Evaluating Impacts of Alternative Adaptation Strategies on the Dynamics of Human-Water Systems

A Methodological Framework for an Integrated Modular SWAT and Multi-Attribute Revealed Preference Model

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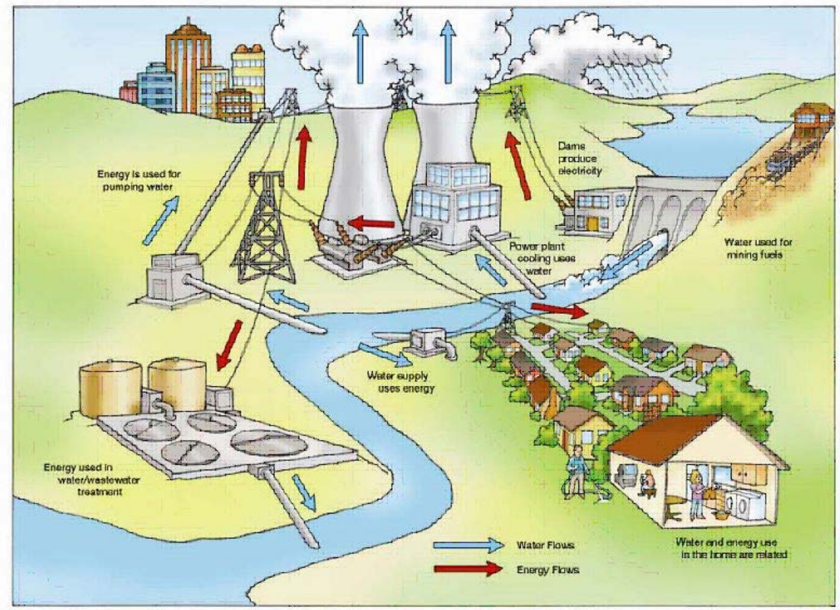
INTRODUCTION

- The Motivation
  - Water is a fundamental resource for geophysical, ecological and socio-economic systems
  - Water connects natural and human systems
    - Social-ecological systems (Berkes and Folke, 1998)
    - Anthropocene (Crutzen, 2002)
    - Socio-hydrology (Sivapalan *et al.*, 2012)
  - In such integrative context, economic principles represent a means of managing water resources in SESs



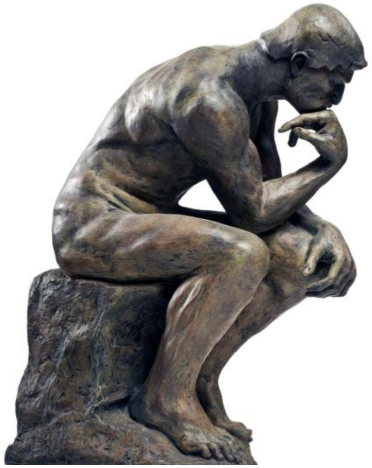
- The Objective
  - To propose a methodological framework for the integration of modelling techniques capable of capturing the dynamics of human-water systems;
  - To evaluate the utilization of a modular approach to connect, in a sequential fashion, a multi-attribute revealed preference model (RPM) with SWAT

METHODOLOGY – RPM

- Revealed Preference Model (RPM)
  - Built upon revealed preference theory (Samuelson, 1938) and behavioural economics principles:

    “Given the budgetary constraint and alternative baskets of goods having the same price, agents reveal their preference by choosing a particular basket”

  - Four fundamental assumptions:
    1. Rationality (i.e. chose what is best for them)
    2. Transitivity (i.e. if A>B and B>C, then A>C)
    3. Consistency (i.e. same conditions, same preferences)
    4. Price Inducements (i.e. incentives affect preferences)



  - In microeconomic modelling of agricultural systems:
    - Focus: analysing the patterns of **crop yields**, **revenues**, and **costs**
    - Spatial scale: **farm** or **district** scales

Methodology – RPM

- The **preference** of agents depends on the provision of attributes they value (e.g. profit, avoidance of risk, etc.)
- The **attributes**, in turn, depend on available choices (e.g. crop varieties, crop rotation, water availability, capital investment, etc.)
- Mathematically:

$$\underset{x}{\text{Max}}\ U(x) = U(z_1(x);\ z_2(x); z_3(x) \ldots\ z_m(x))$$

s.t.: $0 \leq x_i \leq 1$

$\sum_{i=1}^{n} x_i = 1$

$X \in F(x)$

$z = z(x) \in R^m$

- where *U* is the utility function, *F(x)* is the domain of feasible choices, *x* is the decision variable (i.e. unique combination of crops and land management techniques), and *z(x)* is the correspondent unique combination of attributes.

