# Rationalizing Systems Analysis for the Evaluation of Adaptation Strategies in Complex Human-Water Systems

Arthur Hrast Essenfelder[1], C. Dionisio Pérez-Blanco[2], and Alex Mayer[3]

[1]University of Venice
[2]Universidad de Salamanca
[3]Michigan Technological Univ

November 23, 2022

**Abstract**

Water resources management is a non-trivial process requiring a holistic understanding of the factors driving the dynamics of human-water systems. Policy-induced or autonomous behavioral changes in human systems may affect water and land management, which may affect water systems and feedback to human systems, further impacting water and land management. Currently, hydro-economic models lack the ability to describe such dynamics either because they do not account for the multi-factor/multi-output nature of these systems, and/or are not designed to operate at a river basin scale. This paper presents a flexible and replicable methodological framework for integrating a microeconomic multi-factor/multi-output Positive Multi-Attribute Utility Programming (PMAUP) model with an eco-hydrologic model, the Soil and Water Assessment Tool (SWAT). The connection between the models occurs in a sequential modular approach through a common spatial unit, the "Hydrologic-Economic Representative Units" (HERUs), derived from the boundaries of decision-making entities and hydrologic responsive units. The resulting SWAT-PMAUP model aims to provide the means for exploring the dynamics between the behavior of socio-economic agents and their connection with the water system through water and land management. The integrated model is illustrated by simulating the impacts of irrigation restriction policies on the Río Mundo sub-basin in south-eastern Spain. The results suggest that agents' adaptation strategies in response to the irrigation restrictions have broad economic impacts and subsequent consequences on surface and groundwater resources. We suggest that the integrated modeling framework can be a valuable tool to support decision-making in water resources management across a wide range of scales.

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***Arthur H. Essenfelder[1]; C. Dionisio Pérez-Blanco[2]; Alex S. Mayer[3]***

[1]CMCC Foundation - Euro-Mediterranean Centre on Climate Change and Ca'Foscari University of Venice, Venice, Italy; [2]Department of Economics and Economic History, Universidad de Salamanca, Salamanca, Spain; [3]Department of Civil and Environmental Engineering, Michigan Technological University, Houghton, MI, USA

## Key Points

- Socio-economic agents' **decision-making** is a determinant factor driving/affecting hydrologic processes
- A **holistic, multi-factor** perspective is required to evaluate the impacts of policy interventions in complex human-water systems
- Socio-hydrologic analysis requires both **innovative and integrative** socio-economic and eco-hydrologic **modelling frameworks**

## Motivation

Water resources management is a nontrivial process requiring a holistic understanding of the factors driving the dynamics of human-water systems.

Policy-induced or autonomous behavioural changes in human systems may affect water and land management, which may affect water systems and feedback to human systems, further impacting water and land management.

Effective planned adaptation actions should take into account responses at the individual level; as a consequence, interactions between agricultural and hydrologic systems should be taken into account when designing policies in order to ensure the sustainability of social-ecological systems.

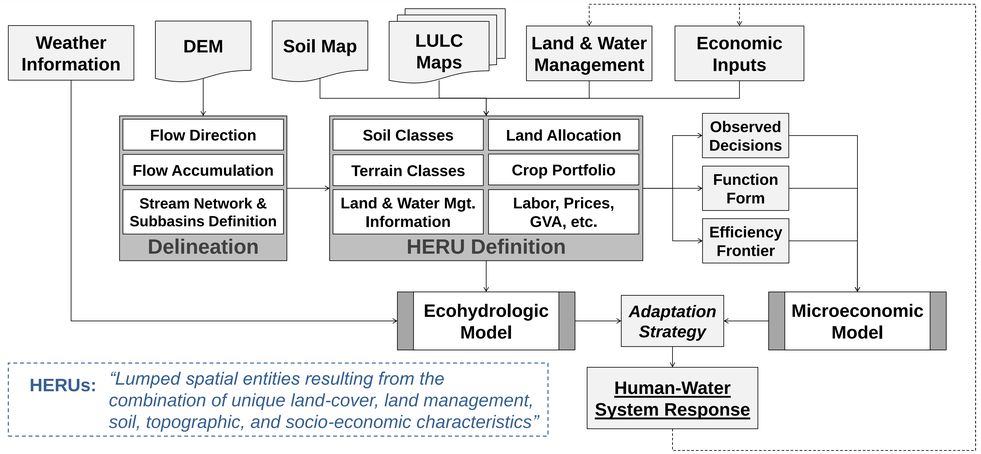
Mathematical models can be valuable tools to support decision-making in water resources management, provided that the information is reliable.

