river systems and the potential benefits of clean up operations to restore rivers, as is required by the EU Water Framework Directive. However, development of mines to restore and enhance the economy of Eastern European countries is also an issue, creating a separate set of problems that require careful environmental impact assessment and new management strategies to control future pollution issues.

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