Methodology – RPM

- The domain of feasible choices *F(x)* describes the constraints agents face when deciding on land use and land use change, including:
  - irrigable and total land available;
  - climatic conditions;
  - know-how;
  - regulations, and;
  - water availability.

- Water availability constraint, of particular relevance for the purpose of the case study to be shown, can be expressed as:

$$\sum_{i=1}^{n} w_i \, x_i \, \mathrm{ha} \leq W_g$$

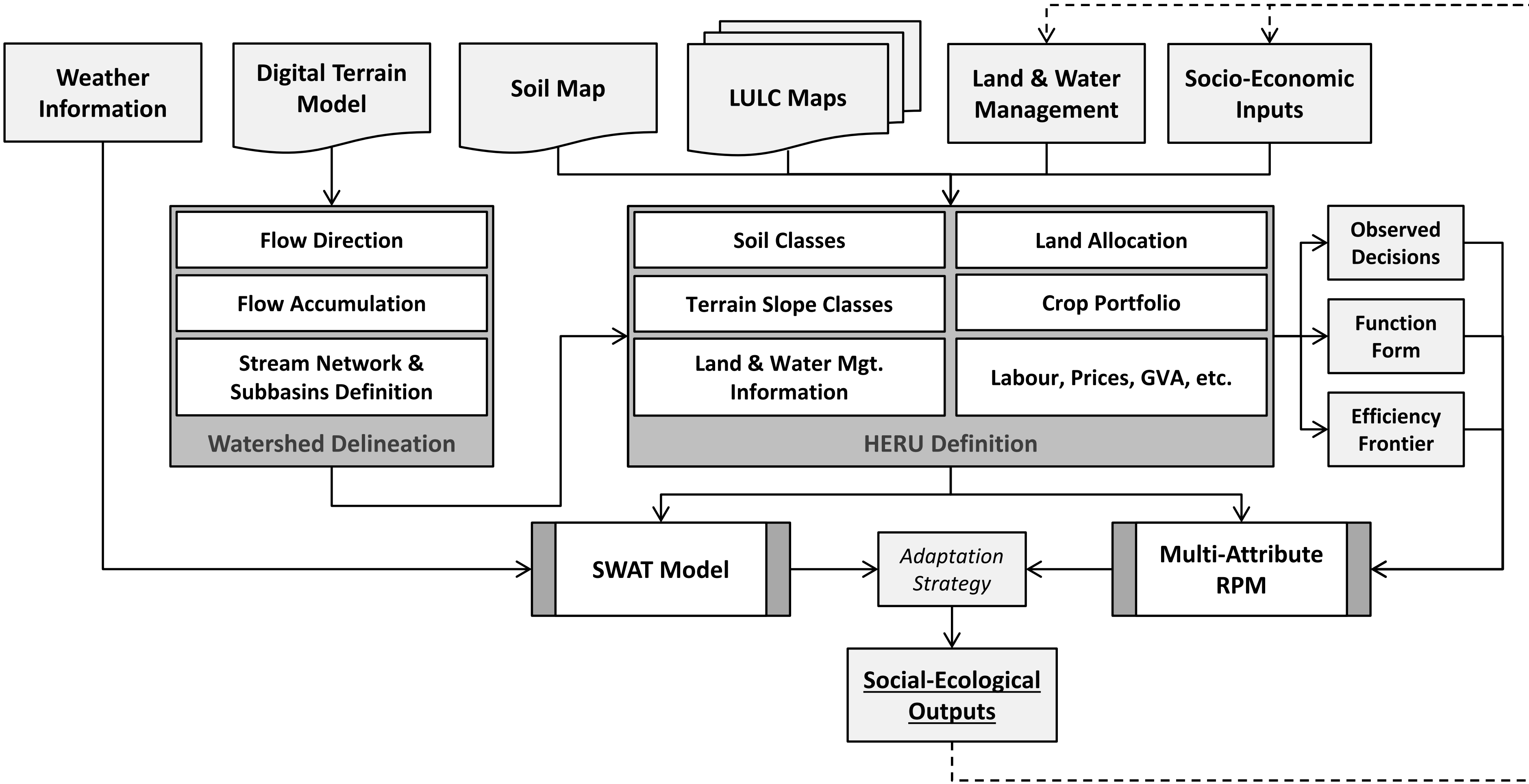
- Where w_i is the amount of water needed to irrigate one hectare of crop x_i, and W_g represents the water availability per ha.
- The model is then calibrated by determining the objective function that minimizes the error between the observed and calibrated decisions with respect to the relevant combination of attributes

