



System Dynamics and Economic Analysis for the Evaluation of Water Management Strategies in the Souss-Massa basin, Morocco

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Plan

- **Introduction.**
- **System Dynamics for water resource management.**
- **Study area.**
- **System Dynamics for Water Resources Management: A Case Study from the Souss-Massa basin.**
- **Using System Dynamics to Inform Scenario Planning: Application to the Souss-Massa basin, Morocco.**
- **Conclusions.**
- **Perspectives.**

Introduction

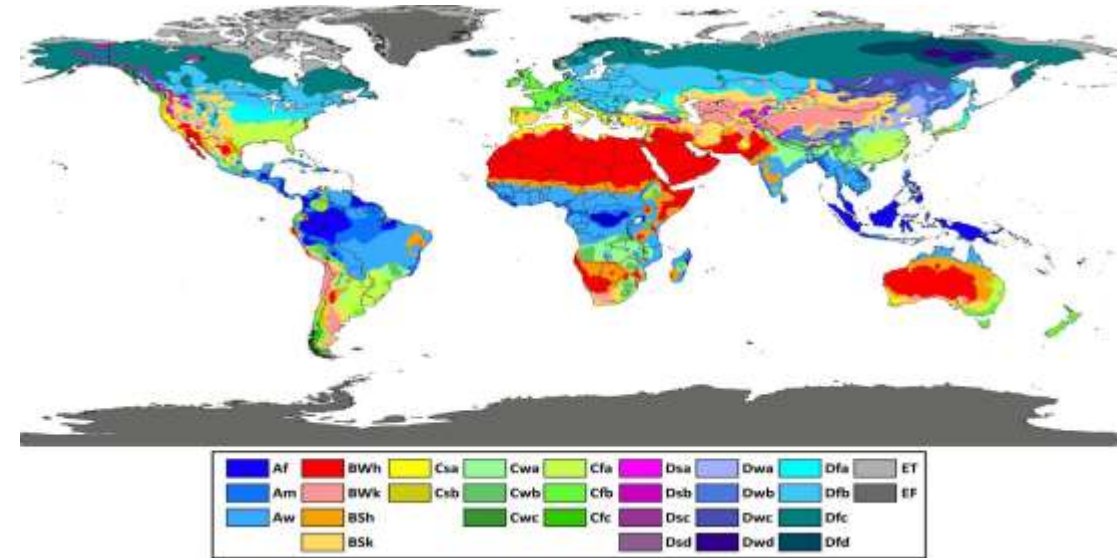
Understanding Morocco's Climate and Water Availability

Morocco's dominant **Köppen climate classification** classes are **BWh** and **Csa**, corresponding to **desert** and **Mediterranean** climates.

Hot, dry summers and mild, wetter winters.

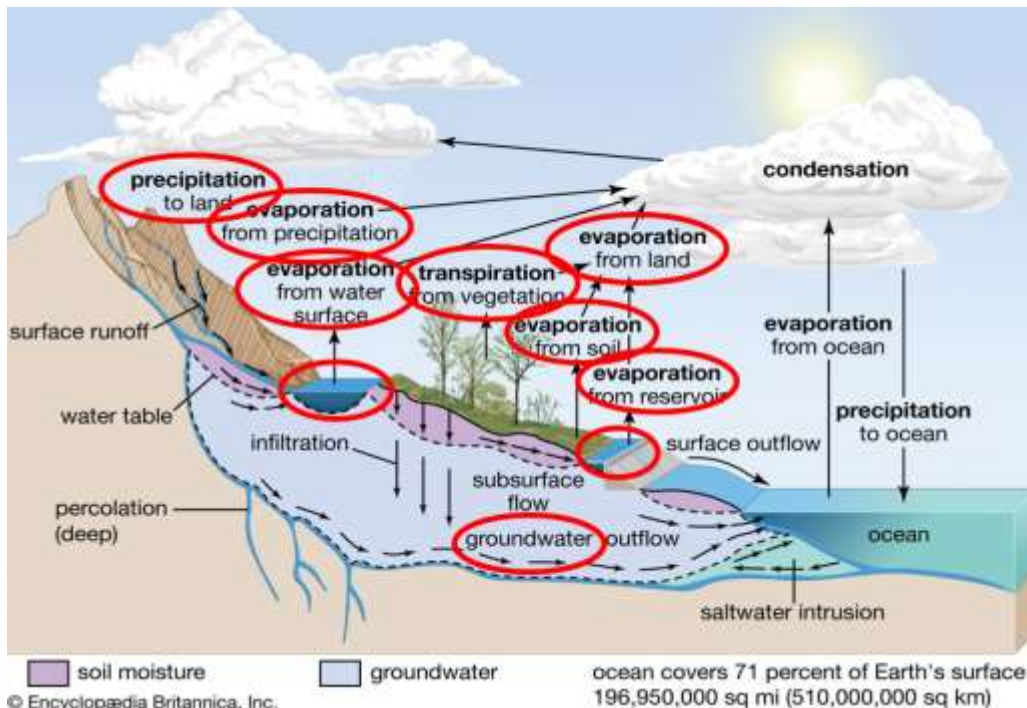
Heavy reliance on irrigation during the dry season.

Efficient irrigation water management is crucial for sustaining agriculture.



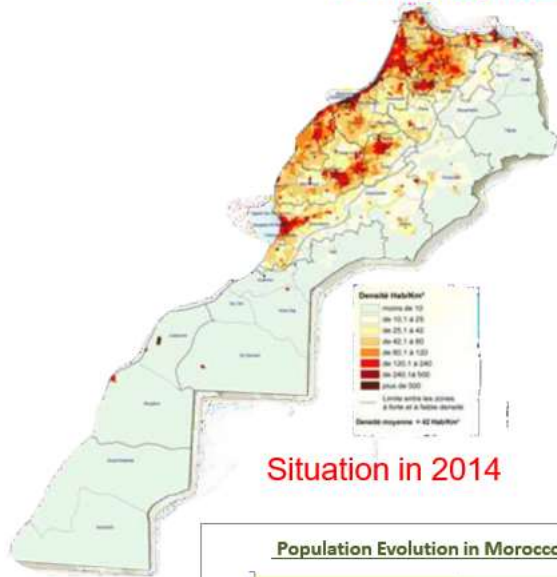
Water Availability in **Morocco** (statistics of 2023, MEW):

- Receives **140 billion m³** of water annually from **precipitation**.
- 118 billion m³** per year is lost through **evapotranspiration**.
- Renewable water resources** are estimated at **22 billion m³** per year, including **18 billion m³** of surface water and **4 billion m³** of groundwater.

