Projecting water demands and allocation using generic hydroeconomic modelling

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Context: tension on water resources

- Water scarcity expected to increase with global changes in some regions

- Constraint for economic activities and populations

  => Anticipate future water scarcity issues

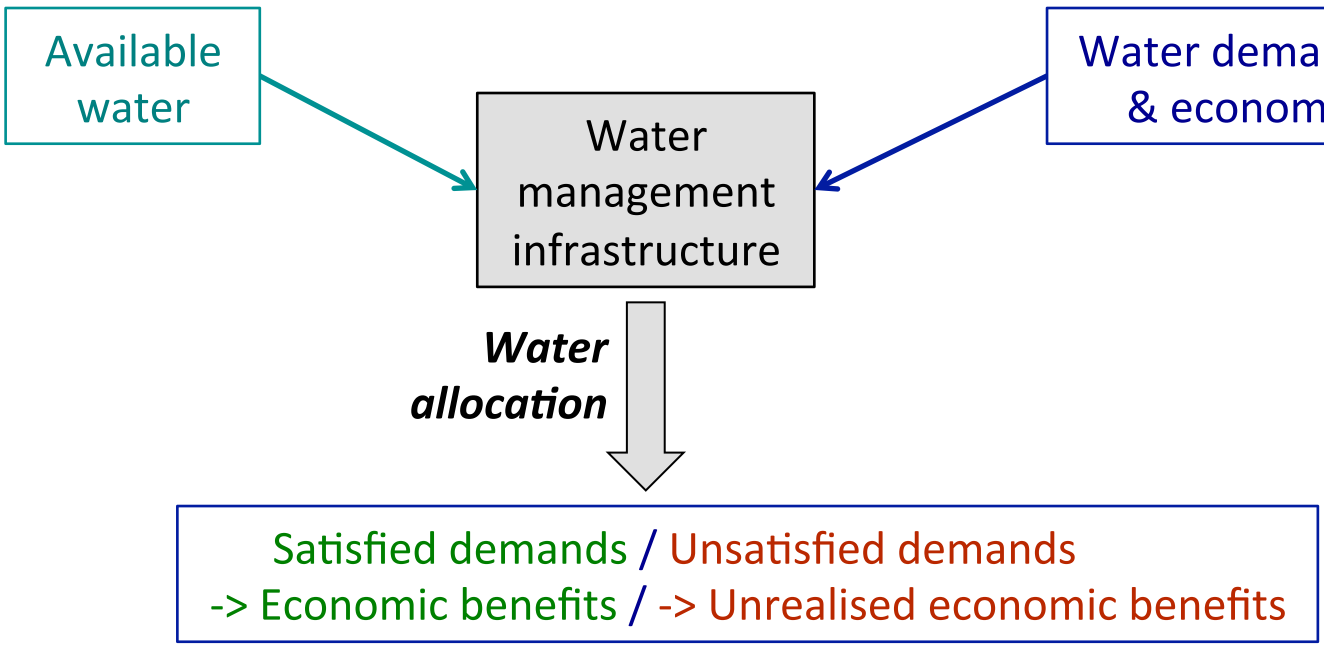
- Objectives:
  - Project quantities at stake + Associated economic losses

- **Approach:**

  => Hydroeconomic modelling

Hydroeconomic modelling

- Compare available water <-> demands
- Represent water management infrastructure (dams)
- Take into account the economic dimension



- Cost of water scarcity defined as: “unrealised economic benefits” (direct costs)

Large-scale hydroeconomic modelling

- Hydroeconomic models mainly developed at the river basin scale
- Economic dimension generally absent from large-scale assessments

