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Cross-sectoral conflicts for water under climate change: the need to include water quality impacts

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Abstract— Climate change is expected to increase pressures on water use between different sectors (e.g. agriculture, energy, industry, domestic uses) and ecosystems. While climate change impacts on water availability have been studied widely, less work has been done to assess impacts on water quality. This study proposes a modelling framework to incorporate water quality in analyses of cross-sectoral conflicts for water between human uses and ecosystems under climate change and socio-economic changes. We illustrate this with an example that shows that increasing river temperatures and declines in summer low flow under climate change are likely to increase environmental restrictions on cooling water use, with substantial reductions in power plant capacities in Europe and the US. Hence, conflicts between environmental objectives and electricity supply are expected to increase due to both changes in water availability and water quality (water temperature) under climate change. A new impact modelling framework is proposed, which integrates relations between water availability, water quality and cross-sectoral water uses, including water requirements for ecosystems. This could provide improved understanding of how climate change and socio-economic developments will affect the ‘water-energy-food-ecosystem nexus’.

Index Terms—river flow, water temperature, water quality, climate change, socio-economic developments, human water use, ecosystems

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1 Introduction

Climate change in combination with other anthropogenic changes is expected to contribute to an increasing pressure on water between human water use sectors (e.g. agriculture, energy, industry, domestic uses) and ecosystems (Alcamo et al., 2003). In addition, water demand is expected to increase with a growing and more prosperous global population (Vörösmarty et al., 2000). Sufficient water of suitable quality to guarantee human uses and ecosystem health could therefore become a main challenge in the next decades.

The increasing awareness that climate change may affect water resources has greatly stimulated the study of the hydrological impacts of a changing climate. While impacts on water quantity have been studied widely on different scales, varying from catchment (e.g. van Roosmalen et al., 2009) to continents (e.g. Feyen and Dankers, 2009) and the world (e.g. Döll and Müller Schmied, 2012), considerably less work has been done to assess climate change impacts on water quality. However, most sectors require not only sufficient water availability (quantity), but also suitable water quality. For instance, water temperature is a critical parameter for cooling water use in the energy and industrial sector, while salinity and nutrient concentrations are important for agricultural and drinking water uses. The need to expand hydrological impact assessments to incorporate water quality issues has therefore been increasingly recognized (Kundzewicz and Krysanova, 2010; Whitehead et al., 2009).

In this paper, we propose a modelling framework to incorporate water quality, in addition to water availability, in studies of cross-sectoral water stress under global change. We illustrate the need to include water quality by focussing on water temperature, which is most directly affected by climate change. Water temperatue also influences several other water quality parameters, such as dissolved oxygen and nutrient concentrations and toxicity of heavy metals (Ducharne, 2008; Murdoch et al., 2000). Water temperature and river flow are also major parameters that characterize the physical conditions of freshwater habitats (Carpenter et al., 1992; Rahel et al., 1996), and are of economic importance for cooling water use for thermoelectric power production and manufacturing (Manoha et al., 2008). We highlight cross-sectoral conflicts for water availability and quality, by focussing on impacts of changes in river flow and water temperature on cooling water use in the energy sector and freshwater ecosystem health.

2 Modelling of conflicts for water availability and water temperature between energy sector and freshwater ecosystems

To simulate large-scale conflicts for water between cooling water use in the energy sector and freshwater ecosystems, we worked on the development of a large-scale water temperature module linked to a macro-scale hydrological model. We used a physically-based modelling framework, consisting of the stream temperature River Basin Model (RBM) (Yearsley, 2009; Yearsley, 2012) and the Variable Infiltration Capacity (VIC) macro-scale hydrological model (Liang et al., 1994). RBM was further developed for applications to large rivers worldwide, including human impacts of thermal pollution and reservoir impacts on water temperature (van Vliet et al., 2012a). The resulting framework simulated observed conditions realistically (van Vliet et al., 2012a). It was then forced with an ensemble of bias-corrected general circulation model (GCM) output for the 21st century (Hagemann et al., 2011) provided within the EU FP6 WATCH project. Overall, water temperature sensitivities are exacerbated by projected declines in low-flows, resulting in a reduced thermal capacity (van Vliet et al., 2011). Strong increases in water temperature and reductions in low flows are mainly projected in the south-eastern United States, southern and central Europe and eastern China (van Vliet et al., 2013) (Fig. 1). These regions could therefore be potentially affected by increased deterioration of water quality and freshwater habitats, and reduced potentials for human water uses under future climate.