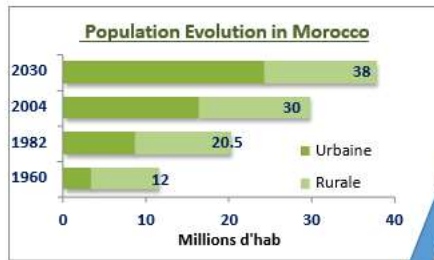


Introduction

Demographics



Situation in 2014



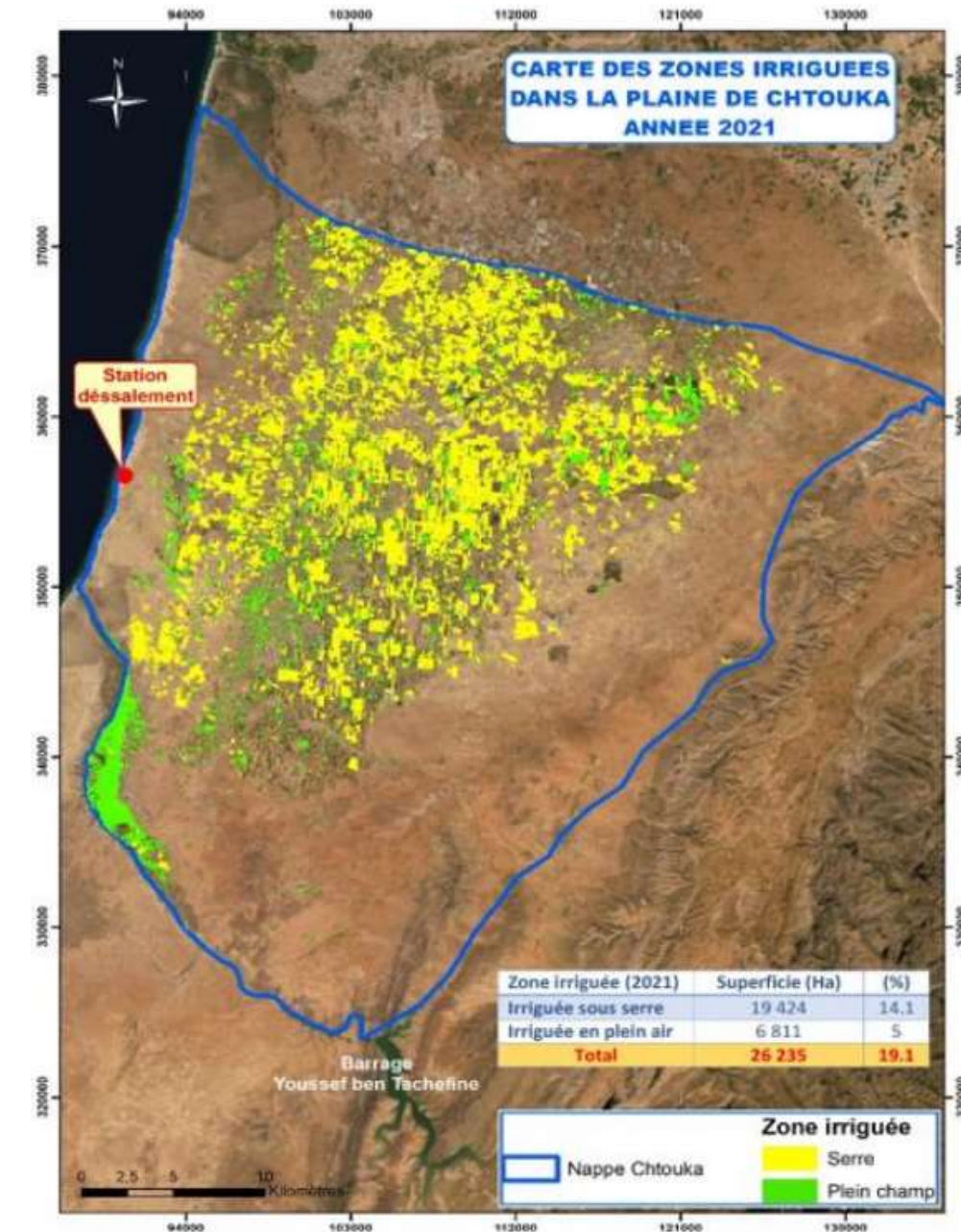
High demand for water !

Economy

- Strong agricultural component + mining, fishing, etc.
- Beginning of diversification: emergence of new sectors: services, tourism, industry, major infrastructure, etc.

Water Supply	Volume in millions of cubic meters (Mm ³)
Surface water	402
Groundwater	425
Unconventional water (Desalination + Treated wastewater)	14
Total Supply	841
Water Demand	Volume in millions of cubic meters (Mm ³)
Domestic, industrial and tourism water demand	109
Agricultural water demand	909
Total Demand	1018
Balance	-177

Water balance in the Souss-Massa region (ABHSM, 2023)



Irrigated areas in the Chtouka plain in 2021 (ABHSM, 2023)

Introduction

Morocco's Response to Water Scarcity: Supply-Demand Strategies



Dam Policy: 13 to 150 dams since gaining independence in 1956.



Interbasin Water Transfer (IBWT) **balance** in the spatial distribution of water availability across Morocco's 10 basins.



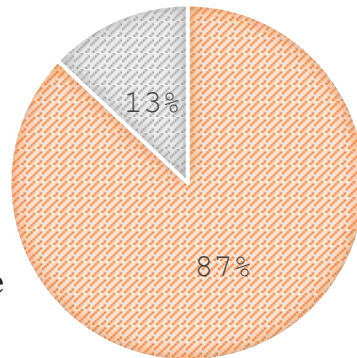
41 wastewater treatment and reuse projects have been implemented (green spaces and golf courses).



12 desalination plants, serving coastal cities such as Laayoune, Agadir and Casablanca.



■ Agriculture ■ Other sectors



- **Law 36-15 on water (Since 2016).**
- **National Irrigation Water Saving Program (PNEEI 2008-2020).**
- **National Water Plan (PNE 2020-2050).**
- **National Drinking Water Supply and Irrigation Program (PNAEPI 2020-2027).**
- **Groundwater Contract (Since 2010).**



- ❖ **Water use efficiency remains below 50% (MAPM).**
- ❖ **Existing systems rely on outdated protocols which do not account for crop water needs when scheduling irrigation.**
- ❖ **Significant gap between farmers' actual needs and the available solutions.**
- ❖ **Overexploitation of resources and reliance on costly, energy-intensive technologies.**
- ❖ **Socio-economic inequalities, fragmented (in silos) governance, and weak local implementation.**



The need for holistic and systemic water management !

Introduction

Research Problem

- What are the **key interactions** and **dynamics** among **water resource subsystems** within the Souss-Massa region, and how do they shape **sustainability** outcomes?
- How can **System Dynamics (SD) modeling** strengthen **scenario-based planning** for water management under **climate variability** and **socio-economic pressures** in the Souss-Massa region?
- What comparative **advantages** does **System Dynamics (SD)** offer over **conventional approaches** in addressing the **complexity of water governance**?

Introduction

Research Objectives

To address these questions, the thesis will focus on several **key objectives**:

- To **review SD applications in water management**: principles, frameworks, gaps, and sustainability insights.
- To **assess Souss-Massa water resources** through integrated **hydro-socio-economic data** and reliable **water balance**.
- To **build an SD model** linking hydrology, climate, and socio-economics to **test policies** and **support regional development**.
- To **simulate scenarios** (Business As Usual (BAU) vs. strategies) to **evaluate sustainability** and **groundwater resilience**.
- To **demonstrate the advantages of SD** over conventional methods for **understanding complexity** and **designing integrated strategies**.
- To **advance SD modeling** for arid/semi-arid contexts under **data scarcity**, **climate variability**, and **anthropogenic pressures**.

System Dynamics for water resource management

The limitations of conventional modeling approaches for integrated water resources management (IWRM)

Conventional IWRM models are:

- **Reductionist and mechanistic.**
- **Poorly adapted to the complexity of the processes involved.**

Conventional IWRM models require **technical expertise** and a **large amount of reliable data.**



There is a **lack of interconnection** between hydrological subsystems.

Insufficient consideration of **socio-economic aspects.**

**There is a need to focus more on refining IWRM concepts.
Managing water in a Holistic and Systemic way !**

System Dynamics for water resource management

Systemic Models : System Dynamics

System Dynamics principles

Interaction and feedback between different subsystems.