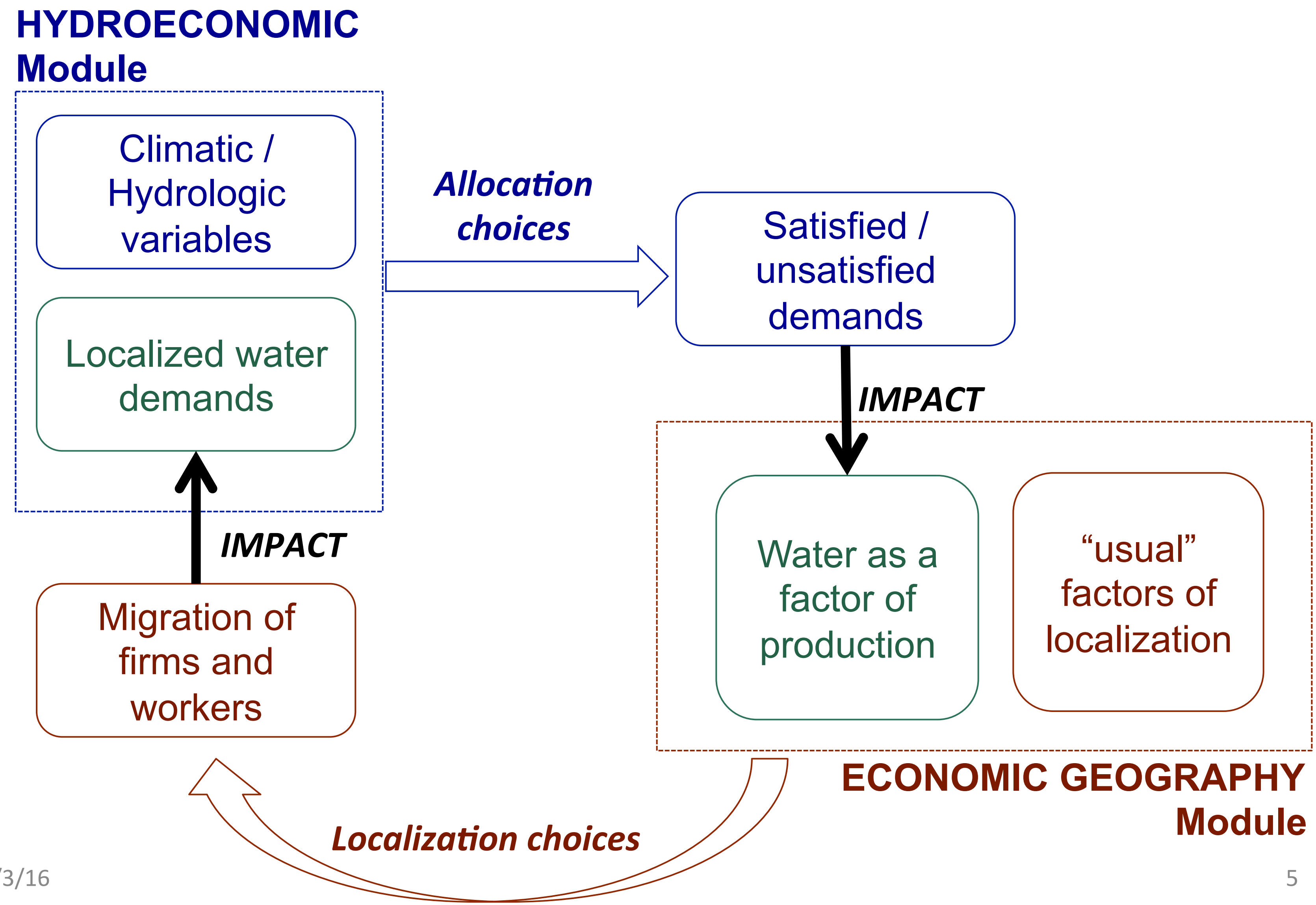
- **Approach:**

  ⇒ **Generic** hydroeconomic modelling

  (ODDYCCEIA hydroeconomic framework)

- Main challenge: maintain a double focus
  - large-scale coverage
  - representation of heterogeneities at the river basin level

Example of application: inter-basin activities locations



Outline

I. Project demands and their associated economic values

Domestic and irrigation sectors

II. Compare to available water

Manage dams, allocate water to minimize the cost of water scarcity

III. Application to Algeria

I. PROJECTING DEMANDS AND THEIR ECONOMIC VALUES

Domestic and irrigation sectors

Demand side

Introduction

- Irrigation and domestic demands projected in terms of quantity and economic value

- Economic value of water:

Exchange value ≠ Use value

→ **Price**

→ **Domestic sector:**
- Willingness to pay, economic surplus (consumer good)

Agriculture:
- Economic benefits (water used as intermediate input)

Introduction

- Usual valuation methods:
  - Irrigation: residual method
  - Domestic: econometric estimation of demand functions

=> Here: simple methodologies suitable for large-scale

1. DOMESTIC WATER DEMANDS

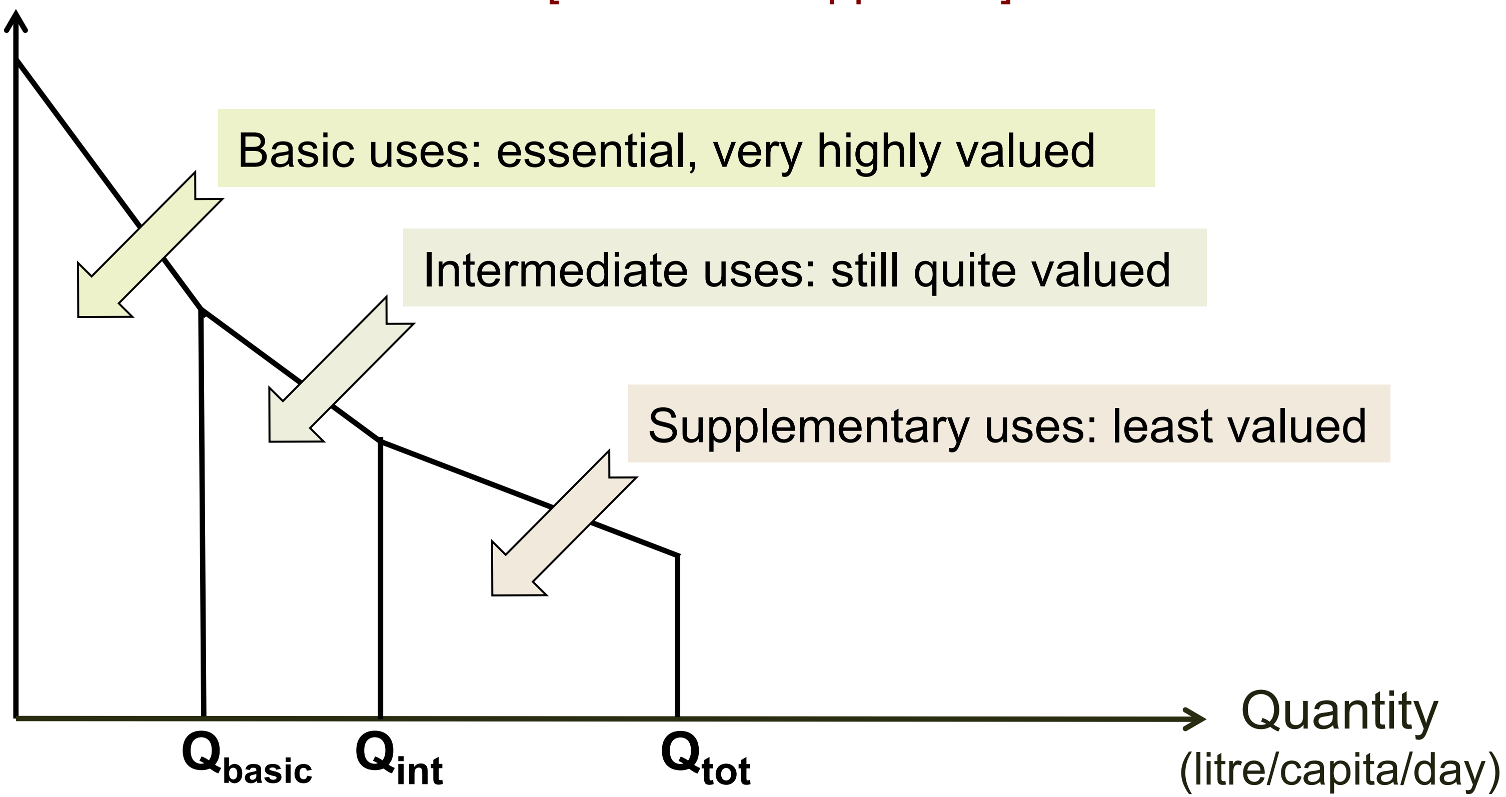
- Project the combined effects of:
  - demographic growth
  - economic development
  - Evolution of water cost (and price)
- Method: build demand functions, at country scale
  - average demand per capita (GDP_t, $price_t$)
  - multiplied by $population_{t,city}$
- Spatial distribution: population homogeneously distributed among existing locations

