Environmental Modelling & Software 69 (2015) 42–54

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

An interdisciplinary modelling framework for selecting adaptation measures at the river basin scale in a global change scenario

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ARTICLE INFO

Article history:
Received 21 February 2014
Received in revised form
26 February 2015
Accepted 28 February 2015
Available online

Keywords:
Global change
Adaptation
Integrated river basin modelling
Programme of measures
Interdisciplinary
Least-cost optimisation

ABSTRACT

Shaping global change adaptation strategy in water resource systems requires an interdisciplinary approach to deal with the multiple dimensions of the problem. The modelling framework presented integrates climate, economic, agronomic and hydrological scenarios to design a programme of adaptation measures at the river basin scale. Future demand scenarios, combined with a down-scaled climate scenario, provide the basis to estimate the demand and water resources in 2030. A least-cost river basin optimisation model is then applied to select adaptation measures ensuring that environmental and supply management goals are achieved. In the Orb river basin (France), the least-cost portfolio selected suggests mixing demand and supply side measures to adapt to global change. Trade-offs among the cost of the programme of measures, the deficit in agricultural water supply and the level of environmental flows are investigated. The challenges to implement such interdisciplinary approaches in the definition of adaptation strategies are finally discussed.

1. Introduction

Over the past decade, river basin agencies and stakeholders have been confronted with changing environmental, economic and societal conditions. Climatic conditions are evolving in many regions of the world, leading to increased water scarcity and risk of drought (Arnell, 2004). Climate change and the increased demand for food production lead to an extension and intensification of irrigated agriculture. Urban water use also increases due to the concentration of population in cities and the emergence of new consumption patterns (Hunt and Watkiss, 2011), particularly in the Mediterranean Basin (Thivet and Fernandez, 2012). These trends result in increasing pressure on surface and groundwater resources and dependent ecosystems. Concomitantly, societies have rising expectations in terms of environmental protection. This has materialized in many legislative frameworks, such as the EU Water Framework Directive aiming at achieving the good status of European water bodies (EU, 2000) and, more recently, the EU communication (Blueprint) to Safeguard Europe's Waters (EC, 2012) that identifies directions to achieve the good status, highlighting the interest of water efficiency measures among others.

Water planners need to anticipate how to adapt management practices and infrastructure development for some future state of their water resource systems. This requires that they develop a systemic approach depicting the natural and socio-economic factors and processes that determine future dynamics of river basins. The factors and interaction processes can be formally represented through the development of integrated river basin management models (Jakeman and Letcher, 2003; Letcher et al., 2007), which can be used either to learn about the impact of alternative water management strategies or to identify optimal strategies under future climate, demand and regulatory scenarios.

Developing such integrated models to estimate future changes and frame adaptation plans is not, however, a trivial task. It requires integrating concepts, methods and modelling tools from various domains of expertise and scientific disciplines. For instance, forecasting future urban water demand (Bauman et al., 1998) might require the participation of demographers (population growth forecasts), urban planners (housing stock and characteristics), economists (impacts of changing tariffs, changes in economic activities) and engineers (water supply and water saving options). Similarly, forecasts of future change of agricultural irrigation water demand should be informed by an economic analysis of future agricultural and international trade policies (economics and political science); by a technical assessment of

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http://dx.doi.org/10.1016/j.envsoft.2015.02.023
1364-8152/

innovations likely to emerge in terms of crop varieties, cropping practices and irrigation techniques (engineering sciences); by modelling crop water requirements (agronomy) under changing climatic conditions (Rinaudo et al., 2013a); and by a stakeholder analysis (sociology) to infer the objectives, priorities, expectations, behaviour and needs of the different agricultural stakeholders.

Modelling complexity also comes from the imperative to support decision making in a context where heterogeneous stakeholders participate in the search for a negotiated solution, moved by different interests and multiple objectives. Involving the stakeholders in the development of the model or some of its components theoretically ensures a better understanding of the underlying assumptions, thereby increasing its acceptability and credibility. However, the complexity of models, and the associated uncertainty, can be such that it stretches the understanding capacity of many stakeholders. A common issue among all the modelling tools and methods developed to address water management issues is indeed the one of uncertainty and its propagation that challenges the capacity of scientists to accurately represent the reality and provide reliable information about the future (Refsgaard et al., 2007).