Conversion of the entire system into **an interconnected series of stocks and flows.**

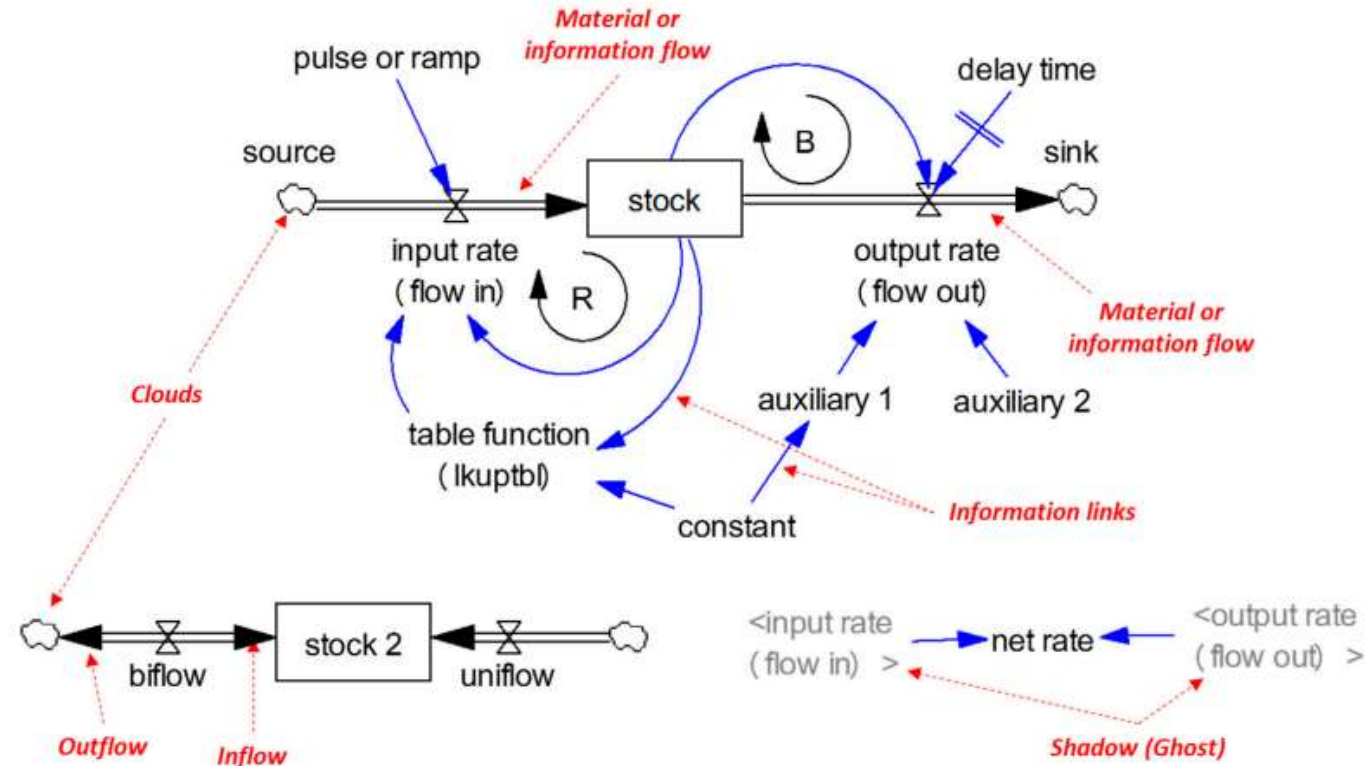
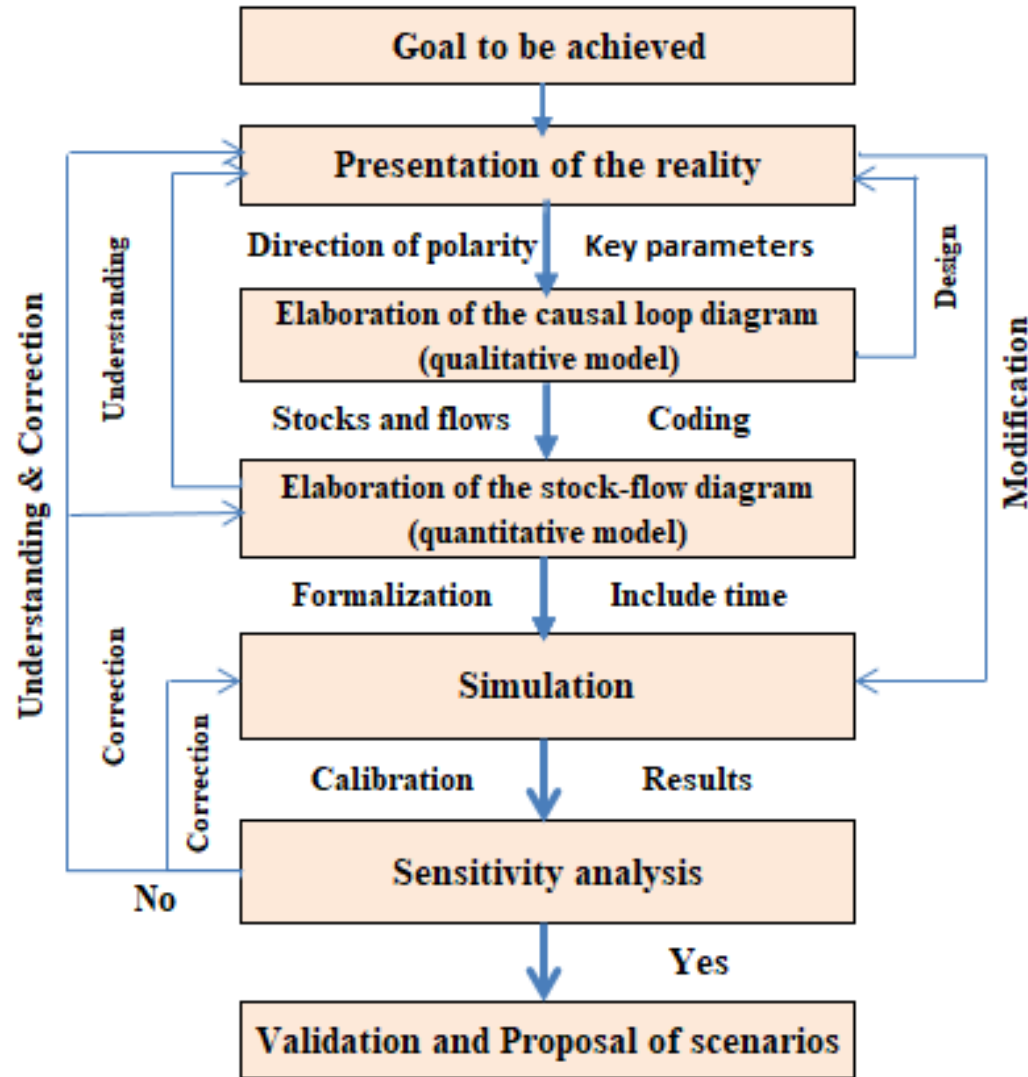


Taking into account **holistic interactions between parameters, rather than analyzing each parameter in isolation.**

Visualize **the evolution of each parameter over time**, so you can **plan effective long-term strategies.**

