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Integrated hydro-ecological and economic modeling of environmental flows: Macquarie Marshes, Australia

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ABSTRACT

This study provides a method to combine hydro-ecological response model outputs and nonmarket economic values of wetland inundation to estimate a unit price of environmental water. We show how an integrated socio-economic and hydro-ecological modelling approach may assist policy makers with water allocation decisions across competing uses. The IBIS decision support system incorporates a hydro-ecological model and is used to estimate the habitat suitability condition of wetland attributes for a given hydrology scenario. Non-use economic values of wetland attributes obtained by non-market valuation studies are then linked to the hydro-ecological model outputs to estimate marginal value of environmental flows. The contribution is to provide a robust, scientifically and economically valid method to estimate the marginal value of environmental water and to quantitatively evaluate the trade-offs involved in water allocation decisions across competing uses for water.

1. Introduction

River irrigation water demand has increased dramatically over the past few decades and has become the single most important factor in the reduction of stream flows in four continental river basins (Grafton et al., 2012). Critical to promoting better river basin governance is a quantitative method for comparing extractive and non-extractive values for water (Ward and Booker, 2003). Such a framework would allow decision makers to evaluate the trade-offs from re-allocating water used for extractions to environmental flows.

Two key challenges when comparing the payoffs to extractive water use versus non-extractive stream flows include: (1) the need for ecological response models to predict the likely outcomes of increased stream flows and (2) a method to value these ecological responses in monetary terms. These two approaches have rarely been combined in a way that generates a scientifically valid method to estimate marginal values of water that are consistent with economic theory, stream hydrology and modelled ecological response.

In one of the earliest integrated modelling application, Ward and Lynch (1996) linked a travel cost model of recreational water use in the New Mexico's Rio Chama basin to an integrated model that optimizes the economic performance of water allocations across upstream hydroelectricity production and instream and downstream recreation demands. Subsequently, a similar approach was applied by several other studies (see for example Van den Bergh et al., 2001; Ward and Booker, 2003; Ward and Pulido-Velazquez, 2008; Gürlük and Ward, 2009; Bryan et al., 2010).

A key limitations of the integrated approach used by the previous studies is that it evaluates the benefits and costs of a specific (or multiple) water management or optimization scenario(s). For example, Ward and Lynch (1996) compared the economic benefits and costs of an optimal versus a historical water management plan. Ward and Booker (2003) evaluated 'with and without minimum stream flows (50 cubic feet per second)' scenarios to assess the economic benefits of the endangered Rio Grande silvery minnow conservation. This scenario specific approach does not generate a unit value of environmental flows that can be used to assess the net marginal benefits of reduced water extractions under a generic policy context. We respond to these technical and policy challenges by developing a framework that generates a unit price of increased environmental flows. This unit value approach has two advantages compared to the scenario specific approach. First, it can be used to evaluate any generic policy scenario which

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involves trade-offs across extractive and non-extractive water uses. Hence, it allows a large degree of flexibility in water policy analysis. Second, it can be used to assess economic efficiency (instead of cost-effectiveness)[1] of water allocation decisions by applying the principle of equimarginal value which requires the marginal (incremental) value per unit of water used to be equal across all uses.

The integrated model presented in this paper considers the potential ecological benefits achieved by increasing flows in a wetland ecosystem. Our method combines a hydro-ecological model of a wetland with economic, stated preference models of household willingness to pay for an improvement in environmental attributes. First, we employ hydrological and ecological response models to project the likely outcomes of delivering environmental water to an ecological asset (e.g. wetland) by relating hydrological parameters (e.g. inundation duration) to species water requirements. Second, we use stated preference valuation studies to estimate nonmarket values associated with wetland ecosystem protection. These valuation studies use a hypothetical market or referendum with respondents to elicit household preferences for ecological/environmental attributes. Our model thus helps to estimate the economic value of an additional unit of water in the environment (i.e. unit value of environmental water). Such a price allows quantitative monetary comparisons about the marginal benefits of reallocating water to the environment from extractive uses.

Our contribution is three-fold. First, we provide a general framework that combines both hydro-ecological and economic modelling to valuing environmental flows that can be applied in any river basin where there is sufficient data. Second, we demonstrate how the framework can be applied to generate unit value of environmental water using data and models developed for the Macquarie Marshes, a wetland of global significance located in the Murray-Darling Basin of Australia. Third, we demonstrate how the estimated values can be used to evaluate the trade-offs between water extractions for agriculture and stream flows by drawing upon actual data from the Australian water market.

