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Integrated assessment of policy interventions for promoting sustainable irrigation in semi-arid environments: A hydro-economic modeling approach

Irene Blanco-Gutiérrez [a,*], Consuelo Varela-Ortega [a], David R. Purkey [b]

[a] Department of Agricultural Economics and Social Sciences, Universidad Politécnica de Madrid, ETSI Agrónomos, Av. Complutense s/n, Ciudad Universitaria, 28040 Madrid, Spain

[b] Stockholm Environment Institute US Center, 400 F St., Davis, CA 95616, USA

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ABSTRACT

Sustaining irrigated agriculture to meet food production needs while maintaining aquatic ecosystems is at the heart of many policy debates in various parts of the world, especially in arid and semi-arid areas. Researchers and practitioners are increasingly calling for integrated approaches, and policy-makers are progressively supporting the inclusion of ecological and social aspects in water management programs. This paper contributes to this policy debate by providing an integrated economic-hydrologic modeling framework that captures the socio-economic and environmental effects of various policy initiatives and climate variability. This modeling integration includes a risk-based economic optimization model and a hydrologic water management simulation model that have been specified for the Middle Guadiana basin, a vulnerable drought-prone agro-ecological area with highly regulated river systems in southwest Spain. Namely, two key water policy interventions were investigated: the implementation of minimum environmental flows (supported by the European Water Framework Directive, EU WFD), and a reduction in the legal amount of water delivered for irrigation (planned measure included in the new Guadiana River Basin Management Plan, GRBMP, still under discussion). Results indicate that current patterns of excessive water use for irrigation in the basin may put environmental flow demands at risk, jeopardizing the WFD's goal of restoring the 'good ecological status' of water bodies by 2015. Conflicts between environmental and agricultural water uses will be stressed during prolonged dry episodes, and particularly in summer low-flow periods, when there is an important increase of crop irrigation water requirements. Securing minimum stream flows would entail a substantial reduction in irrigation water use for rice cultivation, which might affect the profitability and economic viability of small rice-growing farms located upstream in the river. The new GRBMP could contribute to balance competing water demands in the basin and to increase economic water productivity, but might not be sufficient to ensure the provision of environmental flows as required by the WFD. A thoroughly revision of the basin's water use concession system for irrigation seems to be needed in order to bring the GRBMP in line with the WFD objectives. Furthermore, the study illustrates that social, economic, institutional, and technological factors, in addition to bio-physical conditions, are important issues to be considered for designing and developing water management strategies. The research initiative presented in this paper demonstrates that hydro-economic models can explicitly integrate all these issues, constituting a valuable tool that could assist policy makers for implementing sustainable irrigation policies.

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1. Introduction

Water is a vital resource for life, but also a critical limiting factor for economic and social development in many parts of the world. Water scarcity and drought situations are increasing the pressure on water resources and the environment, as well as leading to growing conflicts among competing water use sectors and regions (Gleick et al., 2009; World Bank, 2006).

In Spain, as in many other arid and semi-arid regions, irrigated agriculture is responsible for most consumptive water use and plays an important role in sustaining rural livelihoods (Lopez-Gunn et al., 2012; Varela-Ortega, 2007). Historically, publicly-funded irrigation

* Corresponding author. Tel.: +34 91 336 57 83; fax: +34 91 336 57 97.
E-mail addresses: irene.blanco@upm.es (I. Blanco-Gutiérrez), consuelo.varela@upm.es (C. Varela-Ortega), dpurkey@sei-us.org (D.R. Purkey).

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development plans promoted irrigation expansion and economic growth in agrarian Spain, but increased environmental damage and led to excessive and inefficient exploitation of water resources, raising serious questions over the environmental and economic sustainability of irrigated systems (Varela-Ortega, 2011). In recent years, increased focus has been placed on the protection and better allocation of water resources, and therefore on broader integrated water resources management strategies, policies, and tools.

In the European (EU) policy arena, water policies and agricultural policies are also moving in the direction of integrated resources management. Over the last decade, the two crucial EU policies in relation to irrigated agriculture -the Common Agricultural Policy (CAP) and the Water Framework Directive (WFD) have progressed toward common objectives and strategies in order to protect and improve the natural environment.

The last review of the CAP, the 'Health Check' reform (EC, 2009), seeks to increase the competitiveness and sustainability of EU agriculture by supporting market-oriented and environmentally friendly agricultural production. The reform introduces new income support schemes for farmers, promotes greener farming practices, and includes water and climate change as specific requirements in its programs. On the other hand, the WFD (EC, 2000) places special emphasis on environmental protection objectives aiming to achieve a sustainable 'Good Ecological Status' (GES) of all water bodies across every European river basin district by 2015. As opposed to earlier segmented EU water protection programs, the WFD adopts a multi-sectoral and holistic river basin management approach and offers an important opportunity to incorporate economic instruments and integrated management tools and strategies into water resources planning (Heinz et al., 2007).

