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Balancing competing water demands in intensively-irrigated regions: A hydro-economic analysis of cross-scale interactions between natural and socio-economic systems

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Water scarcity is an issue of major concern in arid and semi-arid areas, characterized by periodic droughts and high rainfall variability. In Spain, water stress situations are provoking a growing competition for water and land resources across sectors, regions, and stakeholder groups. Alongside this, rising water consumption occurs together with water quality deterioration and environmental degradation. Balancing competing water uses for meeting human and ecosystem needs requires a holistic and multi-disciplinary approach to water resource management. Over recent years, increased emphasis has been placed on integrated water management strategies, policies, and tools. In particular, hydro-economic models have proven to be useful tools for conducting IWRM and for providing relevant insights for water resources planning and policy, institutional and financial design. This study presents an extension of the available hydro-economic modeling tools in terms of model performance, application, and linking. It describes a novel spatial and temporal integration of a multi-scale economic model of farm-decision optimization with the GIS-based Water Evaluation And Planning system (WEAP). This integrated modeling framework is applied to the Middle Guadiana River Basin, a large semiarid region in Spain's southwest of intensely-irrigated farmland dependent on surface water, to analyze the potential implications of the EU WFD under diverse climate sequences. The economic model is a non-linear mathematical programming model, developed to optimize land use decisions and to replicate the behavior of several farm types and Irrigation Communities that represent a comprehensive array of irrigation technologies, crop mix, farming techniques, water allotments, and water use patterns. The hydrology model WEAP, configured as a contiguous set of sub-catchments, was developed to simulate watershed hydrologic processes and to provide basin-scale insights about water management and planning. The integration of the economic and hydrology models is made, empirically, by replicating the different irrigation demand nodes and simulating the same scenarios in both models and, technically, by an automated interface that facilitates data-interoperability and data-exchange through iterative loop procedures. Results show that location of water use within the basin, access to modern irrigation techniques, farm size, crop diversification, and crop growing season are key factors for determining farmers' capacity to adapt to climate and policy stimuli. The old ICs with conventional furrow-irrigation systems and small rice-growing farms located upstream on the river will be the most economically affected by the application of the required environmental flows to meet the WFD's goals, as compared to similarly located ICs with modern pressurized systems, and high crop and farm-size diversity. However, for all ICs, regardless of their location, these impacts will worsen in dry climate periods, and particularly in the summer months, when water shortages occur and there is an important increase of crop water requirements. The study concludes that the implementation of the WFD, geared fundamentally by ecological sustainability provisions, will not discriminate between efficient and inefficient irrigation systems and will fail in reaching an adequate balance for securing water for nature protection and water for maintaining rural livelihoods in the area of study. The research underlines the necessity to further develop other dimensions (social, economic, institutional) within the WFD umbrella and to institute clear guidelines to assist policy makers for addressing consistently its established economic principles and measures. From a methodological perspective, the findings indicate that the accuracy of the models in predicting farmers' and water systems' behavior improves when the economic and hydrology models are linked together, evidencing the potential of integrated tools in replicating the reality of complex water systems. The methodology developed in this research is transferable to other world regions and, therefore, it constitutes a robust tool for approaching IWRM and helping closing the gap between theory and practice.

Key-words: IWRM, economic optimization, hydrology simulation, dynamic integration, irrigation demand management, environmental flows, drought.