Building a simple demand function

- 3-part inverse demand function (average demand per capita)

Willingness to pay ($/m³)

Q_{int} and Q_{tot}: evolve with economic development [WaterGAP approach]

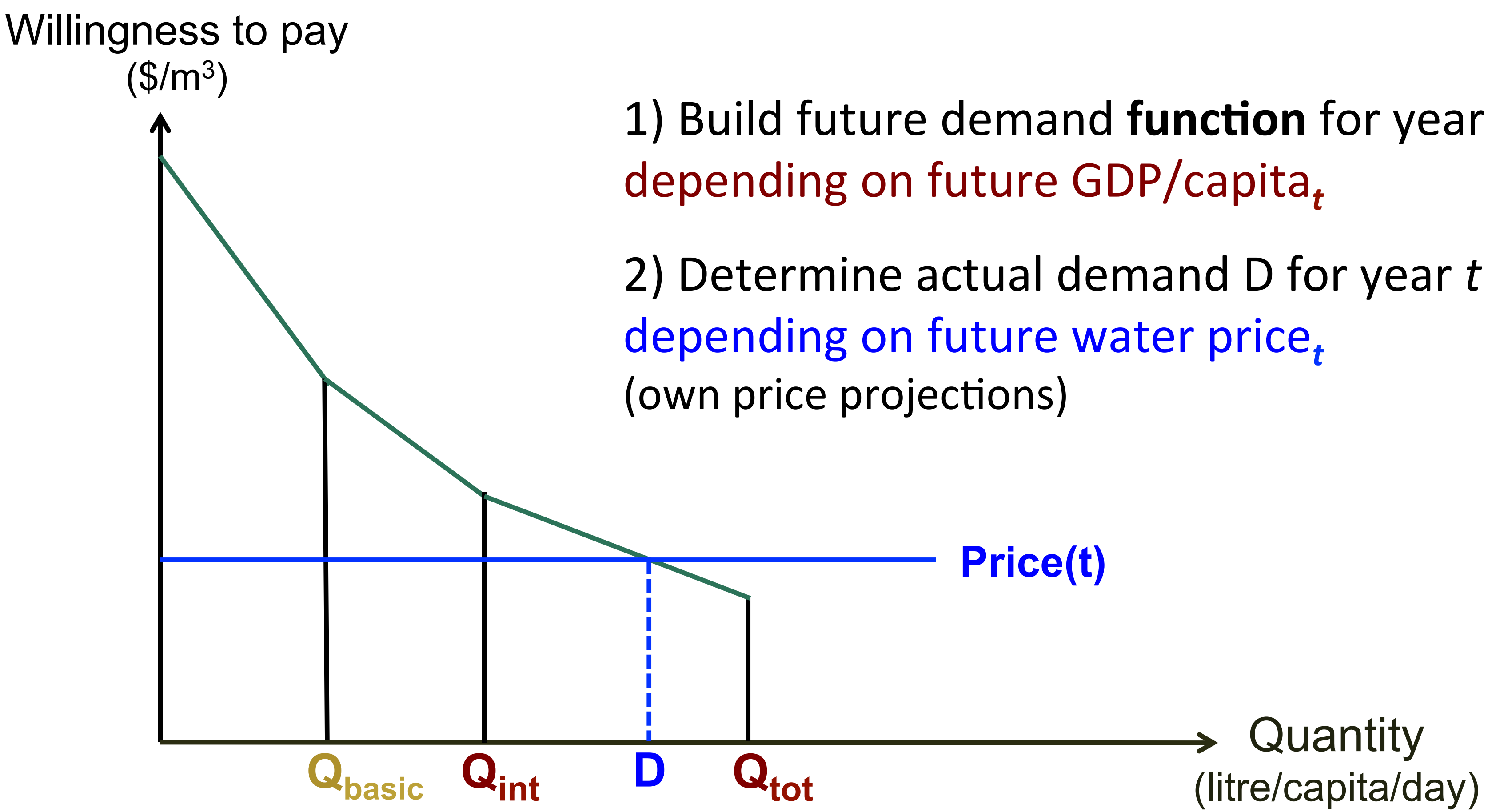


Projecting demands

- 2 steps

1) Build future demand **function** for year *t* depending on future GDP/capita$_t$