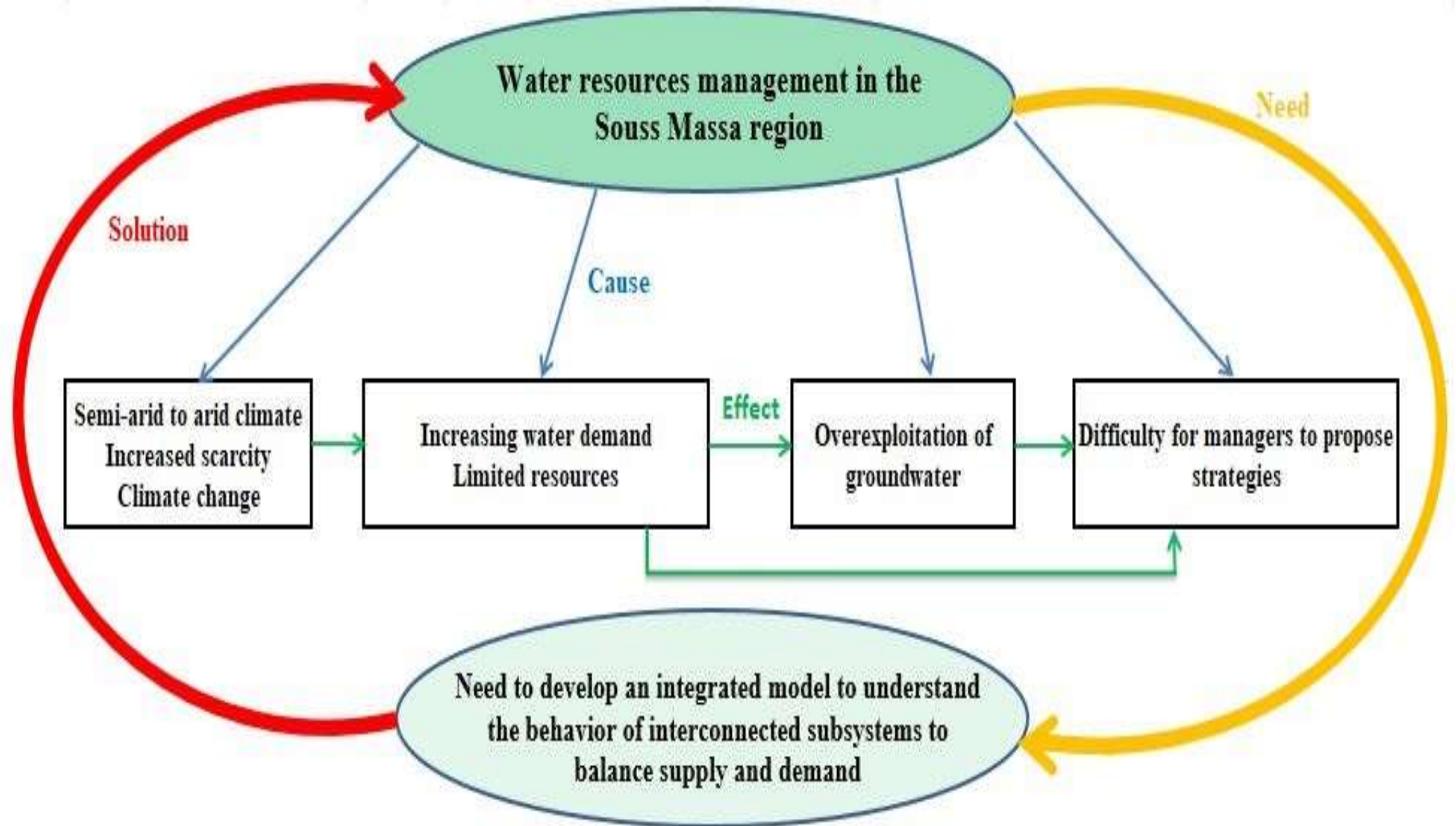
Causality principle.

System Dynamics Modeling Approach



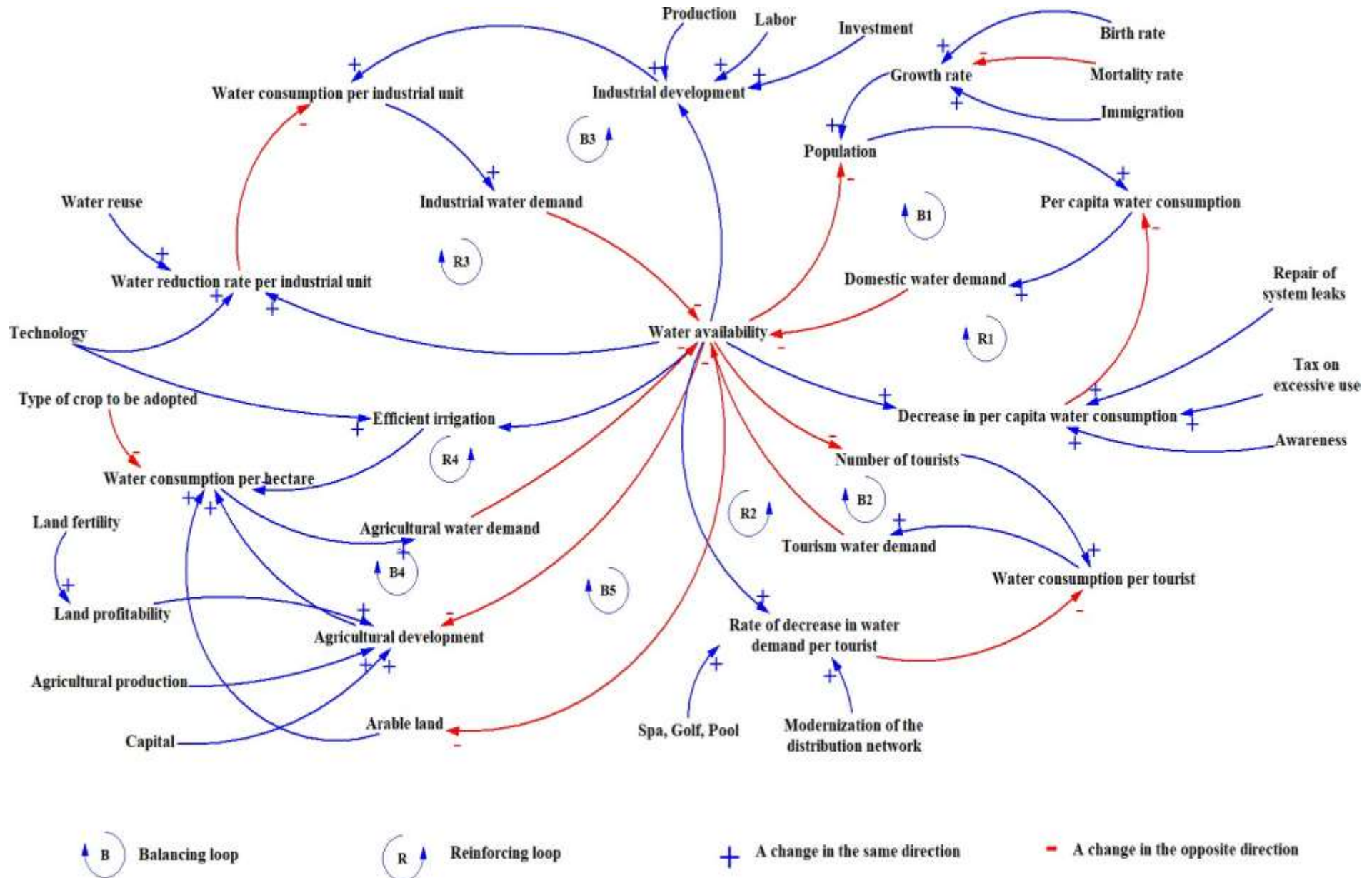
System Dynamics Archetypes (Sterman, 2000)