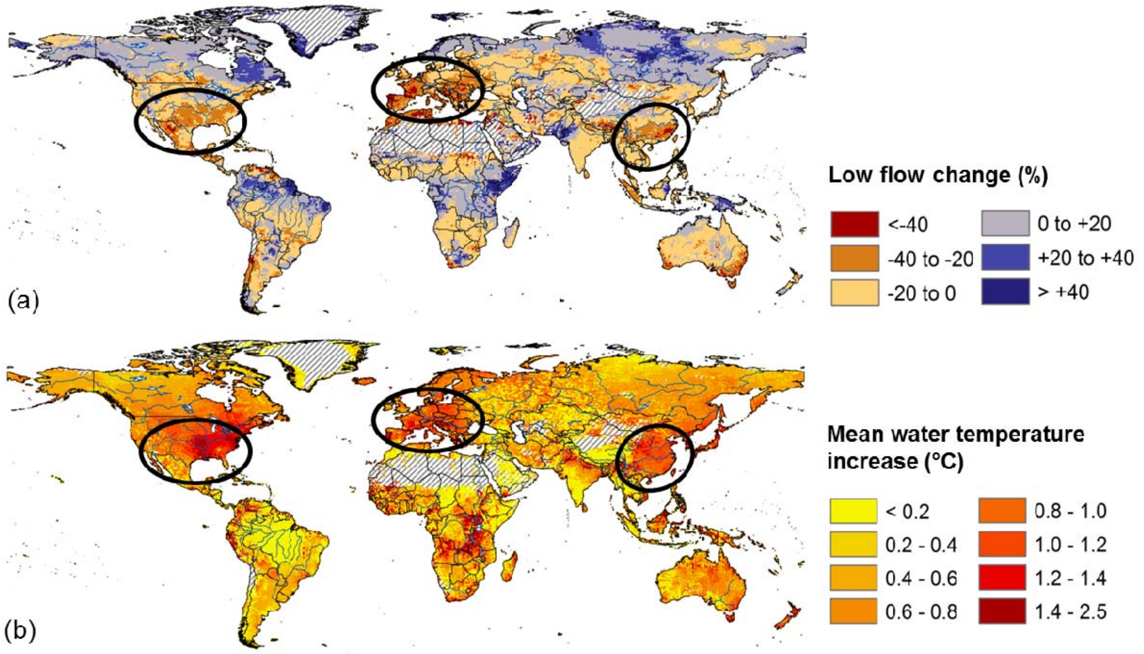

Fig. 1: Impact of climate change on low river flows (10-percentile daily flow)(a) and mean water temperatures (b) for 2031-2060 relative to 1971-2000 using the GCM ensemble mean simulations for SRES A2. The results are masked (hatched areas) for regions with very low (<1 m^3s^{-1}) river flow.

Impacts of projected changes in river flow and water temperature on cooling water use in the energy sector and freshwater ecosystems (i.e. fish habitats) were assessed in more detail. The frequency and magnitude of exceeding maximum temperature tolerance values of several fish species increased significantly for considerable areas of current suitable habitats (van Vliet et al., in revision). This could, in combination with changes in flow regime, affect the distributions of freshwater species. To maintain and protect current freshwater ecosystems, environmental standards are defined with regard to the volume and temperature of water for cooling water use (European Water Framework Directive and Fish Directive, and U.S. Clean Water Act). In Europe and the U.S., most electricity (91% and 78%, respectively) is currently produced by thermoelectric power plants depending on cooling water, and large fractions of water for cooling are extracted from rivers. Projected increases in river temperatures and declines in low summer flow for both regions are expected to increase environmental restrictions on cooling water use. This could result in substantial reductions in summer mean usable capacity of 6–19% for Europe and 4–16% for the US (depending on cooling system type and climate scenario for 2031-2060 relative to 1971-2000) (van Vliet et al., 2012b) (Fig. 2). Conflicts between environmental objectives and economic consequences of reduced electricity production are thus expected to increase in both regions due to the combination of increases in water temperatures and declines in summer low flow under climate change.