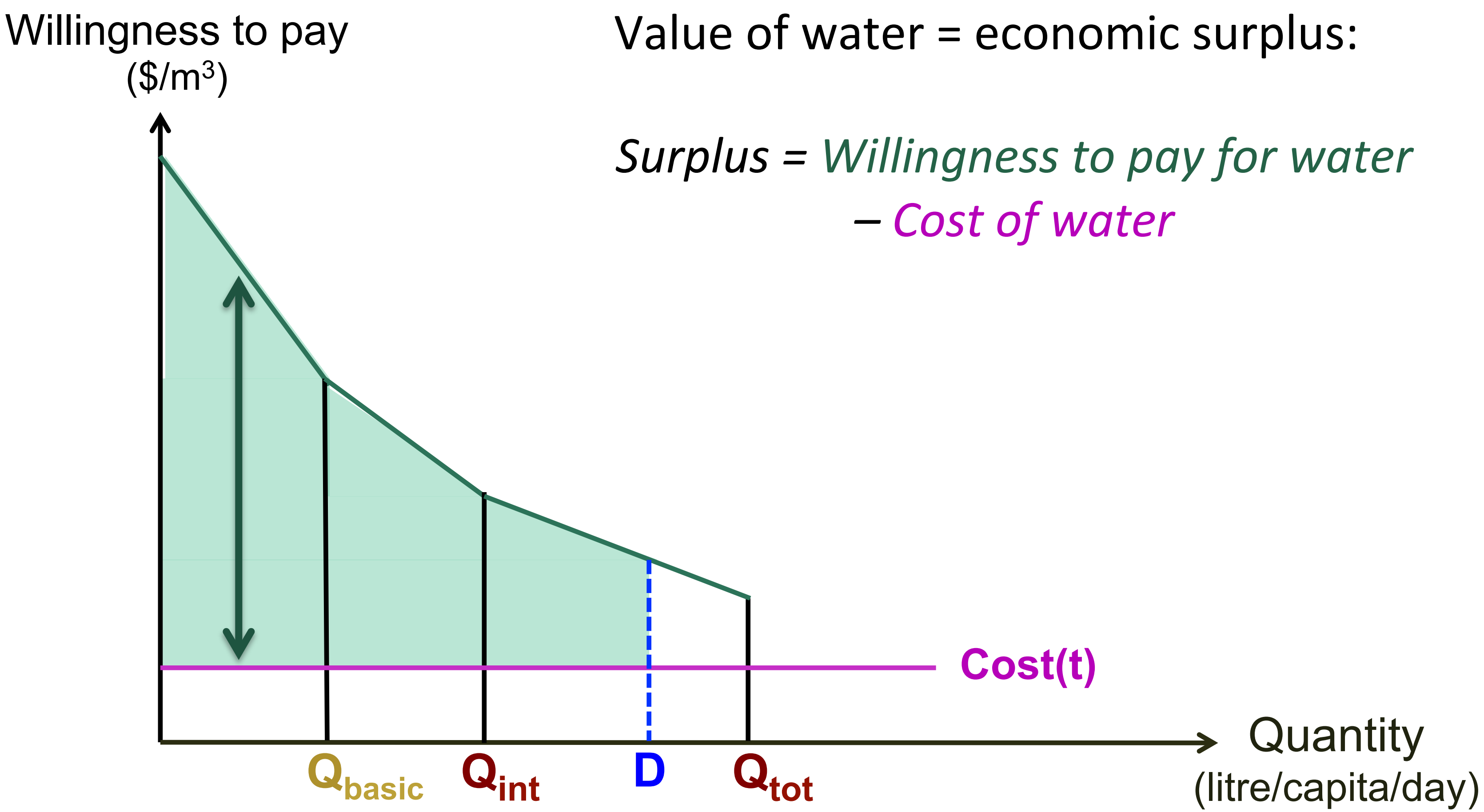
2) Determine actual demand D for year *t* depending on future water price$_t$ (own price projections)



Projecting demands and values

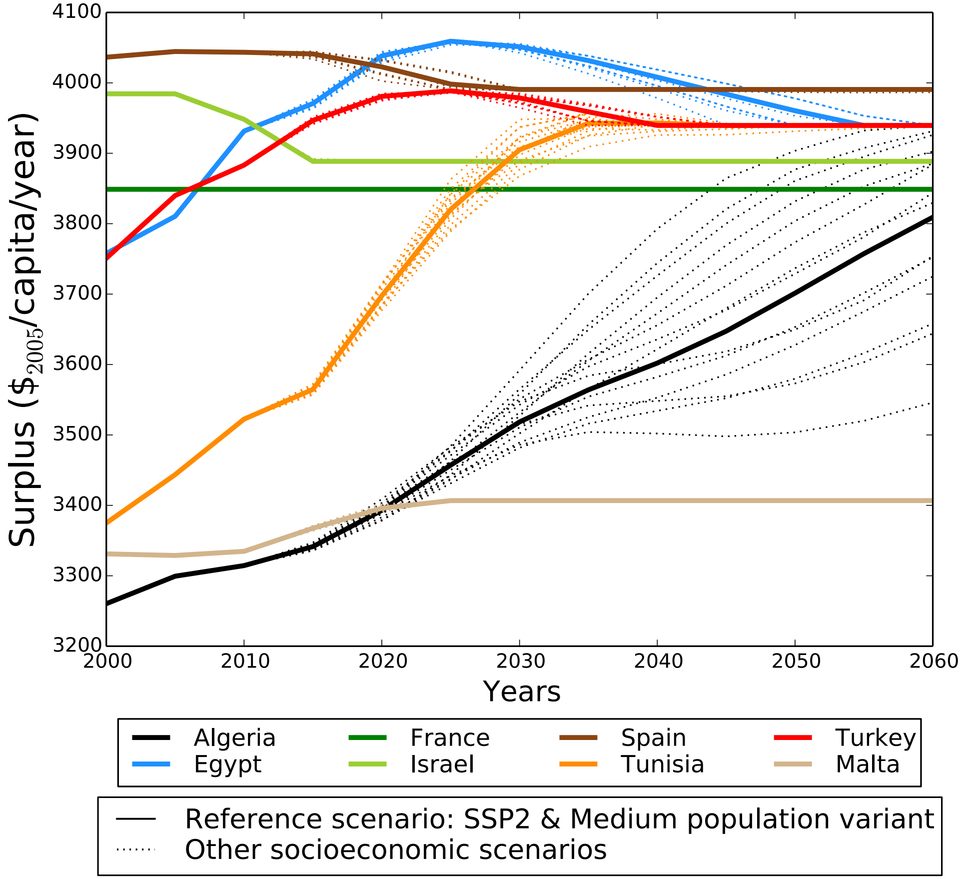
Value of water = economic surplus:

Surplus = Willingness to pay for water
– Cost of water



Application to Mediterranean countries

- Robust to most uncertainties except level of demand saturation and quantity of basic water needs
- Evolution of surplus per capita in different countries



2. IRRIGATION WATER DEMANDS

- Irrigation water needs [Nassopoulos, 2012]
  - 12 crop types, located in irrigation perimeters
  - Irrigation requirements computed for the different stages of the growing season [Allen, 1998]
  - Water requirements: deficit between *ETc* and *usable precipitation*
  - Future irrigation water demand projected under climate change (CNRM model [Dubois et al., 2012] outputs, A1B scenario)

- Irrigation water value
  - Yield comparison approach

Yield comparison approach

- Yield comparison between rainfed and irrigated crops
  => additional net benefit associated with the use of water

Volumetric value

Net benefit if crop is irrigated — Net benefit if crop is rainfed

$$V = \frac{[Y_{ir} \times Price_{crop} - Cost_{ir}] - [Y_{rf} \times Price_{crop} - Cost_{rf}]}{W}$$

Quantity of irrigation water

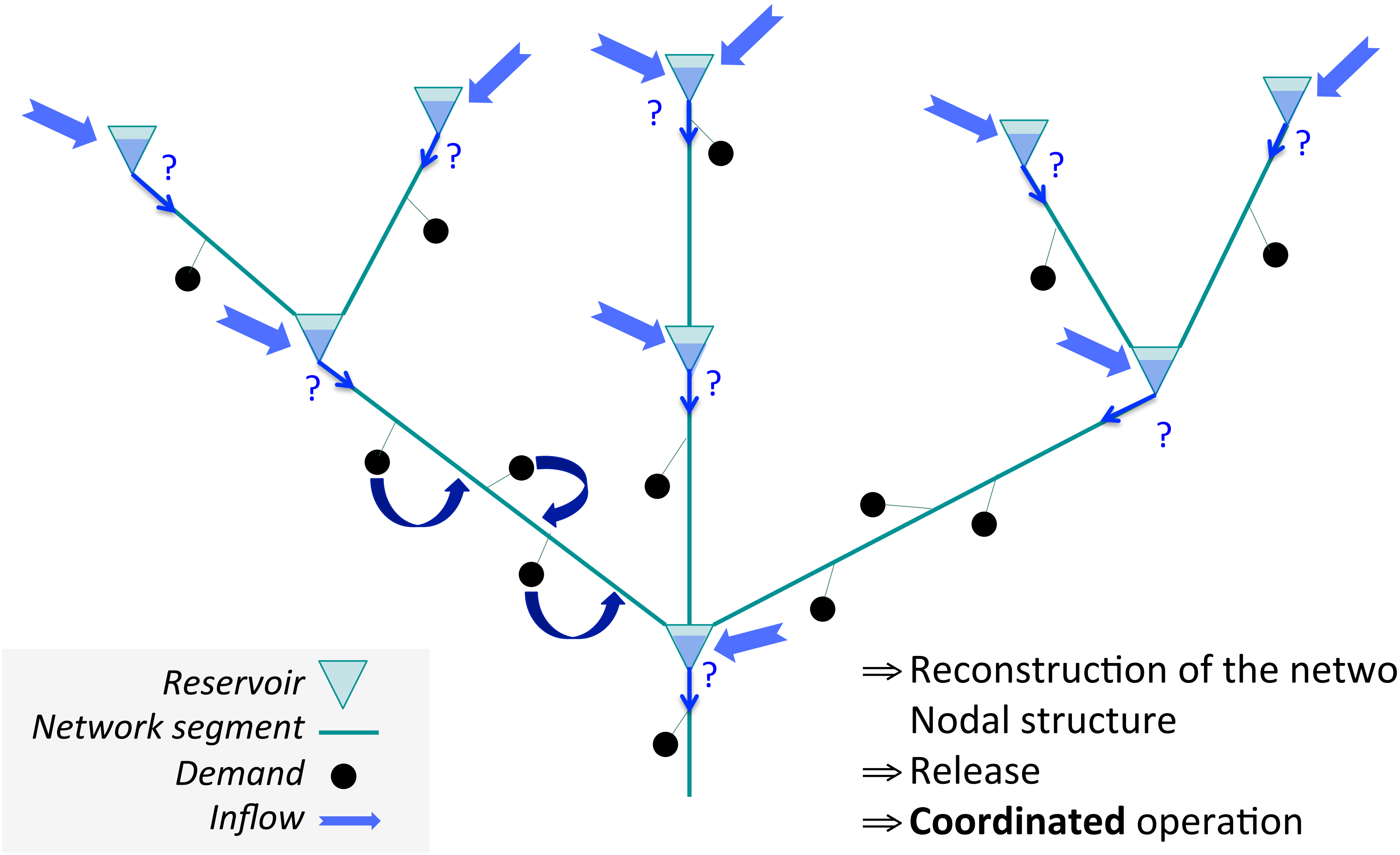
- Model yield as a simple function of available water and crops water needs
  - Calibrated using LPJmL model outputs [Bondeau et al., 2007]
  - $Y_{rf}(precip, ETc)$ $Y_{ir}(precip, W, ETc)$