Study area



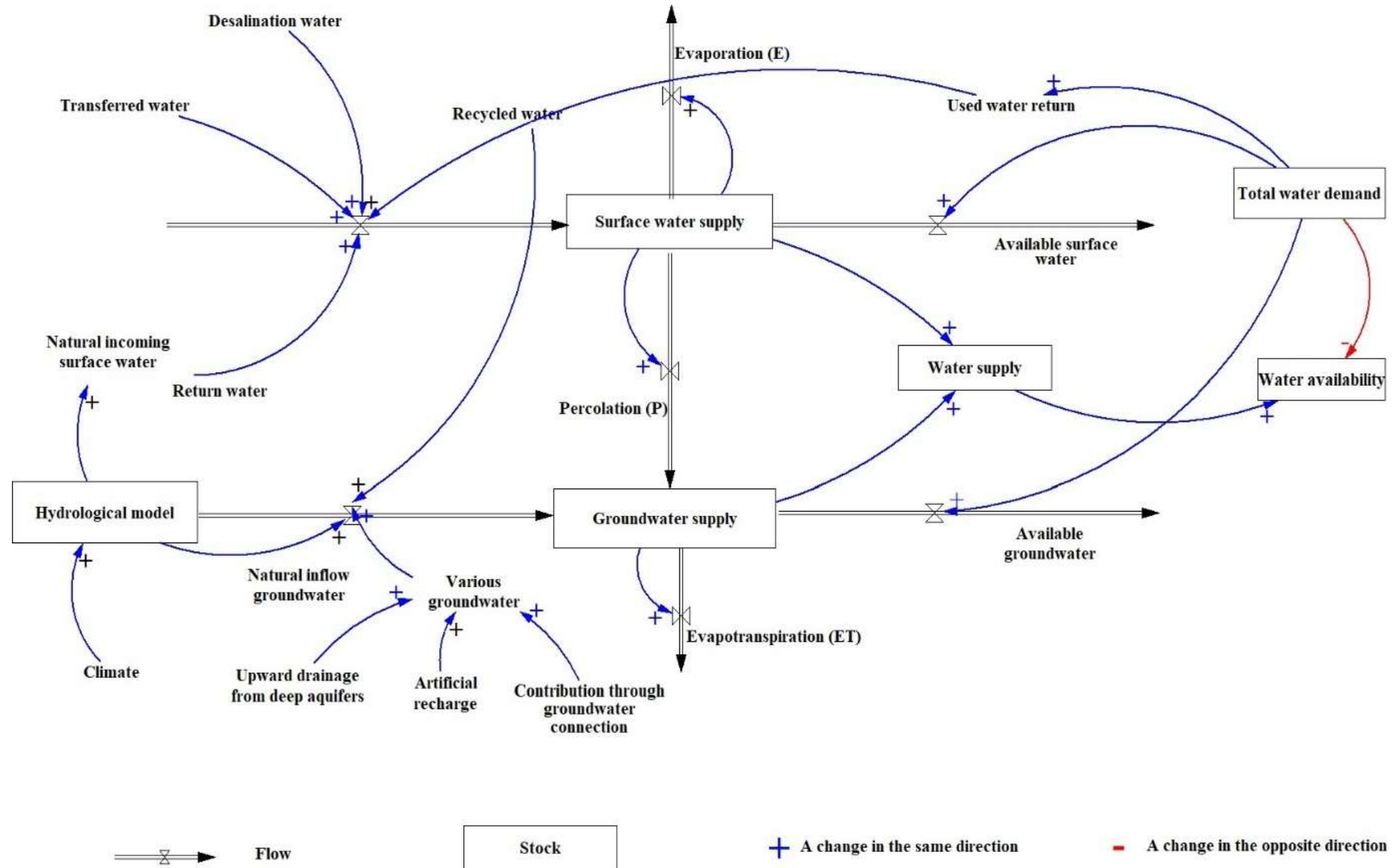
Research problem in the Souss-Massa region

Key results: Qualitative model mapping the key parameters that impact water demand in the Souss-Massa basin



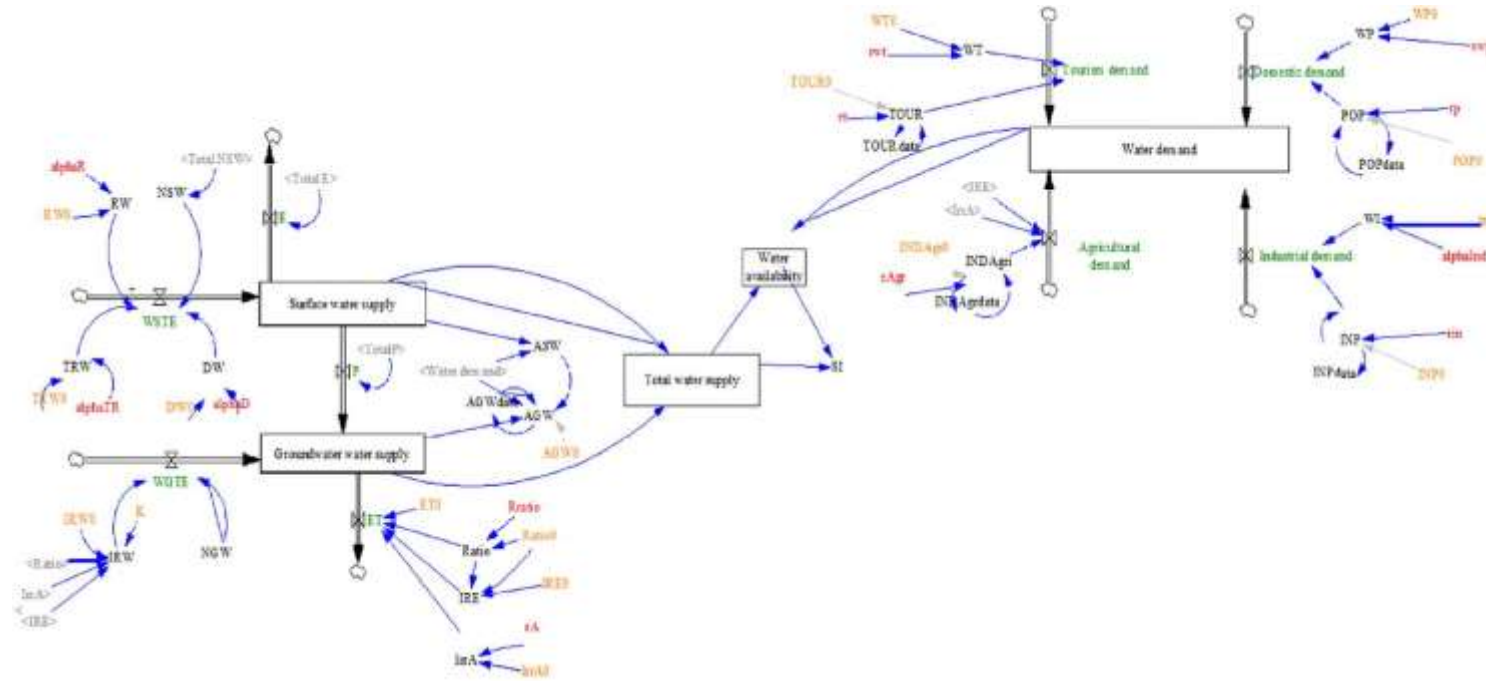
Water demand causal loop diagram (CLD) (Guemouria et al., 2023)

Key results: Quantitative model showing the interactions between key water supply parameters in the Souss-Massa basin

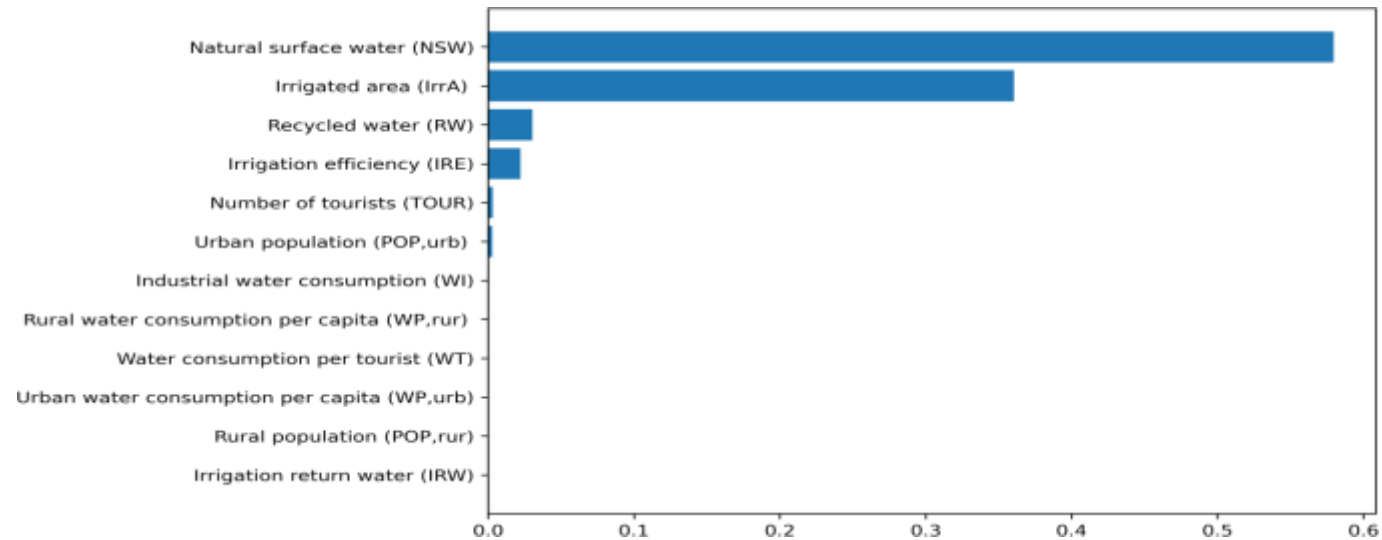


Water supply stock-flow diagram (SFD) (Guemouria et al., 2023)