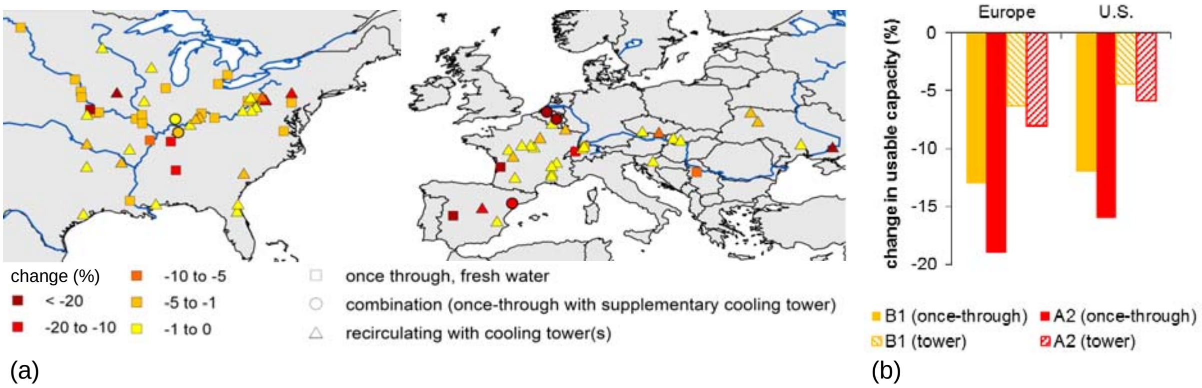

Fig. 2: Changes in summer mean usable capacity of thermoelectric power plants in the U.S. and Europe for SRES A2 emission scenario for 2031-2060 relative to 1971-2000 assuming current environmental regulations to protect ecosystems (figure panel of van Vliet et al. (2012b), with permission of Nature Climate Change) (a). Histograms present the regional average changes in usable power plant capacity for power plants with once-through and combination cooling systems and power plants with recirculation (tower) cooling systems for both the SRES A2 and B1 scenario (b). For more results see van Vliet et al. (2012b).

3 Conceptual modelling framework including water quality impacts

Most of the modeling frameworks that are currently used for climate change impacts analyses on water resources focus on water quanity and ignore water quality. Global water stress was commonly estimated by calculating the withdrawals-to-availability ratio (e.g. Alcamo et al., 2007; Arnell et al., 2011) using only river discharge and water withdrawal simulations. However, most water use sectors require not only sufficient water availability (quantity), but also suitable water quality.

The proposed modelling framework (Fig. 3) consists of a multi-model ensemble of both climate change scenarios (based on representative concentration pathways (RCPs) (Moss et al., 2010) and shared socio-economic pathways (SSPs) (Kriegler et al., 2012). These climate and socio-economic scenarios are used in global hydrological models with linked water quality modules and sectoral water use modules. To integrate relations between water availability, water quality and cross-sectoral water uses, both surface water availability and water quality will be simulated. In addition, water demand for different sectors and water requirements for freshwater ecoystems will be calculated with regard to both water availability and water quality.

Water quality parameters that are relevant for agriculture, domestic uses and ecosystem health are for instance salinity, nutrients, heavy metals and PAHs (polycyclic aromatic hydrocarbon). Water temperature is mainly important for energy and industrial uses, and also for human health (drinking water) and ecosystem functioning. For most of these water uses, specific threshold values that reflect a deterioration or reduction in water usage potential are defined. For instance, for drinking water production, the World Health Organization (WHO, 2011) defined water quality standards, like the 25°C water temperature limit for which thermophilic pathogens (e.g. Legionella Campylobacter and Vibrio cholerae) in surface waters with low residual concentrations of chlorine proliferate. The focus should therefore be on the availability of water of suitable water quality for each water use function. In addition, water quality can also influence water demand and these impacts could also be included in water stress analyses. For instance, the water demand for thermoelectric power strongly increases when water temperature rises (van Vliet et al., 2012b). Changes in thermoelectric water demands and water stress under future climate could therefore be underestimated if impacts of water temperature increases are ignored. Davies and Simonovic (2011) also showed that inclusion of dilution capacity for pollutants in water demands has large impacts on calculated water stress levels. Future changes in water quality under climate change and socio-economic changes would therefore be important to consider. The use of simulations of river flow, water quality and water demand (with regard to both availability and quality), is therefore highly recommended to improve the assessment of water stress under global change.