METHODOLOGY – SWAT

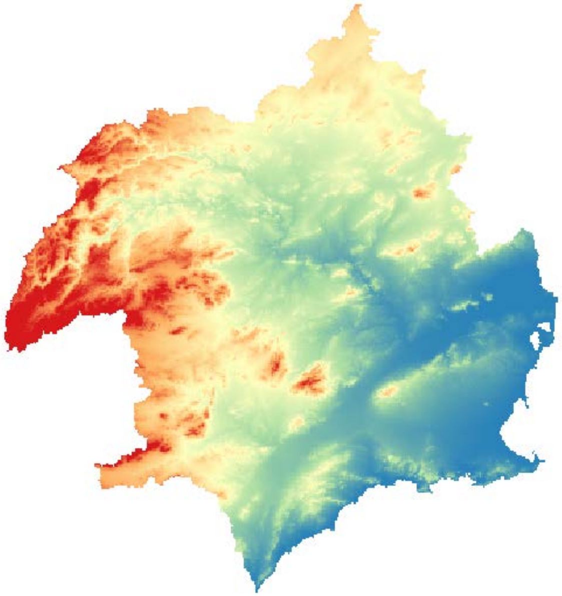
- Why using SWAT as the hydrologic counter-part?
  - SWAT is an eco-hydrological model
  - Different land management operations (e.g. irrigation, crop rotation, etc.)
  - Accessible source code

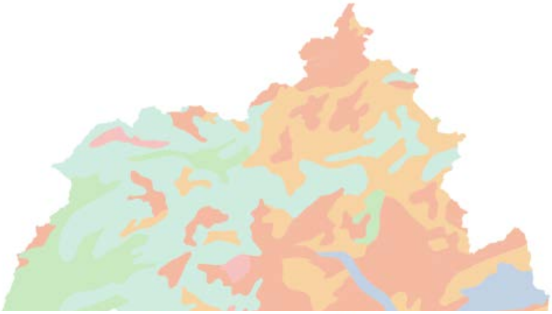
- Which processes are of particular interest?
  - Land use & land management:
    - Crop selection, crop rotation, irrigation water requirements, etc.
  - Water balance
    - Curve number, runoff, evapotranspiration, revap, irrigation, etc.