Sustainable management of water resources and dependent ecosystems requires an understanding of climate change impacts on river flows (Caballero et al. 2007) and groundwater levels (hydrology and hydrogeology), and on the aquatic environment (hydro-ecology). Last but not least, a cross-fertilization of engineering, economics and other sciences is needed to define complex adaptation strategies that involve new combinations of water demand management measures (*e.g.* water conservation measures), infrastructure operation (*e.g.* management of reservoir or irrigation systems) and development of new capacity (*e.g.* groundwater exploitation or desalination projects). Therefore, we would expect an interdisciplinary modelling approach to provide the most relevant insights to water managers and policy makers. Combined with the participatory process, interdisciplinary modelling can help to develop a shared understanding of the water problems as a foundation for negotiated management and policy solutions (Heinz et al., 2007). Indeed, the integration of knowledge from different disciplines beyond their respective paradigms and the interconnection of mono-disciplinary intellectual silos has been highlighted as one of the salient dimensions for the success of integrated modelling approaches (Hamilton et al. 2015).

Pioneering efforts to develop an interdisciplinary approach addressing water planning issues date back to the Harvard Water Program in the late 1950s, when economics, social sciences and engineering were first brought in to support water policy making. Nowadays, such initiatives have become even more necessary due to the growing complexity of water management issues (Reuss, 2003). River basin management models – often coupled with Decision Support Systems tools – have been developed at basin scale to assess the performance of water resource systems under different scenarios and policy strategies (Andreu et al., 1996; Labadie, 2004). More recently, hydro-economic models (HEM; Harou et al., 2009) took one step further into interdisciplinary modelling by integrating economics and water resources management into a coherent framework. At basin scale, HEMs have been applied to assess the marginal economic value of storage and environmental flows and so provide economic indicators and instruments, as required by the EU WFD (Pulido-Velazquez et al., 2008, 2013; Riegels et al., 2013). In Europe, they are expected to assist in recommending measures for the next round of EU water policy (De Roo et al., 2012). In the United-States, HEMs have been applied to analyse the adaptation of inter-tied water supply system to global change in California (Tanaka et al., 2006; Medellín-Azuara et al., 2008) and New Mexico (Hurd and Coonrod, 2012). Various research initiatives have been launched to integrate the impact of climate change, from an interdisciplinary perspective, into the implementation process of the WFD (Quevauviller et al., 2012; Pouget et al., 2012). However, despite a few pioneering studies, the vast majority of existing studies stop short at the impact assessment stage, which means they provide only a limited contribution to the question of adaptation (Wilby and Dessai, 2010).

In the literature, the issue of selecting measures for the planning of water resources has been long addressed as the problem of capacity expansion optimization (planning and scheduling of infrastructure over time) through least-cost optimization models (O'Laoghaire and Himmelblau, 1974, Loucks et al., 1981; Ejeta and Mays, 2005, Matrosov et al., 2013). From this perspective, the part of the framework presented dedicated to the selection of measures could be seen as a least-cost planning model without option scheduling. Indeed, we consider that the main focus of the work is located one step before the scheduling in the planning process. The framework presented clearly deals with the definition of the planning scenarios (demand and hydrological) and objectives (environmental flows, agricultural development) before the phasing of the investment. The added value of the contribution lies in the combination of different modelling disciplines to define the climate and demand change scenario, and then assess trade-offs between the cost of the programme of measures and other planning objectives at the river basin scale.

This paper presents an interdisciplinary modelling framework to select adaptation measures at river-basin scale in a global change scenario. The method is tested on the Orb river basin, a Mediterranean basin in Southern France, where global change is expected to exacerbate the difficulties of meeting the growing water demands and the WFD environmental in-stream flow requirements. We describe first the general modelling framework that is used to generate future global change scenarios, to assess the impact of global change and to design the Programme of Measures (PoM) at basin scale; this is followed by a description of the demands and water resources modelling, and of the selection of adaptation measures through a Least-Cost River Basin Optimisation Model (LCRBOM). Next, we introduce the case study of the Orb basin, and describe the future socio-economic and environmental scenarios applied. One single scenario is selected to illustrate the application and potential of the framework. The results quantify future deficits in the supply of agricultural demand, and identify where adaptations to global change are required. Trade-offs between cost of the adaptation measures, agricultural deficits and environmental flow requirements are finally evaluated to highlight the potential of the interdisciplinary modelling framework to support water resources management. The final section presents the limitation of the models and discusses potential future developments, with feedback on the interdisciplinary process.

2. Material and methods

2.1. Interdisciplinary modelling framework

Because the interdisciplinary modelling framework presented in this paper is aimed at planning, the first challenge consists of identifying the main variables that determine the future of the system, and then in mobilizing and coordinating the corresponding disciplines able to model the processes impacting these variables. Fig. 1 depicts the interdisciplinary modelling framework we adopted and the variables chosen for our case study – a catchment that is fairly representative of those located on the northern rim of the Mediterranean basin. It shows that the water deficit – to be