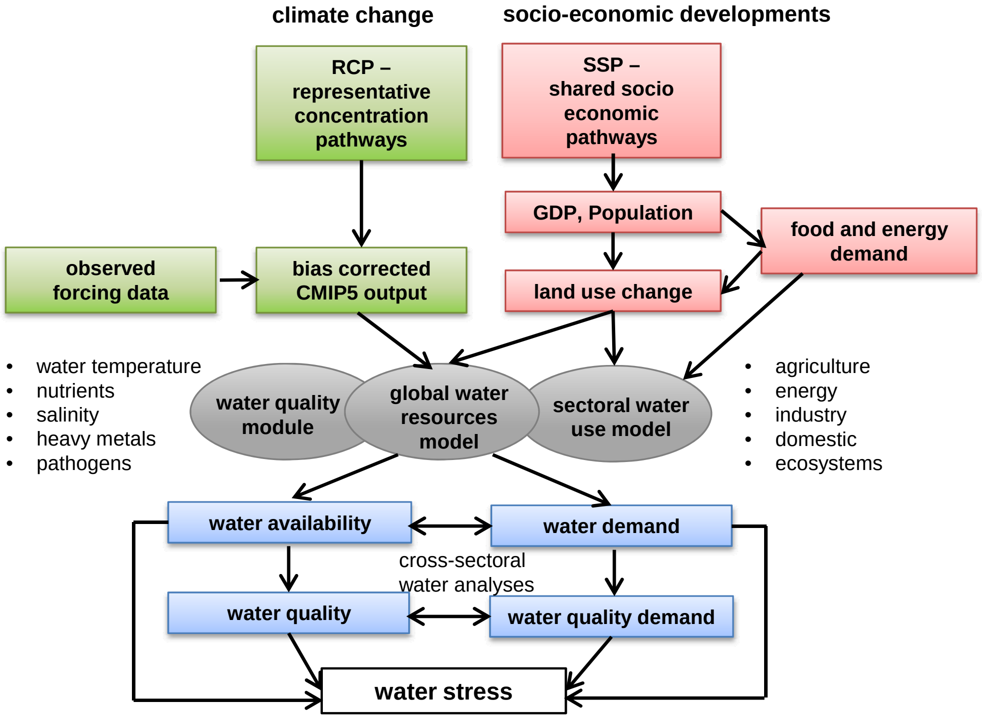

Fig. 3: Proposed modelling framework to integrate relations between water availability, water quality and cross-sectoral water uses under climate change and socio-economic developments.

4 Conclusions

Most water use sectors require not only sufficient water availability (quantity) but also suitable water quality. As pointed out in Section 2, the pressure on water between cooling water use in the energy sector and freshwater ecosystems in Europe and the U.S. will increase under climate change, because of changes in both summer flow and water temperature. Ignoring water temperature increases could result in an underestimation of the pressure on water between the energy sector and freshwater ecosystems.

For assessments of water stress and cross-sectoral conflicts for water under future climate and socio-economic changes, we therefore propose a modelling framework that includes both water availability and water quality.

Although the focus of our study has been limited to climate change impacts on global river flow and water temperature, the hydrological - stream temperature modelling framework (VIC-RBM) used in this study has potential to include other water quality parameters (van Vliet et al., 2013; Yearsley, 2009). An extension of the modelling framework to other water quality parameters affected by water temperature (e.g. dissolved oxygen), streamflow (e.g. conservative substainces) or both (nutrients, pathogens) could be a next step. Analysis of the competition for water between different water use sectors and freshwater ecosystems including water quality impacts, could contribute to improved understanding of the developments of the ‘water-energy-food-ecosystem nexus’ in the 21st century.

5 References

Alcamo, J. et al., 2003. Global estimates of water withdrawals and availability under current and future "business-as-usual" conditions. Hydrological Sciences Journal-Journal Des Sciences Hydrologiques, 48(3): 339-348.

Alcamo, J., Flörke, M., Marker, M., 2007. Future long-term changes in global water resources driven by socio-economic and climatic changes. Hydrological Sciences Journal-Journal Des Sciences Hydrologiques, 52(2): 247-275.

Arnell, N.W., van Vuuren, D.P., Isaac, M., 2011. The implications of climate policy for the impacts of climate change on global water resources. Global Environmental Change-Human and Policy Dimensions, 21(2): 592-603.