Most hydro-economic models lack the ability to describe such dynamics either because they do not account for the multi-factor/multi-output nature of these systems and/or are not designed to operate at a river basin scale.

## Methodology

**SWAT** Soil & Water Assessment Tool

- Conceptual, semi-distributed **eco-hydrologic** model
- Suitable for **regional-scale** applications
- Capable of assessing **land management** processes
- **Open source** and based on a **modular** approach

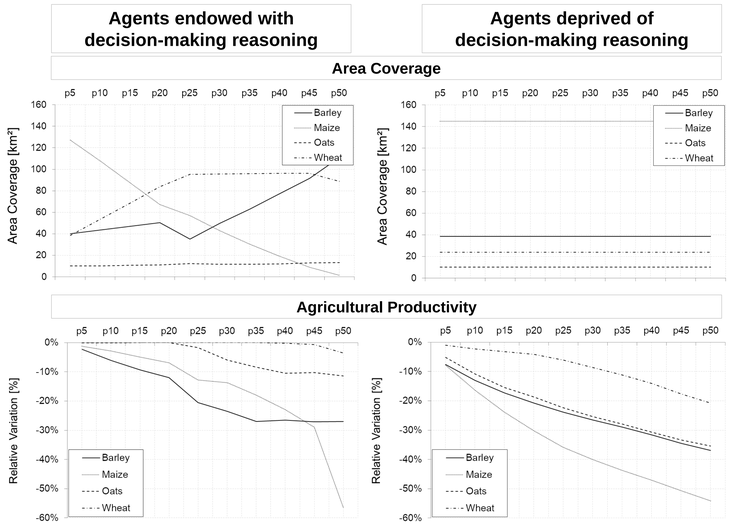


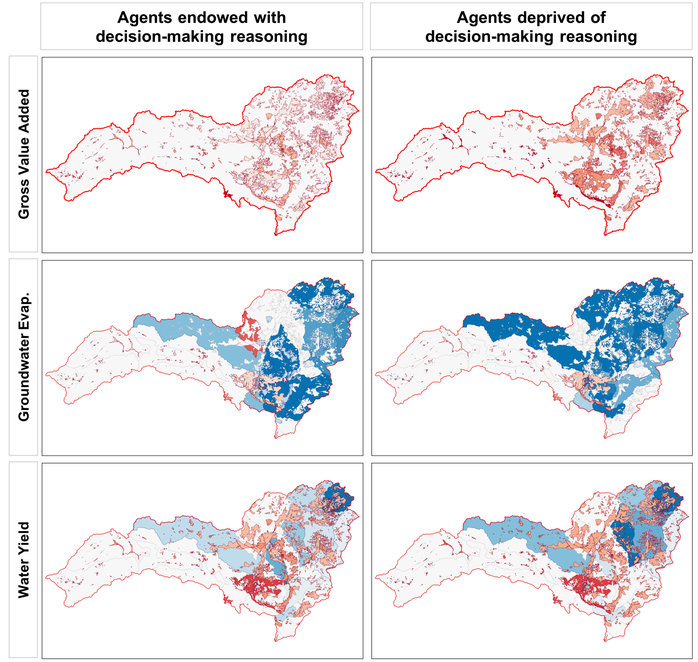

**HERUs:** *"Lumped spatial entities resulting from the combination of unique land-cover, land management, soil, topographic, and socio-economic characteristics"*

**PMAUP** Positive Multi-Attribute Progm.

- Non-linear, **multi-attribute** objective function
- Parameters elicited based on **observations**
- Calibrated with **GAMS CONOPT**
- Simulates **economic agents'** responses to policies

## Results




## Conclusions

- Complex human-water systems requires integrative methodological frameworks to capture the connections and feedbacks between systems;
- Spatially connected elements such as HERUs can help better describing the complex interaction between human and water systems;
- Dynamic agricultural and hydrologic behaviours must be taken into consideration when designing water policy interventions.

http://www.cmcc.it/
CMCC – Risk Assessment and Adaptation Strategies (RAAS)
arthur.essenfelder@cmcc.it

https://www.unive.it/
UniVe – Ca' Foscari University of Venice
arthur.essenfelder@unive.it

This research was partially sponsored by EIT Climate KIC under the project AGRO ADAPT-Service for local and economy wide assessment of adaptation actions in agriculture and Fundación Salamanca Ciudad de Cultura y Saberes, Program for the Attraction of Scientific Talent, Sustainable Watersheds—Emerging Economic Instruments for Water and Food Security (SWAN).
The data on which the results and discussions presented here are based can be accessed in: https://doi.org/10.5281/zenodo.1217993.