The remaining article is organized as follows: Section 2 presents an overview of the existing integrated modelling approaches. A description of the case study area is presented in Section 3 followed by our methodological framework in Section 4. Section 5 presents the integrated modelling results. Section 6 demonstrates how these results can be used to compare extractive and non-extractive values. Section 7 and 8 present discussions and concluding remarks respectively.

2. Literature

The need for integrated modelling to promote transparency and efficiency in water resource management has received a significant interdisciplinary attention in recent times. A majority of the integrated water management studies combine either 'hydrologic and economic' or 'hydrologic and ecological' aspects of water resources systems (see Harou et al., 2009 for a review). Integrated hydro-economic models (e.g. AQUARIUS) allow decision makers to evaluate the physical and economic impacts of existing and alternative structural measures, changes in temporal and spatial allocation of flows among competing water uses subject to environmental and institutional restrictions (Diaz et al., 2000; Brown et al., 2002). These models do not explicitly account for ecological responses. Integrated hydro-ecological models, on the other hand, estimate the ecological effects of altering water management strategies by combining ecosystem response models with river hydrology subject to existing infrastructure (e.g. weirs, regulators) and reservoir releases (e.g. Higgins et al., 2011). These models identify the flow and operational regimes that achieve an optimal trade-off between ecological health and human needs. The economic aspect received little attention in these models.

Integrated 'hydro-ecological and economic' models have rarely been developed and applied in environmental flow management decisions although they have been applied in other contexts. For instance, Ward and Pulido-Velazquez (2008) applied an integrated biophysical, hydrologic, agronomic model to assess the likely impacts of (irrigation) water conservation subsidies in the Upper Rio Grande Basin of North America. Their study showed that conservation subsidies are in fact likely to cause water depletion through increased water extraction. The handful of studies that applied integrated hydrology, ecology and economics model for environmental flow analysis have evaluated alternative land-use and infrastructural investment/management scenarios (see for example Ward and Lynch, 1996; Van den Bergh et al., 2001; Ward and Booker, 2003; Bryan et al., 2010). Van den Bergh et al. (2001) applied a linked spatial hydrological, ecological and economic model in the floodplain of river Vecht (the Netherlands) to evaluate the economic benefits of three alternative land-use patterns (i.e. agriculture, nature conservation, recreation). Bryan et al. (2010) applied a hydro-ecological and economic model in the River Murray floodplain in South Australia. Their model generated a decision support tool which can identify and rank a range of cost-effective infrastructure investments and a plan for their operation specifying where and when to capture and release water in riparian ecosystems.

3. Study area: the Macquarie Marshes

The Macquarie Marshes, located on the Macquarie River in New South Wales (NSW), Australia, are the largest of many freshwater wetlands of tributary rivers in the Murray-Darling Basin. The Marshes are a well-known site for breeding of colonial waterbirds (e.g. straw-necked ibis, intermediate egrets and the endangered Australasian bittern) and support a diverse mosaic of vegetation types including the iconic *Eucalyptus camaldulensis* (River red gum). About 10 percent of the Marshes is listed as a wetland of international importance under the Ramsar Convention.

Flows in the Macquarie River catchment have been regulated since 1896, with heavy regulation of flows in the lower Macquarie River and Macquarie Marshes since the installation of Burrendong Dam in 1967 (Kingsford, 2000). This dam has significantly altered the flow regime on the lower Macquarie River by reducing the frequency of large- and medium-sized floods and eliminating many periods of very low or zero flow (Ralph and Hesse, 2010). Remaining flows are further controlled by a series of weirs, regulators, bypass canals, earthen embankments and irrigation channels that aid the diversion and abstraction of water for agricultural, industrial and domestic purposes. The largest benefit of the dam goes to irrigated agriculture, particularly to the water-intensive high-profit cotton industry. The gross value of irrigated agricultural production (GVIAP) in the Central West region of NSW where the Macquarie catchment is located was AU $196 million in 2010–11 (ABS, 2012).[2]

Evidence suggests that the regulation of flows in the Macquarie Marshes has affected the ecological integrity of the aquatic systems by changing the food sources and altering waterbird habitat and breeding conditions (Sabella, 2009). Although some waterbird species are adapted to permanent wetlands, many species

[1] Efficiency involves achieving an outcome with highest possible benefit while cost-effectiveness implies generating an outcome with least possible cost. Efficiency and cost-effectiveness do not necessarily lead to same outcomes.

[2] GVIAP data were not available for Macquarie catchment.