Key results: System Dynamics model simulation & Sensitivity analysis



System Dynamics model simulation in the Souss-Massa basin (Guemouria et al., 2023)

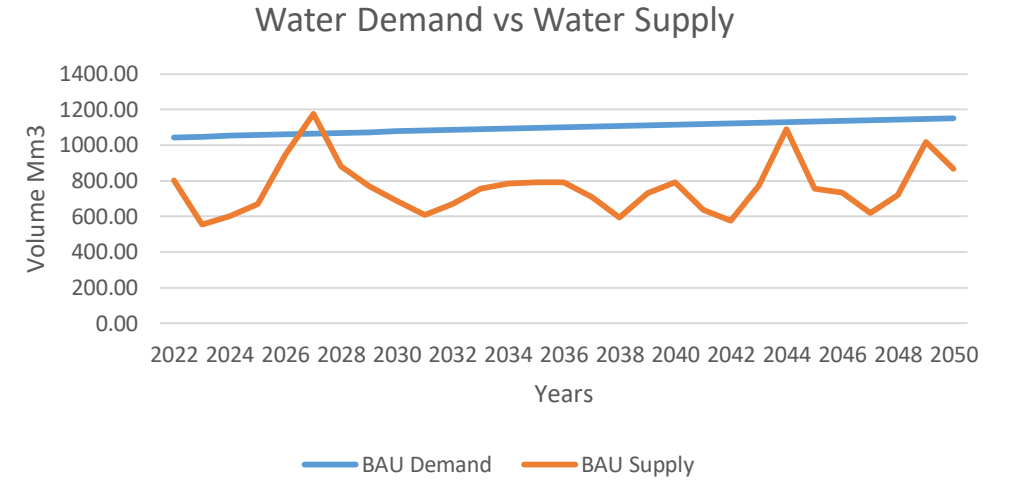
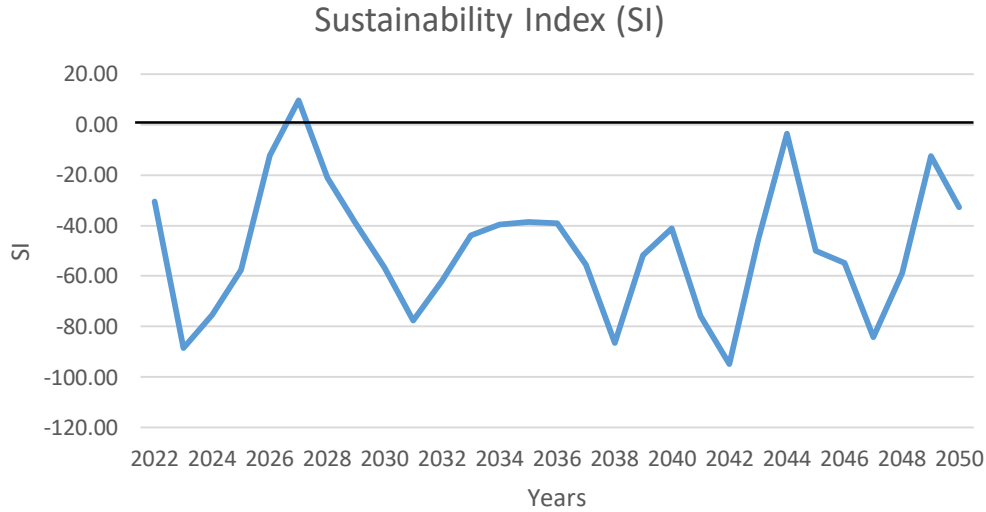


Ranking of key model parameters (Guemouria et al., 2023)

Key results

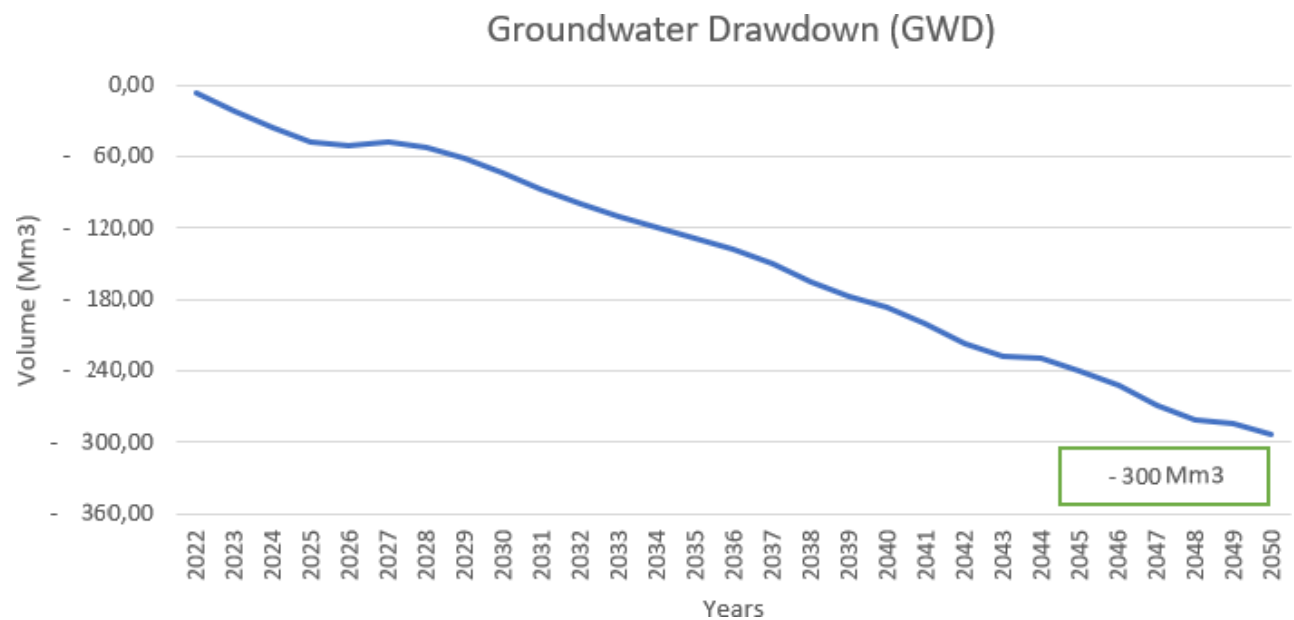
Simulated scenarios

Scenarios	Description
Business As Usual (BAU)	BAU scenario based on decision-makers' forecasts between 2022 and 2050
Scenario 1	Irrigation efficiency improved by 10%
Scenario 2	Irrigation efficiency improved by 20%
Scenario 3	Coupling scenario 2 with a doubling of the volume of reused water
Scenario 4	Coupling scenario 3 with a doubling of desalinated water volume
Scenario 5	Coupling scenario 1 with a doubling of the volume of reused and desalinated water + Stagnation of irrigated areas
Scenario 6	Coupling scenario 5 with a 7% increase in water supply
Scenario 7	Coupling scenario 1 with a doubling of the volume of reused and desalinated water + 15% reduction in irrigated area