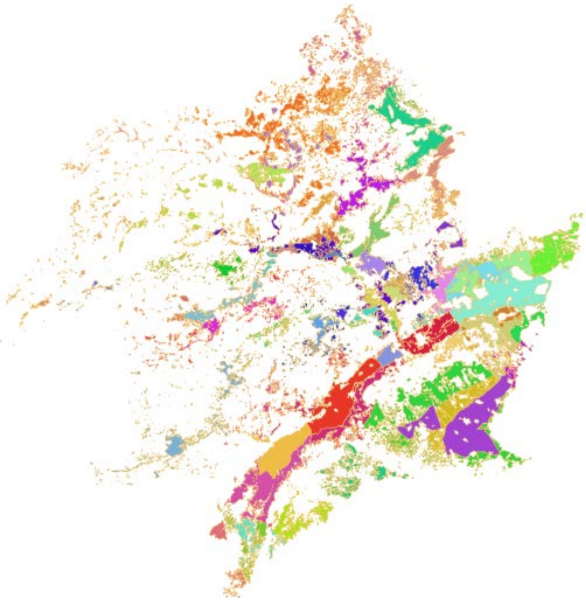
THE METHODOLOGICAL FRAMEWORK

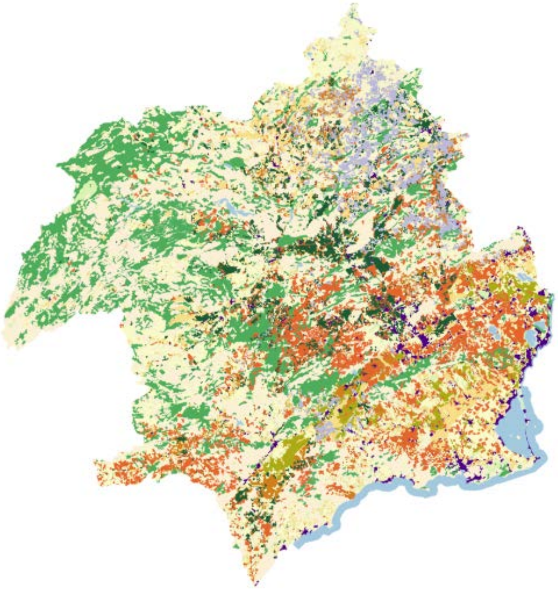


The Methodological Framework







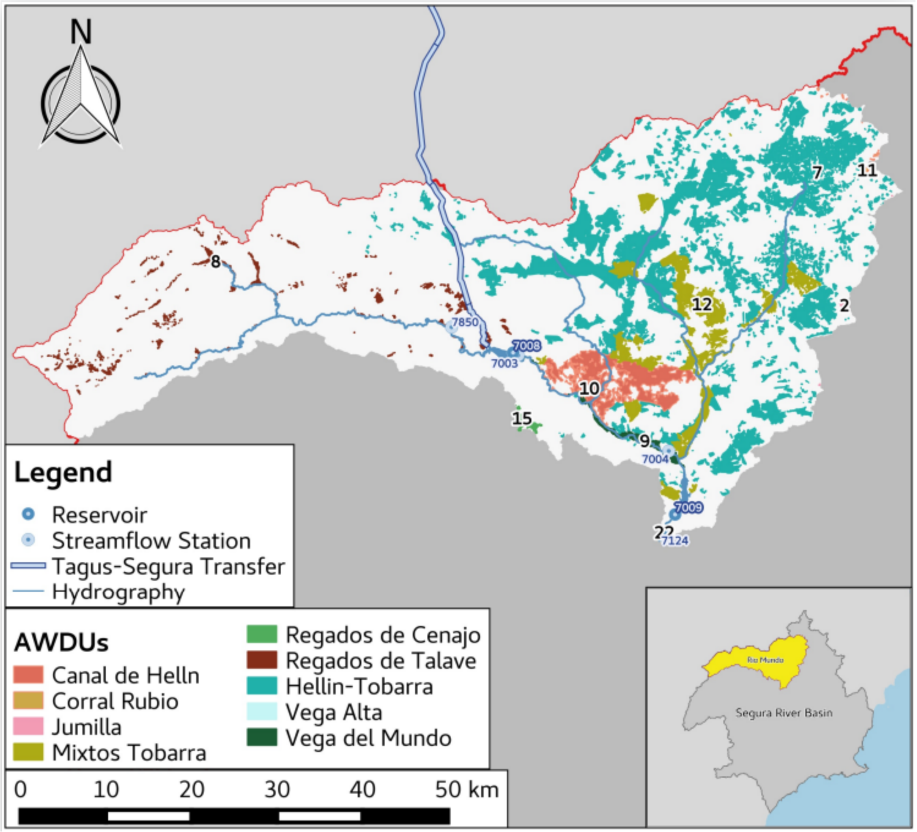


- **HERUs**:

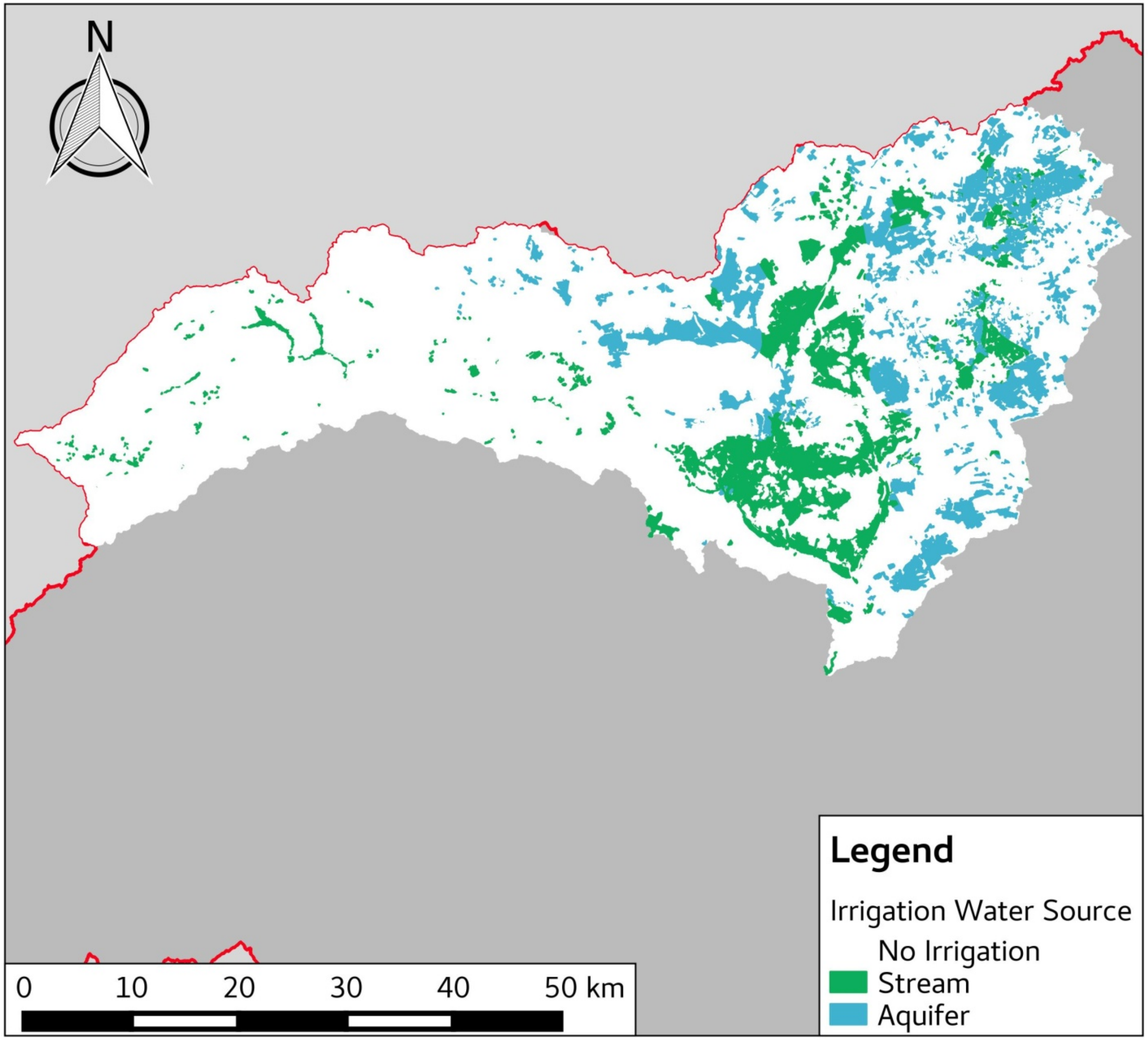
  “Lumped spatial entities resulting from the combination of unique land-cover, land management, soil, topographic, and socio-economic characteristics”

The Case Study

- The problem
  - Allocation of water resources for irrigation
  - Implementation of a water policy restriction in the study area
- The objective of the study
  - To explore how different water policy restrictions can affect the land management and hydrology of the Rio Mundo Watershed
- The case study
  - Area ≈ 2,500 km^2
  - Characterised by:
    - Agricultural Water Demand Units;
    - Reservoirs;
    - Water transfer (Tagus-Segura);

