A generic hydroeconomic model to assess future water scarcity

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❶ Introduction

Climate change and socioeconomic evolutions are expected to increase water scarcity in the Mediterranean region.

Water resources are managed at the water basin level, and heterogeneity between basins (physical geography, climate, human activities etc.) is decisive for the determination of water availability. But inter-basins relations, through markets of goods requiring water for their production and locations of water-dependant activities and settlements, are also important.

It is therefore interesting to maintain a double focus while assessing water scarcity: a large-scale coverage, and a representation of spatial heterogeneity at the river basin level.

Besides, modelling the economic benefits associated with water use, and the constraints associated with water shortage, is particularly important to address inter-basins issues.

In this work, we present a generic hydroeconomic model, built to address these questions.

❷ Demand projection and valuation

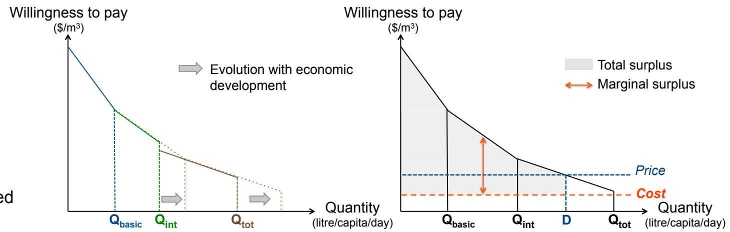
Domestic sector

Our approach is to build simple **3-part inverse demand functions, scaled by economic development.**

- 1st part: basic water requirements, consumption and hygiene, very highly valued;
- 2nd part: intermediate uses, additional hygiene and less essential uses;
- 3rd part: supplementary consumption, further indoor uses and outdoor uses, least valued.

Willingness to pay along the curve estimated based on:

- econometric studies
- data on water prices and water withdrawals
- assumptions



Q_{int} and Q_{tot} increase with GDP/capita, with a saturation[1] (calibrated at country-scale).

Domestic water value measured by **economic surplus.**

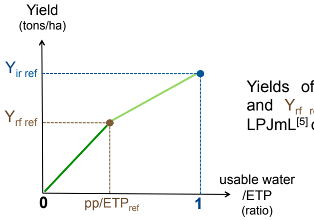
Agricultural sector

- **Irrigated crops localisation** determined from globally available data on irrigated areas and crops[2].
- **Crops irrigation requirements (potential demand)** defined as the deficit between potential ETP and usable precipitation, and computed for the different stages of the growing season[3].
- Climatic data taken from the CNRM climatic model outputs[4].

Economic value of irrigation water based on a "yield comparison approach" between rainfed and irrigated crops:

$$V_{water} = \frac{[Y_{ir}(pp, Q_{water}) - Y_{rf}(pp)] \times Price_{crop} - Cost_{ir}}{Q_{water}}$$

Where yields are computed as a simple function of usable water:



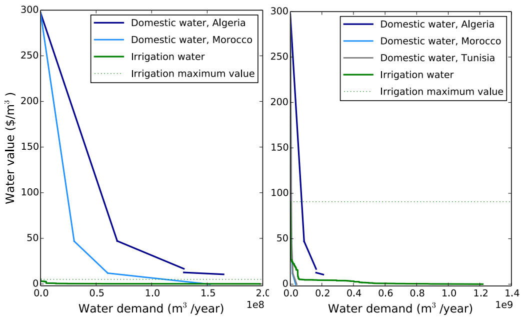
Yields of reference $Y_{ir\ ref}$ and $Y_{rf\ ref}$ are based on LPJmL[5] or FAOSTAT

+ Scenario on future yield increase[6]

Application to Algeria

Projected irrigation and domestic demands for year 2050 in Algeria:

- At the country scale, the domestic sector becomes an important sector of water use in 2050, catching up with irrigation
- Results are contrasted between different types of basins:



Basin A: coastal cross-border basin

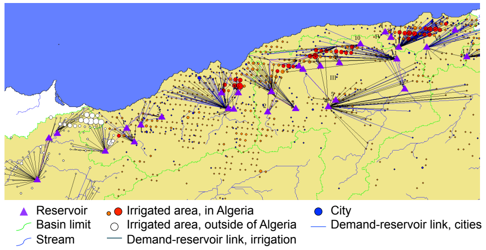
Basin B: internal drainage basin

❸ Supply side

Reconstruction of the network

At large scale, the physical links between reservoirs and demands are unknown, the network has to be reconstructed[7].