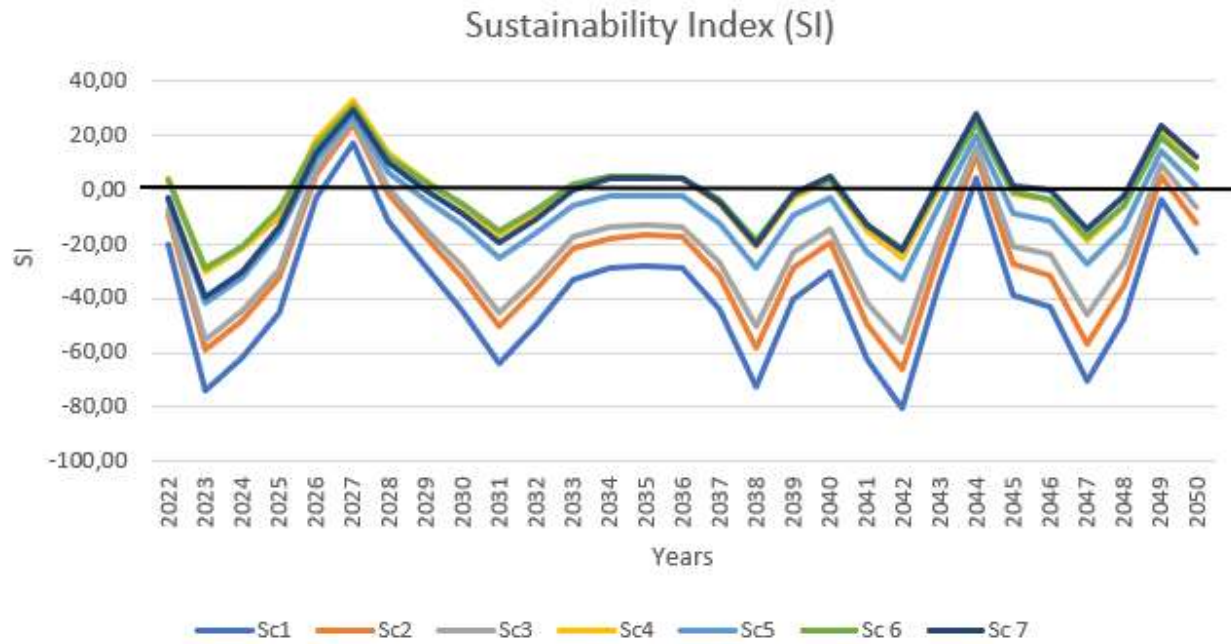


Change in sustainability index for the BAU scenario (Guemouria et al., 2025)

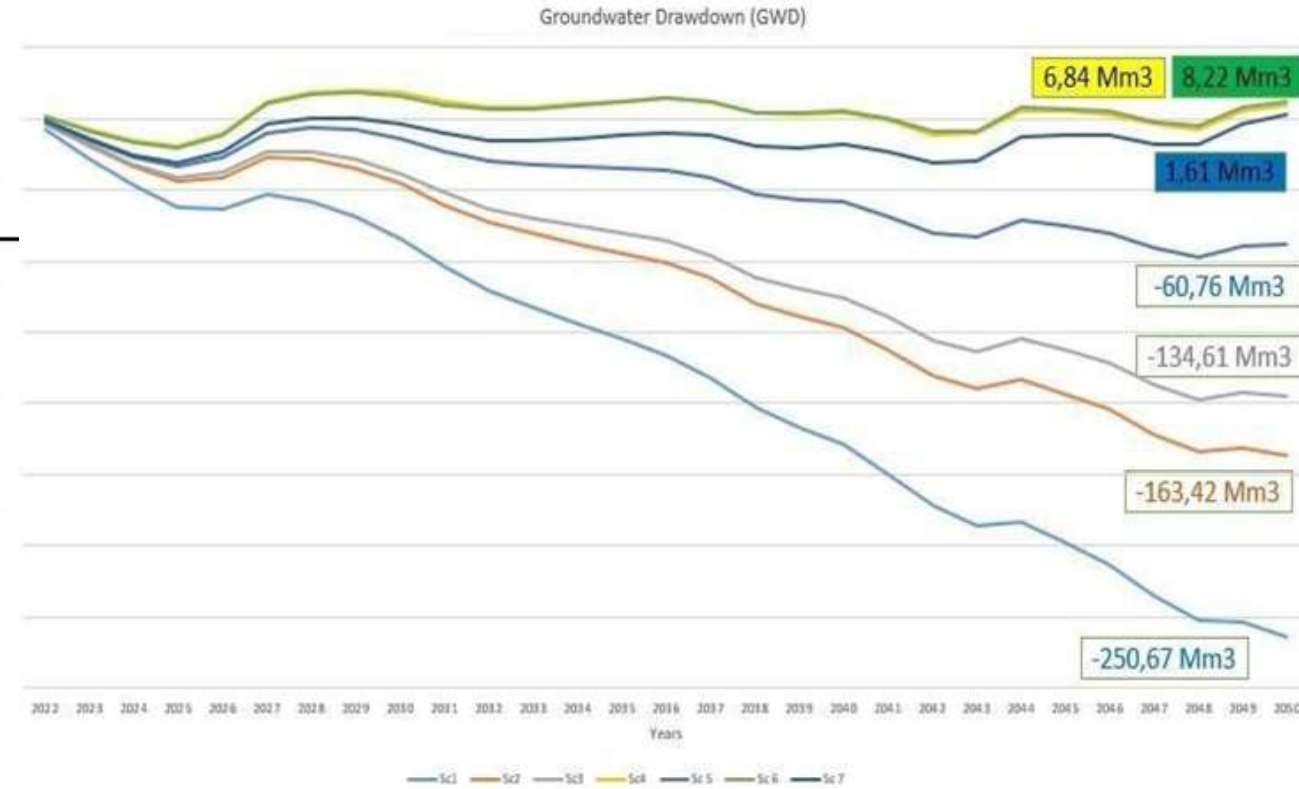
Changes in water demand and supply for the BAU scenario (Guemouria et al., 2025)



Change in groundwater drawdown for the BAU scenario (Guemouria et al., 2025)



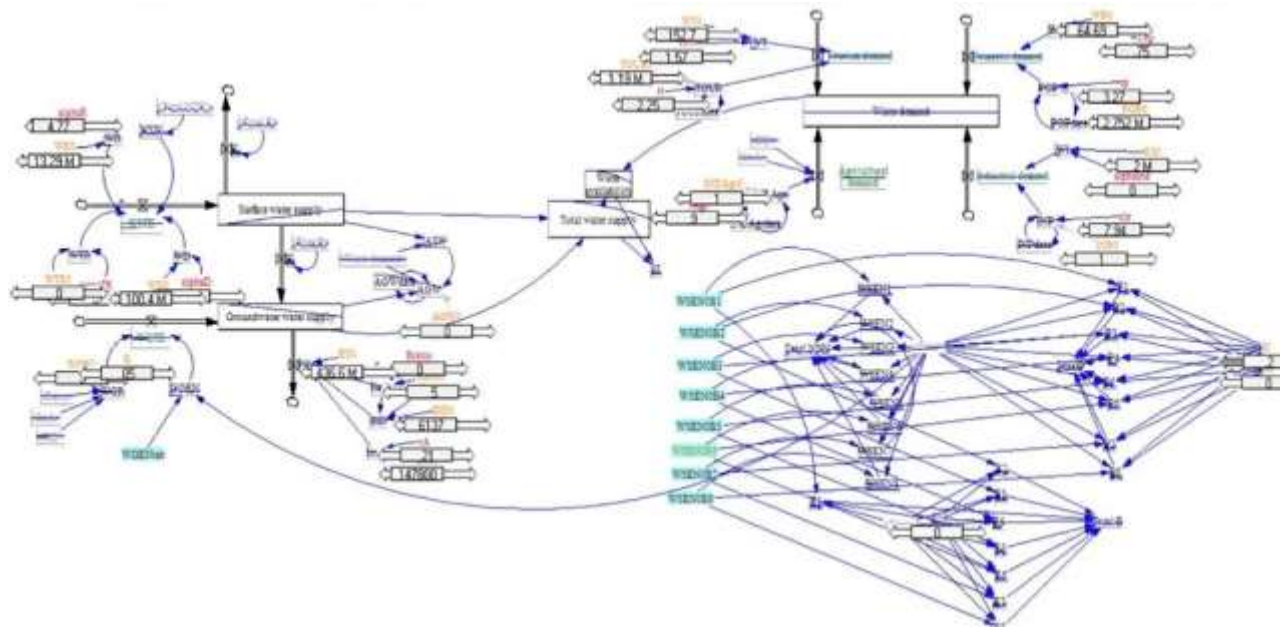
Change in sustainability index for the 7 scenarios (Guemouria et al., 2025)