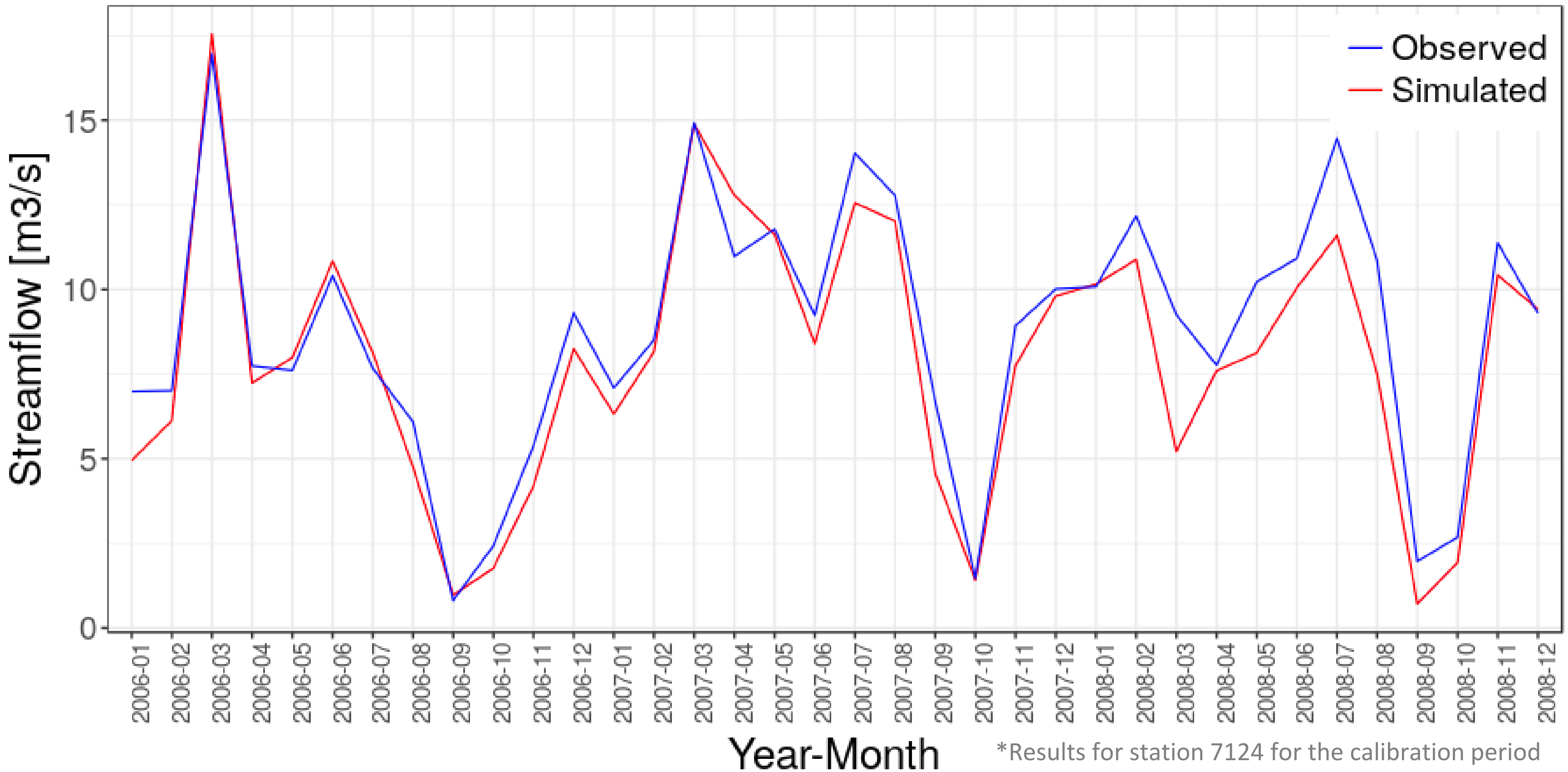


THE CASE STUDY



PRELIMINARY RESULTS

Station	NSE
7850	0.72
7003	0.86
