Journal of Hydrology 538 (2016) 293–303

Contents lists available at ScienceDirect

Journal of Hydrology

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

Review Paper

Using ecosystem services to represent the environment in hydro-economic models

Andrea Momblanch [a,*], Jeffery D. Connor [b], Neville D. Crossman [b], Javier Paredes-Arquiola [a], Joaquín Andreu [a]

[a] Research Institute of Water and Environmental Engineering, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain
[b] Commonwealth Scientific and Industrial Research Organisation, Land and Water, PMB 2, Glen Osmond, SA 5064, Australia

ARTICLE INFO

Article history:
Received 18 February 2016
Received in revised form 4 April 2016
Accepted 9 April 2016
Available online 16 April 2016
This manuscript was handled by Geoff Syme, Editor-in-Chief, with the assistance of Jesús Mateo-Lázaro, Associate Editor

Keywords:
Water resources management
Hydro-economic models
Environmental impacts
Ecosystem services framework

SUMMARY

Demand for water is expected to grow in line with global human population growth, but opportunities to augment supply are limited in many places due to resource limits and expected impacts of climate change. Hydro-economic models are often used to evaluate water resources management options, commonly with a goal of understanding how to maximise water use value and reduce conflicts among competing uses. The environment is now an important factor in decision making, which has resulted in its inclusion in hydro-economic models. We reviewed 95 studies applying hydro-economic models, and documented how the environment is represented in them and the methods they use to value environmental costs and benefits. We also sought out key gaps and inconsistencies in the treatment of the environment in hydro-economic models. We found that representation of environmental values of water is patchy in most applications, and there should be systematic consideration of the scope of environmental values to include and how they should be valued. We argue that the ecosystem services framework offers a systematic approach to identify the full range of environmental costs and benefits. The main challenges to more holistic representation of the environment in hydro-economic models are the current limits to understanding of ecological functions which relate physical, ecological and economic values and critical environmental thresholds; and the treatment of uncertainty.

Contents

1. Introduction

Adequate flows of fresh water in rivers support food and energy production, other economic activities such as river navigation and productive fisheries, as well as clean water provision through processes such as dilution and biological degradation (Momblanch et al., 2015). All these uses compete for water resources with diverse use rights (Babel et al., 2005), and different opportunities and costs associated with adapting to less water availability (Booker, 1995).

* Corresponding author.

http://dx.doi.org/10.1016/j.jhydrol.2016.04.019
0022-1694/

The 1972 amendment to the US Clean Water Act established national water quality standard to preserve aquatic life, recreational uses, and their values (Copeland, 2010). Since then, there has been an increased focus on understanding the environmental and socio-economic benefits of leaving water in streams, rivers and aquifers rather than extracting it for consumptive use. For example, in the Murray–Darling Basin in Australia, Connor (2008) found that additional flows in the river could significantly reduce costs of salinity damage through dilution, and Crossman et al. (2015) documented substantial carbon sequestration, tourism, and freshwater quality values, among others, from reducing water extraction. Grossmann and Dietrich (2012) assessed carbon sequestration, boating, habitat and biodiversity values of different water management options for the Spreewald Wetland in Germany. These studies used the ecosystem services (ES) concept to report on the benefits. The core ES notion is that a wide range of natural ecosystem processes help sustain and fulfil human life (Daily et al., 1997), and that these services can be translated into economic values. Many ES are only substitutable at high economic costs, and in some cases cannot be replaced (Brauman et al., 2007; Costanza et al., 1997). For example, wetlands have the capacity to purify water by means of biochemical processes (Turner et al., 2008) with capacity being a function of wetland condition and health. The degradation of wetland ecosystems could increase treatment costs of the water extracted for consumptive use (Maltby and Barker, 2009) and/or a reduce the recreation potential (Kahil et al., 2015) leading to loss of income for the tourism industry.

According to the 5th assessment report of the Intergovernmental Panel on Climate Change (2014), renewable fresh water resources are likely to decrease over the 21st century, most significantly in arid and semi-arid regions where increased frequency of drought occurrence is expected (Schwabe et al., 2013). Additionally, water demand is expected to grow with global population growth (UN, 2015), resulting in more waste generation, pollution and land use expansion, which increases the pressure on land and water resources (Shama, 2004). Less water availability and lower quality, together with larger water demands, has led to increasing conflicts among water uses. Examples include conflicts between hydropower production and fisheries in the Mekong River in China (Ringler et al., 2004); irrigation and urban water uses in the Jucar and Vinalopó rivers in Spain (Andreu et al., 2009); and environmental and irrigation water uses in the Murray Darling Basin in Australia (Qureshi et al., 2007) and the Colorado River Basin in the United States (Booker and Young, 1991).