- Average value

II. ALLOCATING WATER

Supply side

Overview



⇒ Reconstruction of the network
Nodal structure

⇒ Release

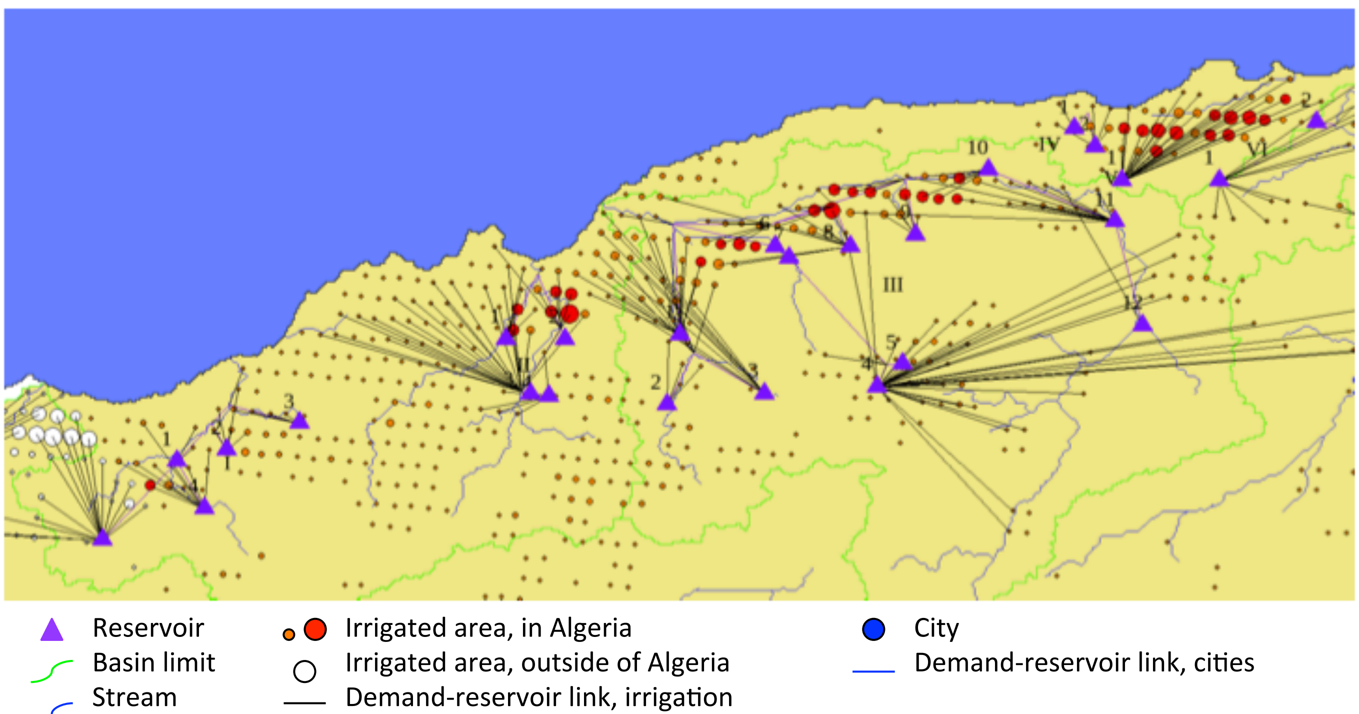
⇒ **Coordinated** operation

⇒ Return flows

1. RECONSTRUCTING THE WATER NETWORK

- Reservoir-reservoir links (upstream-downstream)
- Reservoir-demand links

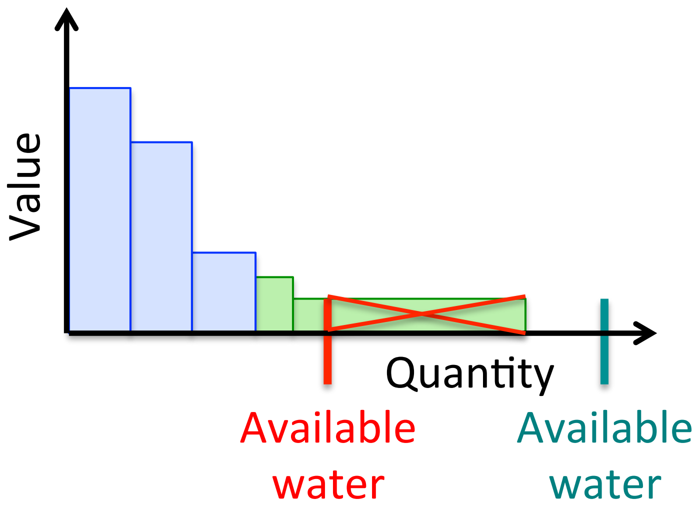
Association paths based on topography. Cost function: penalisation of distance covered and ascending moves. [Nassopoulos, 2012]



2. OPERATING RULES OF RESERVOIRS NETWORKS

- Coordinated operation of reservoirs for a better supply-demand balance
- Objective function: maximise economic benefits of the allocated water
- Parameterisation-Simulation-Optimisation approach
  [Nalbantis and Koutsoyiannis, 1997]

Allocating water between uses based on economic criteria



Demands ordered by decreasing value

- domestic
- irrigation

- If enough water available:

⇒ All demands are satisfied

- If not enough water:

⇒ Demands with the highest value have priority

Taking into account the value of water

- Priorities among demands

  Give priority to the satisfaction of demands with a high valorisation of water

- Demands of a higher priority can be:
  - Located on different segments
  - Occurring at different time-periods

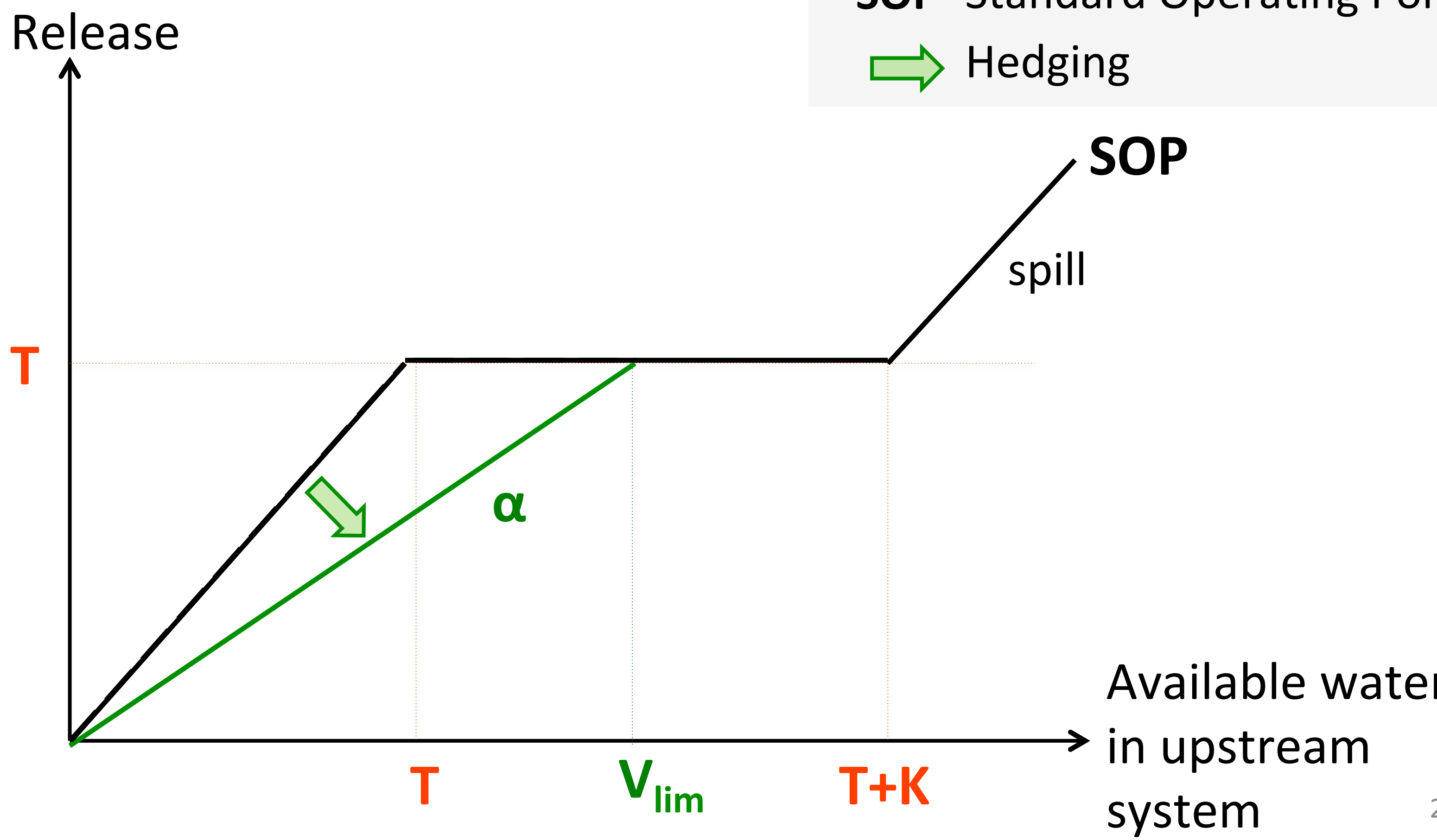
  => Spatial and temporal trade-offs

- Prudential rules

Prudential rule

- 1-point hedging

T Target
K Capacity of reservoir
SOP Standard Operating Policy
⇨ Hedging



Operating rules taking into account water value

- Prudential release rules:
  - Prudential parameters, both intertemporal and inter-branch: ***α*** parameters (hedging)

- Other water release rules:
  - Reservoirs in series: release from most downstream reservoir
  - Reservoirs in parallel: parameter **β**