7004	0.92
7124	0.77



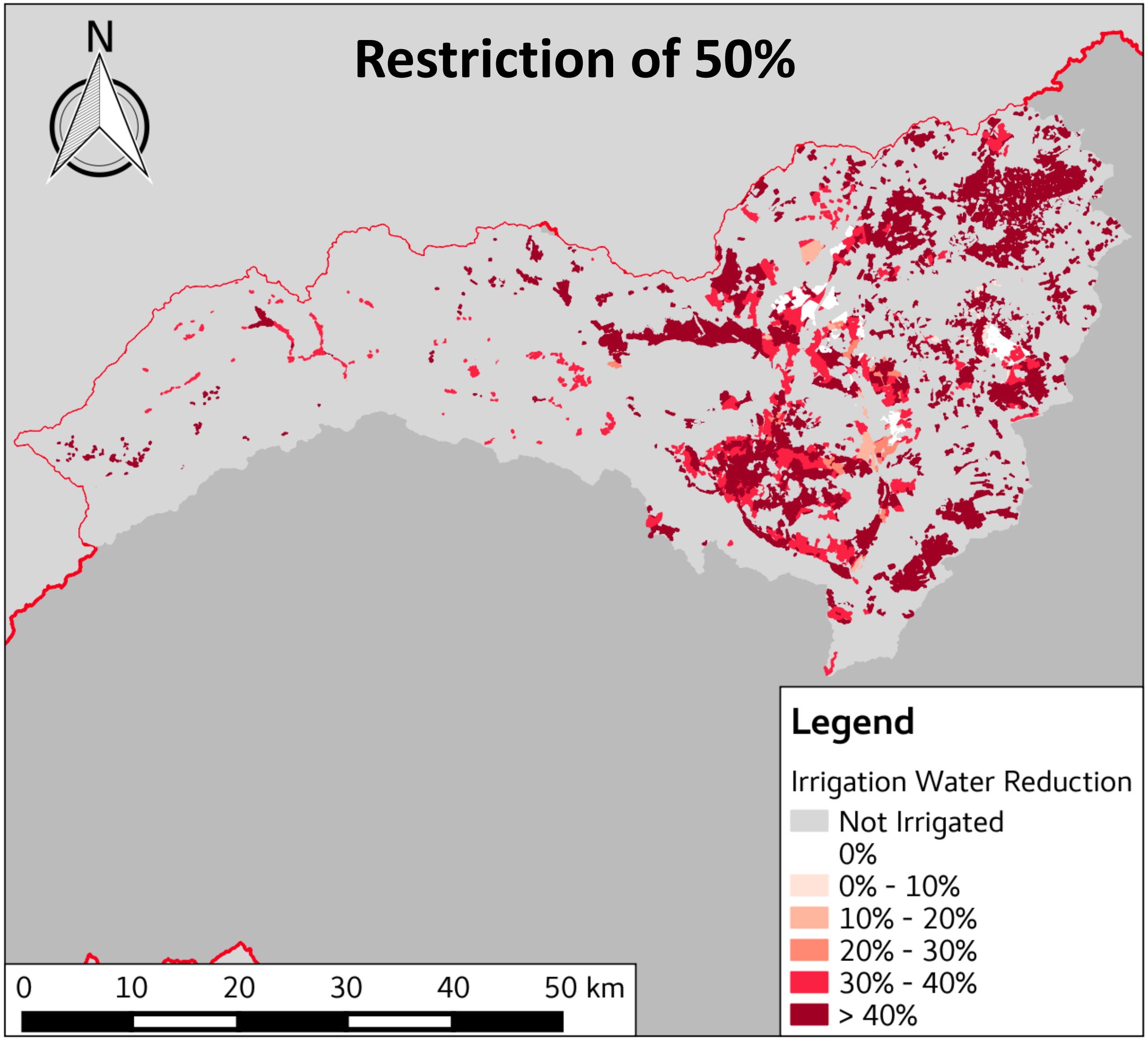
*Results for station 7124 for the calibration period