Integrated water resources management, defined as the coordinated development and management of water, land and related resources to maximise economic and social welfare without compromising the sustainability of vital ecosystems (GWP, 2000), can inform decisions about water sharing in the face of competing water demands and increasing scarcity (Booker et al., 2012). Hydro-economic models (HEMs) are one of the main tools used for integrated water resources management (Booker et al., 2012; Harou et al., 2009). HEMs combine hydrological and water infrastructure representation of water resources systems with economic demand functions for key water uses in order to allocate water subject to physical and institutional constraints (Heinz et al., 2007). HEMs typically use a node network structure with nodes representing points of diversion, inflow, outflow, storage or treatment and links between nodes representing river reach processes (Harou et al., 2009). HEMs can use optimisation or simulation approaches, but typically have the goal of allocating water among multiple uses to optimize economic value (Brouwer and Hofkes, 2008). HEMs have been used to solve water management problems for more than 50 years, and have evolved from analysing single-water use problems at water supply scale (Lefkoff and Gorelick, 1990; Wilchfort and Lund, 1997) to integrated multiple-demand and multiple-source problems at single river basin scale (Davidson et al., 2013b; Divakar et al., 2011) and multi-basin scale (Bekchanov et al., 2015c; Fisher et al., 2002). Groundwater representation and its connection to the surface water system have also featured in HEMs (Daneshmand et al., 2014; Pulido-Velazquez et al., 2006, 2008).

Several studies have reviewed HEMs. For example, Harou et al. (2009) focus on methodological aspects of HEMs, such as model formulation and design, economic valuation methods for the different water uses, and major applications. Heinz et al. (2007) discuss the role of economic approaches in water management to address the European Water Framework Directive (EC, 2000) objectives, analysing diverse assessment and performance criterion, water policies and management options. Booker et al. (2012) review the advances in economic representation, policy objectives and water institutions, and level of integration and complexity of HEMs.

Consistent across reviews of HEMs is the conclusion that representation of environmental costs and benefits in HEMs is patchy and limited. For example, Harou et al. (2009) conclude that environmental water uses are rarely represented with economic value functions in HEMs, although minimum-flow constraints are included more often. They also highlight the importance of incorporating water quality processes and values which are mostly lacking in HEMs. Booker et al. (2012) argue for the expansion of HEMs to jointly tackle environmental, economic, hydrologic and institutional water resources management problems. Other reviews highlight the limited representation of environmental in-stream uses and processes in HEMs (Ringler and Cai, 2006; Ward and Pulido-Velazquez, 2009; Ward and Pulido-Velázquez, 2008), and the dearth of HEMs which account for water management changes on non-market values provided by ecosystems (Griffin and Hsu, 1993; Kragt, 2013).

There has not yet been any attempt at systematic cataloguing and critical assessment of the range of environmental impacts and values included in HEMs. Here we address this gap by: (i) reviewing the range of environmental impacts included in HEMs; (ii) documenting the methods used to represent the economic value of environmental impacts in HEMs, and; (iii) making recommendations to improve the inclusion of environmental impacts and values in HEMs.

We use ES as an organising framework because it offers a systematic way to analyse the potential environmental impacts of changes to water management using the environment-economy connection. This connection is best demonstrated by the ES cascade (Potschin and Haines-Young, 2011) which shows the causal links from a change in biophysical state as a result of altered management, to the ecosystem change and then the change to ES, economic values and human well-being (Fig. 1). In recent years there has been a proliferation of ES frameworks (Haines-Young and Potschin, 2013; MA, 2005; TEEB, 2008; UK NEA, 2011). Common to all ES frameworks is the *provisioning* category, which are directly consumed ES products. An example is fish production in rivers that people value as food. All ES frameworks also include the *regulating* category for ES that arise from maintenance and moderation of environmental conditions. The capacity of wetlands to purify water by means of biochemical processes (Turner et al., 2008) is an example. Also common to ES frameworks is a category for non-consumptive values such as recreational, educational, aesthetic and spiritual. The major difference between ES frameworks is how intermediate ecosystem processes are treated. Some frameworks only include end-products or services consumed or valued directly by humans (MA, 2005; Wallace, 2007), while other frameworks include environmental processes which only indirectly contribute to human welfare, such as decomposition