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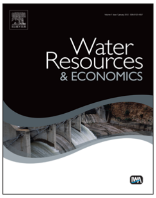

Hydro-economic modelling in an uncertain world: Integrating costs and benefits of water quality management

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ABSTRACT

Decision support tools that aim to assist efficient integrated water resources management should integrate the multiple, interdependent uses of water. There exist, however, few models that assess the trade-offs between environmental and socio-economic impacts of water management changes in an integrated framework. This paper presents a model that integrates hydrological, ecological and economic information in a Bayesian Network modelling framework. A suite of modeling tools was developed to assess the biophysical and economic impacts of catchment management scenarios, for a case study in Tasmania, Australia. We describe how the models are integrated in a Bayesian Network that shows the economic and ecological trade-offs of different catchment management options. The integrated Bayesian Network model demonstrates a flexible approach to incorporate different types of data and explicitly accounts for accumulated uncertainty in information.

1. Introduction

Sustainable management of water resources faces the difficult task of coordinating multiple, often competing, uses of water, in a way that balances environmental and socio-economic demands. Integrated water resources management (IWRM) implies that resources are managed in ways that

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"maximise economic and social welfare in an equitable manner, without compromising the sustainability of vital ecosystems" [1]. If management is targeted at maximising economic and social welfare, we need information about the socio-economic values affected by different uses of water resources, including those associated with agricultural production, biodiversity conservation, recreation and other economic activities.

One of the tools that is often used to support IWRM is hydro-economic modelling. Hydro-economic models aim to integrate hydrology, water management, environmental conditions, and socio-economics aspects of water resources management in a coherent modelling framework [2]. Hydro-economic models bring economics to the core of water resources management, by evaluating the socio-economic values generated by the different uses of water resources [2,3].

Hydro-economic models have been used for decades by engineers and economists to support water management decisions [e.g., [4,5–10]. Many hydro-economic models focus on optimal water extraction to maximise (agricultural) production values, or on minimising the costs of reduced water supply or pollution. In a typical hydro-economic model, water extraction infrastructure (such as canals, reservoirs, pumping stations) is linked to hydrologic features of a system (such as river flows, precipitation, evaporation, groundwater recharge) in a node-link network, where economic costs and benefits are generated by water use and production activities [see [2,5]. Excellent reviews of hydro-economic modelling applications include Ward et al. [11] and Heinz et al. [12] on catchment-scale models; and Harou et al. [2] on water allocation models. McKinney et al. [13], Heinz et al. [12], Brouwer and Hofkes [14], and Cai [15] describe methodological issues related to linking hydrological and economic systems.

Notwithstanding the emphasis of IWRM on maximising economic and social welfare while preserving ecosystems, there are relatively few models that integrate hydrological changes, ecosystem impacts, and economic costs and benefits [14,16,17]. Existing models have limited ability to account for the inherent uncertainty in environmental systems, and there are few models that incorporate the effects of water management changes on nonmarket (intangible) values provided by ecosystems.

Risk and uncertainty play a major role in IWRM, where imperfect understanding or incomplete knowledge about economic, hydrologic, and ecological systems results in uncertainties in input data, model structure, parameter values, and model results. A key challenge to integrated modelling is how to account for fundamentally different types of uncertainties in a consistent way [14]. In modelling, uncertainty is often accounted for through stochastic programming or sensitivity analysis (for example, Cai et al. [18]). In integrated models, traditional stochastic programming with uncertain parameters can meet serious computational difficulty if uncertainties are correlated across items [15]. An alternative approach to accounting for uncertainty in environmental systems is Bayesian network modelling [19–22]. In a Bayesian network, uncertainties are directly incorporated by describing relationships between variables as conditional probability distributions, which effectively expresses uncertainty as a risk (Section 3.2).

Water managers need information about the impacts of policy changes on ecosystem conditions. Hydro-ecological models are aimed at assessing such changes by explicitly considering hydrological and ecological processes, and the interactions between them. Hydro-ecological models may focus on the ecological impacts of eutrophication and acidification of surface water [23]; protection and restoration of healthy natural wetland habitats [24]; or flood control policies [25]. Although most of these models include the direct financial costs of undertaking management actions, few assess the economic costs and benefits that result from a change in ecosystem conditions. An example of a hydro-ecological model that incorporates economics is the NELUP model [26,27]. NELUP assesses how rural land use changes in the River Tyne catchment, UK, affect surface water and groundwater flows. An economic module, based on a linear programming, predicts how agricultural land use varies with different policy conditions and market prices. Subsequently, hydrological and ecological modelling components predict changes in water flows, plant community, and species composition in response to the agricultural land use changes. Another economic-ecological model of water quality is described in Volk et al. [7], who developed a spatial decision support tool called FLUMAGIS. FLUMAGIS integrates water quality models with ecological and socio-economic information for a catchment in Germany. The ecological assessments were based on macro-zoobenthic community, macrophytes, and a typological classification of watercourses. The economic assessments were limited to analysing the