PRELIMINARY RESULTS

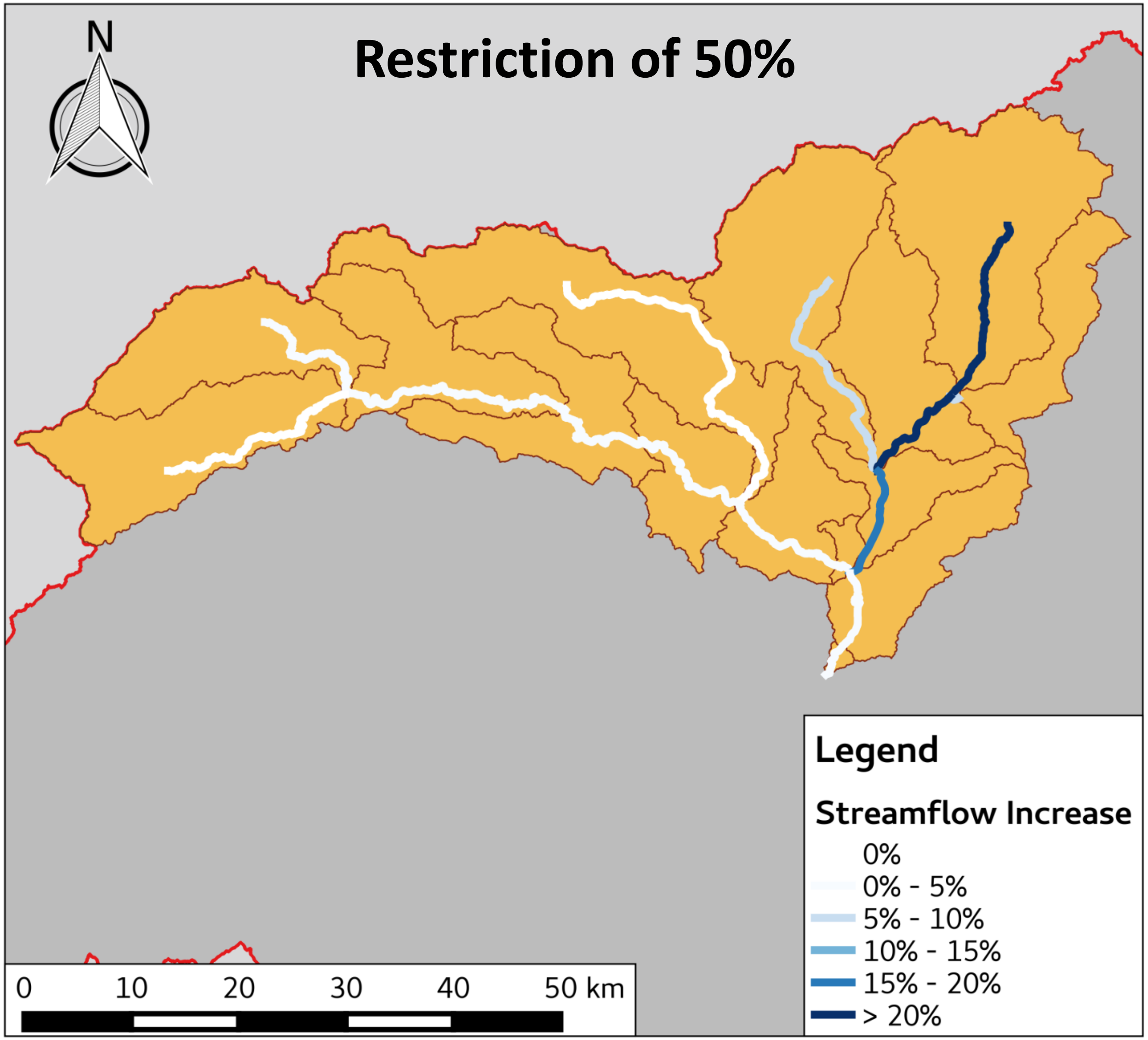
		Water Policy Restriction			
AWDU	**Crop Type**	**0%**	**5%**	**25%**	**50%**
2	Vineyard	100%	100%	100%	100%
7	Almonds	28%	28%	28%	28%
	Maiz	48%	42%	18%	0%
	Wheat	10%	16%	40%	58%
	Orchards	14%	14%	14%	14%
8	Oats	6%	6%	20%	29%
	Barley	17%	17%	20%	29%
	Maiz	17%	17%	0%	0%
	Alfalfa	27%	27%	27%	9%
	Other	33%	33%	33%	33%
9	Barley	13%	17%	27%	42%
	Maize	21%	16%	7%	0%
	Alfalfa	8%	8%	8%	0%
	Orchards	47%	47%	47%	47%
	Other	11%	11%	11%	11%

		Water Policy Restriction			
AWDU	**Crop Type**	**0%**	**5%**	**25%**	**50%**
10	Other	13%	13%	13%	13%
	Almonds	15%	15%	15%	15%
	Barley	10%	10%	28%	30%
	Maiz	20%	20%	2%	0%
	Orchards	41%	41%	41%	41%
11	Other	64%	64%	64%	64%
	Vineyard	36%	36%	36%	36%
12	Other	19%	19%	19%	19%
	Almonds	18%	18%	18%	18%
	Barley	20%	23%	34%	40%
	Maiz	20%	18%	6%	0%
	Orchards	23%	23%	23%	23%
15	Oats	11%	13%	0%	0%
	Barley	17%	15%	28%	33%
	Maiz	28%	28%	28%	33%
	Alfalfa	9%	9%	9%	0%
	Orchards	35%	35%	35%	35%
22	Orchards	100%	100%	100%	100%

Preliminary Results



Preliminary Results



Conclusions

- The coupling of SWAT with a RPM provides an interesting framework for studying alternative adaptation strategies in a watershed
- The utilisation of socio-economic based models can help in better describing the dynamics of agricultural systems in a watershed with respect to pressures
- The coupling of both modelling techniques enables the simulation of the connections and feedback responses between human and water systems

- However, there is still work to do (a lot of) to make the coupled model more dynamic and responsive

Thank You!

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