- reservoirs are located using Aquastat[8]
- current urban areas localisation and population distribution are taken from the GRUMP database[9]
- reservoir-demand association paths are reconstructed based on topological costs: penalisation of distance covered and ascending moves. Water balance constraint on the average annual supply and consumptive demand is also taken into account.
- demands are associated to water inlets, located on the stream, to take into account return flows.



Water supply

On the supply side, we evaluate the impacts of climate change on water resources[7].

- runoff is taken from the outputs of CNRM climate model[4], scenario A1B
- sub-basin flow-accumulation area of each reservoir is determined based on a Digital Elevation Model (HYDRO1k[10])

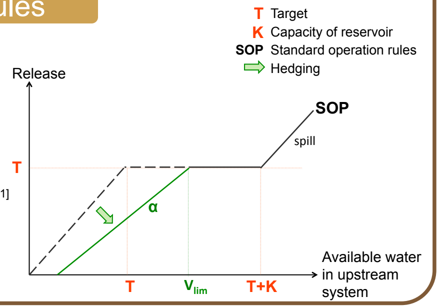
Water release rules

Operating rules of the reservoirs and water allocation between demands are based on the **maximisation of water benefits**, over time and space.

A **parameterisation-simulation-optimisation** approach is used, with three parameters for each reservoir (β, V_{lim} and α).

- Reservoirs in series: water is released from the most downstream reservoir
- Reservoirs in parallel: parameter to decide between upstream branches (β)[11]
- Prudential parameters: for spatial and temporal trade-offs (V_{lim} and α)

=> Deterministic parameter optimisation, to maximise the total value of water.



❹ Conclusions

This large-scale approach uses imprecise data and requires strong assumptions. The level of precision is not suitable to build a detailed representation of the water system at the basin scale.

However, this model can be applied to the study of any issue requiring a wide area, such as virtual water trade, evolution of the energy sector water use, or activities and population relocalisations due to water supply reduction or water demand value changes.

The modular and generic nature of this framework, which only requires globally available data, makes it suitable to apply to diverse regions, in particular to developing regions with low data-availability.

References

[1] Alcamo et al. (2003) Development and testing of the WaterGAP 2 global model of water use and availability, *Hydrological Sciences 48.*
[2] Siebert, S., et al. (2005) Development and validation of the global map of irrigation area. *Hydrology and Earth System Sciences 9.*
[3] Allen, R.G., et al. (1998) Crop evapotranspiration-Guidelines for computing crop water requirements. *FAO Irrigation and drainage paper 56*. Rome: FAO.
[4] Dubois C., et al. (2012) Future projections of the surface heat and water budgets of the Mediterranean sea in an ensemble of coupled atmosphere-ocean regional climate models, *Clim. Dyn.*
[5] Bondeau, A., et al. (2007) Modelling the role of agriculture for the 20th century global terrestrial carbon balance, *Glob. Change Biol. 13(3).*
[6] Alexandratos N, Bruinsma J. (2012) World agriculture towards 2030/2050, the 2012 revision. *ESA Working Paper No. 12-03*. Rome: FAO.
[7] Nassopoulos, H. (2012) Les impacts du changement climatique sur les ressources en eaux en Méditerranée. PhD thesis. Université Paris-Est, France.
[8] AQUASTAT Program (2007) Dams and agriculture in Africa. Available at http://www.fao.org/nr/water/aquastat/dams africa/index.stm.
[9] Center for International Earth Science Information Network (CIESIN), International Food Policy Research Institute (IFPRI), the World Bank, Centro Internacional de Agricultura Tropical (CIAT). (2004) Global Rural-Urban Mapping Project (GRUMP): Settlement points.
[10] HYDRO1k (2009) Hydro1k elevation derivative database. URL http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/ gtopo30/hydro
[11] Nalbantis, I., Koutsoyiannis, D. (1997) A parametric rule for planning and management of multiple-reservoir systems. *Water Resources Research* 33 (9).