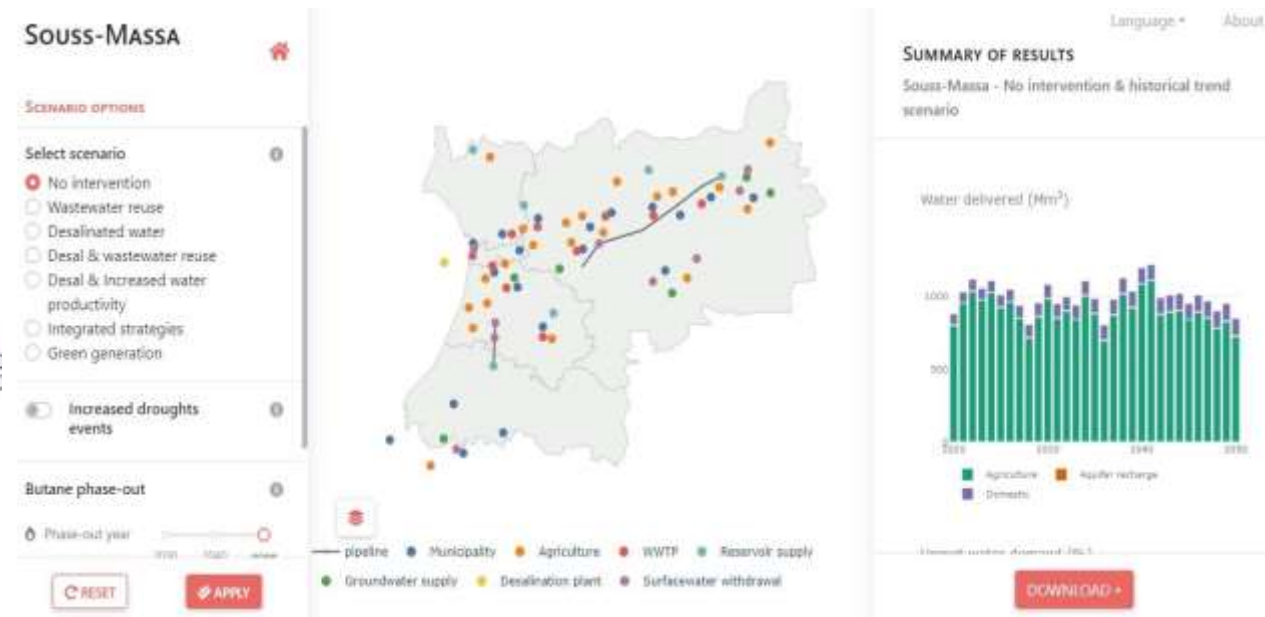
Change in groundwater drawdown for the 7 scenarios (Guemouria et al., 2025)

Key results

System Dynamics model for water resources management in the Souss-Massa basin



System Dynamics modeling for 2050 (Guemouria et al., 2025)



Dashboard for decision-makers

Cost-benefit matrix : Managing Water is Like Managing Your Bank Account !

Scenarios	Irrigation efficiency (ha)	Recycled water (Mm ³ /year)	Desalination water (Mm ³ /year)	Dams (Mm ³ /year)	Water Gain (+) / Deficit (-) (Mm ³ /year)	Water table improvement (Mm ³ /year)	Scenario cost (MDH)
BAU	94000	13.5	35	276	-138	-337	-
Scenario 1	9400	13.5	35	276	+13.31	86.32	1070
Scenario 2	18800	13.5	35	276	+26.63	87.25	2140
Scenario 3	18800	27	35	276	+53.63	28.81	3040
Scenario 4	18800	27	105	276	+158.63 (stock +20.63)	141.45	7655.38
Scenario 5	9400	27	70	276	+221.13 (stock +83.13)	1.61	4381.03
Scenario 6	9400	27	70	27.6	+137.91 (Water supply = Water demand)	13.43	7379

Conclusions

System Dynamics help decision-makers to **better visualize, plan and manage water resources**, both **qualitatively and quantitatively**, in order to achieve **sustainability goals**.

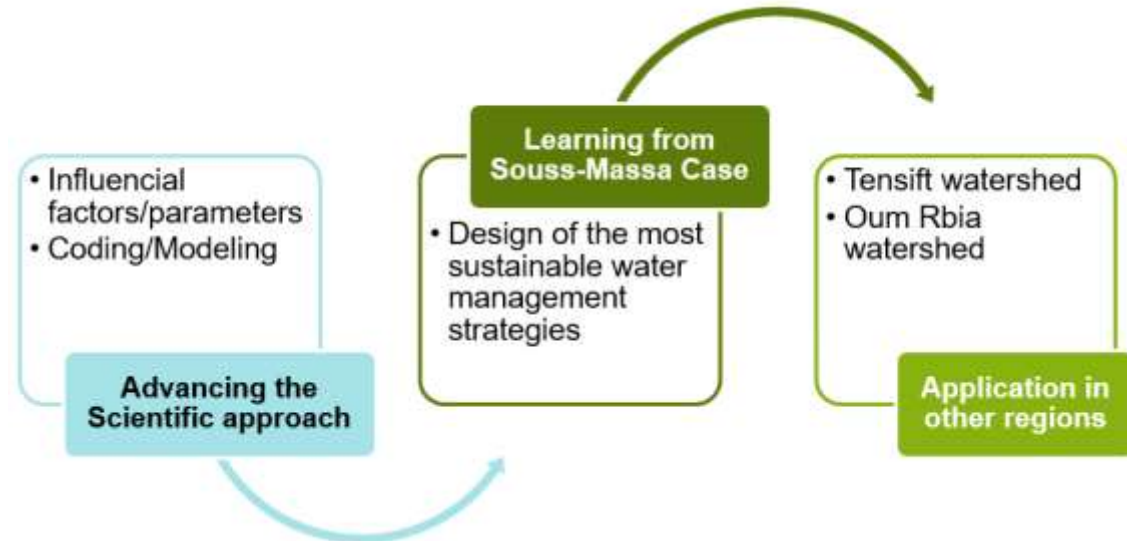


Managing Water is Like Managing Your Bank Account !

In this way, we can better frame our knowledge, take better account of the integrated picture and thus **improve the management and governance of water resources**.



The conceptual model captures, displays and connects all the important "pieces" of the water management puzzle, to **provide a holistic understanding of water resources**.



- To strengthen monitoring networks by integrating remote sensing and real-time climate data to **enhance SD model robustness**.
- To **couple the SD model with decision-support tools** for multi-criteria trade-off analysis.
- To optimize scenarios through **error-propagation analysis** and mathematical **optimization**.
- To ensure **socio-economic viability** and **social acceptability** via **multi-stakeholder governance platforms**.
- From data to decisions: SD-AI-Remote Sensing (GIS) capturing basin variability for **sustainable water governance** in Morocco.

Project initiated by the CDRT in water management sector: SUD-MED Project: UCAM, CESBIO, ORMVAH, ABHT



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