Recent shifts in water management paradigms and policies have fostered the development of integrated multi-disciplinary methods for supporting water decision-making. Among the extensive suite of methods used for integrated water management (Bayesian networks, metamodels, risk-assessment approaches, and others, see Croke et al., 2007), hydro-economic models have emerged as privileged tools to assist policy-makers in the assessment and development of sustainable water management strategies (Booker et al., 2012). The combination of economic insights with hydrology and engineering processes offers a more realistic and coherent framework to analyze the potential implications of water management and climate-related issues for all water users (Brouwer and Hofkes, 2008; Medellín-Azuara et al., 2009). Hydro-economic models improve decision-making by providing relevant insights in terms of water valuation and allocation, integrated water planning and institutional design, and have been successfully used in a wide variety of settings as reported in Harou et al. (2009). Recent hydro-economic model applications have been developed to study water quality problems and environmental restoration issues (e.g. Becker and Friedler, 2013; Qureshi et al., 2008; Yang et al., 2007), droughts and climate change impacts (e.g. Harou et al., 2010; Maneta et al., 2009), water allocation strategies (e.g. George et al., 2011; Gohar and Ward, 2010), water pricing and resource costs (e.g. Riegels et al., 2011; Ward and Pulido-Velázquez, 2009), and land use planning policies (e.g. Ahrends et al., 2008). Many of these applications use hydrologic simulation models, such as MIKE BASIN (Jha and Gupta, 2003), RIBASIM (WL Delft Hydraulics, 2004), MODSIM (Labadie, 2011), SWAT (Neitsch et al., 2011), and WaSIM (Schulla, 2012), in combination with profit optimization techniques, following a compartmental hydro-economic approach (i.e, the economic and hydrological aspects are separated in two independent, but interconnected models). As compared with fully integrated (holistic) models, compartmental approaches permit to combine complex economic and hydrologic tools that can be independently solved and therefore, more easily calibrated, and improved. Nonetheless, they face information transfer difficulties that can be partially surpassed by the adoption of data exchange tools (Brouwer and Hofkes, 2008; McKinney et al., 1999).

Along the same lines, this paper present the development and application of a novel economic-hydrologic modeling framework to evaluate the potential impacts of different policy interventions and a change in climate on the hydrological and agrarian systems of the Middle Guadiana basin, a vulnerable drought-prone agro-ecological area with highly fragmented and regulated river systems in southwest Spain. The integrated modeling framework includes a risk-based economic optimization model of farm decision-making and a hydrologic water resources simulation model WEAP ('Water Evaluation and Planning' system) (Sieber and Purkey, 2011). Both models work in standalone mode, but they are connected through an automated simulation engine, which allows the user to sequentially run the models.

To date, few studies have used WEAP in combination with socio-economic models. Some examples are those of Purkey et al. (2008), where WEAP and econometric methods are applied to assess climate change impacts on water supply and agricultural water management; and of Kemp-Benedict et al. (2010), that illustrate the integration of WEAP with Knowledge Elicitation Tools (KnETs) for sustainability planning. Lately, Varela-Ortega et al. (2011) use a stylized water management WEAP application and a farm-based economic optimization model to analyze water and climate uncertainties on groundwater-supplied irrigation systems. In contrast to the integrated framework developed by Varela-Ortega et al. (2011) that offers a one-way flow of information from the economic to the hydrologic model, the present study includes feedback loops between socio-economic and hydrologic processes and makes use of a hydrologic module in addition to a water management module to better capture all aspects of catchment hydrology. Hence, the present research takes a step forward in terms of model performance, application and linking.

2. The study region and the policy problem

The Middle Guadiana basin constitutes an emblematic case study where to apply and learn for integrated modeling in guiding and supporting water management decision-making. The basin is located on the south-western plateau of the Iberian Peninsula in Spain, and its left boundary acts as a natural border between Portugal and Spain (see Fig. 1). The Middle Guadiana extends over an area of 27,319 km^2 within Spanish territory and is home to 762,131 people.

The region exhibits a semi-arid Mediterranean-Continental climate, characterized by recurrent drought spells and normal years with hot, dry summers and warm, wet winters. The cultivated land covers nearly 1,200,000 ha (44% of the total surface of the basin), of which 130,000 ha are irrigated and almost totally dependent of surface water. Although irrigated agriculture accounts for less than 5% of the land area, it is by far the largest user of water (irrigation represents up to 93% of all water withdrawn) and one of the most important economic drivers in the region (CHG, 2008).

Similarly to other agricultural areas in Spain, this region has beneficiated from public plans for the development of extensive irrigation systems. Since 1952, year in which the first publicly funded development plan (the 'Plan Badajoz') was launched, the irrigated area has tripled and numerous hydraulic infrastructures (dams, reservoirs, canals) have been built. At present, the basin holds 43 large dams with a total storage capacity of almost 8000 Mm^3 (nearly, 15% of the total reservoir capacity in Spain), which makes the Middle Guadiana basin one of the most regulated basins in Europe (CHG, 2008). Irrigation expansion in the area has helped to partially mitigate the impacts of the region's once endemic drought and has brought about socio-economic prosperity to the rural communities

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