Carpenter, S.R., Fisher, S.G., Grimm, N.B., Kitchell, J.F., 1992. Global Change and Fresh-water Ecosystems. Annual Review of Ecology and Systematics, 23: 119-139.

Davies, E.G.R., Simonovic, S.P., 2011. Global water resources modeling with an integrated model of the social–economic–environmental system. Advances in Water Resources 34 684–700.

Döll, P., Müller Schmied, H., 2012. How is the impact of climate change on river flow regimes related to the impact on mean annual runoff? A global-scale analysis. Environ. Res. Lett. , 7(014037).

Ducharne, A., 2008. Importance of stream temperature to climate change impact on water quality. Hydrol. Earth Syst. Sci. , 12: 797–810.

Feyen, L., Dankers, R., 2009. Impact of global warming on streamflow drought in Europe. Journal of Geophysical Research-Atmospheres, 114.

Hagemann, S. et al., 2011. Impact of a Statistical Bias Correction on the Projected Hydrological Changes

Obtained from Three GCMs and Two Hydrology Models. Journal of Hydrometeorology, 12(4): 556-578.

Kriegler, E. et al., 2012. The need for and use of socio-economic scenarios for climate change analysis: A new approach based on shared socio-economic pathways. Global Environmental Change-Human and Policy Dimensions, 22(4): 807-822.

Kundzewicz, Z.W., Krysanova, V., 2010. Climate change and stream water quality in the multi-factor context. Climatic Change.

Liang, X., Lettenmaier, D.P., Wood, E.F., Burges, S.J., 1994. A Simple Hydrologically Based Model of Land-Surface Water and Energy Fluxes for General-Circulation Models. Journal of Geophysical Research-Atmospheres, 99(D7): 14415-14428.

Manoha, B., Hendrickx, F., Dupeyrat, A., Bertier, C., Parey, S., 2008. Climate change impact on the activities of Electricite de France. Houille Blanche-Revue Internationale De L Eau(2): 55-60.

Moss, R.H. et al., 2010. The next generation of scenarios for climate change research and assessment. Nature, 463(7282): 747-756.

Murdoch, P.S., Baron, J.S., Miller, T.L., 2000. Potential effects of climate chance on surface-water quality in North America. Journal of the American Water Resources Association, 36(2): 347-366.

Rahel, F.J., Keleher, C.J., Anderson, J.L., 1996. Potential habitat loss and population fragmentation for cold water fish in the north platte river drainage of the rocky mountains: Response to climate warming. Limnology and Oceanography, 41(5): 1116-1123.

van Roosmalen, L., Sonnenborg, T.O., Jensen, K.H., 2009. Impact of climate and land use change on the hydrology of a large-scale agricultural catchment. Water Resour. Res., 45(W00A15).

van Vliet, M.T.H. et al., 2013. Global River Discharge and Water Temperature under Climate Change. Global Environmental Change, 23: 450–464.

van Vliet, M.T.H., Ludwig, F., Kabat, P., in revision. Global Streamflow and Thermal Habitats of Freshwater Fishes under Climate Change.

van Vliet, M.T.H., Ludwig, F., Zwolsman, J.J.G., Weedon, G.P., Kabat, P., 2011. Global river temperatures and sensitivity to atmospheric warming and changes in river flow. Water Resources Research, 47(W02544).

van Vliet, M.T.H. et al., 2012a. Coupled Daily Streamflow and Water Temperature Modelling in Large River Basins. Hydrol. Earth Syst. Sci., 16: 4303–4321.

van Vliet, M.T.H. et al., 2012b. Vulnerability of US and European electricity supply to climate change. Nature Climate Change, 2: 676–681.

Vörösmarty, C.J., Green, P., Salisbury, J., Lammers, R.B., 2000. Global water resources: Vulnerability from climate change and population growth. Science, 289(5477): 284-288.

Whitehead, P.G., Wilby, R.L., Battarbee, R.W., Kernan, M., Wade, A.J., 2009. A review of the potential impacts of climate change on surface water quality. Hydrological Sciences Journal-Journal Des Sciences Hydrologiques, 54(1): 101-123.

Yearsley, J.R., 2009. A semi-Lagrangian water temperature model for advection-dominated river systems. Water Resources Research, 45 (W12405).

Yearsley, J.R., 2012. A grid-based approach for simulating stream temperature. Water Resources Research, 48(W03506).