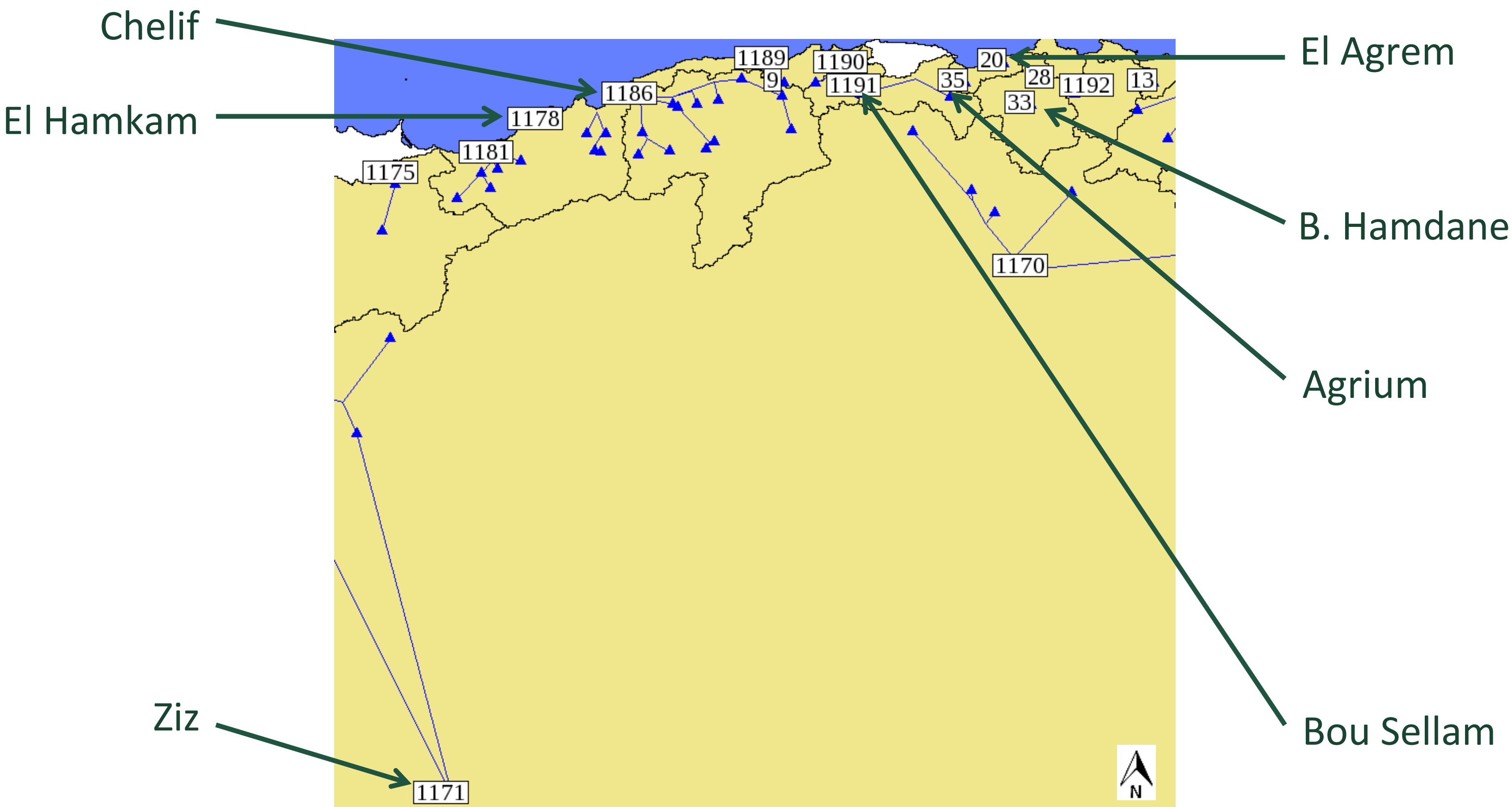
=> 2 parameters for each reservoir (**α** and **β**)

- Parameters are optimised

III. APPLICATION TO ALGERIA

DEMAND-SUPPLY GAP

- a system = river catchment network of reservoirs



Demand satisfaction rates

- Evolution under future conditions (2050 horizon)

System	Quantity			Value		
	Past	Future	**Evolution**	Past	Future	**Evolution**
Agrium	72.4 %	84.4 %	**+ 11.9**	99.7 %	99.9 %	**+ 0.2**
Ziz	11.0 %	15.3 %	**+ 4.3**	22.6 %	28.2 %	**+ 5.6**
Bou Sellam	60.3 %	42.3 %	**- 18.0**	72.8 %	56.0 %	**-16.8**
B. Hamdane	31.8 %	17.5 %	**-14.4**	60.0 %	28.6 %	**-31.3**
El Agrem	53.3 %	11.7 %	**- 41.6**	53.3 %	32.1 %	**-21.1**

2 systems: improvement of supply-demand balance in the future
Most catchments: Increase in supply-demand imbalance in the future

Demand satisfaction rates

- Impact of demand prioritisation
  - Prioritisation: value & prudential rules -> maximise economic benefits
  - No prioritisation: no value & no prudential rules -> maximise quantity

System	Quantity		Value	
	Past	Future	Past	Future
El Hamkam	- 3.3 %	+ 1.6 %	+1.4 %	+3.4 %
Bou Sellam	+ 2.0 %	+ 0.8 %	**+ 11.3 %**	+ 6.4 %
El Agrem	+ 2.5 %	+5.5 %	+ 2.4 %	**+20.2 %**
Chelif	- 0.1 %	+ 0.6 %	+ 6.4 %	+ 6.3 %

With prioritisation: lower satisfaction rate in terms of quantity

With prioritisation: better satisfaction rates in terms of quantity

Positive impact of prioritisation on satisfaction rates in terms of economic benefits

CONCLUSION

Conclusions and discussion

- Large-scale hydroeconomic model
  - Anticipate water scarcity issues under global changes
  - Basin scale + Large-scale coverage
  - Quantities + Associated economic losses

- Use of globally available data has its limits
  - There can be errors in reconstruction of reservoirs-demands networks [Nassopoulos, 2012]
  - Use of models for crops yields and water demands
  - Assumptions for domestic water willingness to pay, agricultural costs etc.

- Not designed to provide a detailed representation of catchments for operational purpose but to **represent heterogeneous impacts of global changes at the local scale**
  - Suitable for the representation of inter-basin interactions (virtual water, water transfers, activity relocation)

Conclusions and discussion

- Heterogeneity between basins
  - Causes?
- Extend to the whole world?
- Evaluation of water management policies, adaptation policies, impacts of climate change
  - at large scale or simultaneously on different basins
- Perspectives:
  - Evaluation of indirect impacts and costs
  - Groundwater
  - Electricity sector
  - Quality

Thanks for your attention

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