Integrated modelling of demand and supply. The role of hydroeconomic models.

Manuel Pulido-Velazquez

Smart Systems for Water Management

22-25 August 2016, Monte Verità, Switzerland

the smart H2O project
A European project on water sustainability

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

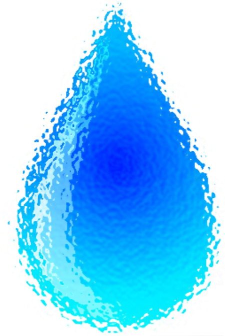
iiama

Research Institute for Water and Environmental Engineering IIAMA, UPV

- Since 2001. 100 researchers. Multidisciplinary research center on water:
  - Civil, Forestry, Agricultural and Industrial Engineering
  - Biology, Chemistry and Environmental Sciences
  - Computer Science, Statistics, Economics, etc.

Mission and vision

- Scientific research, advanced teaching and technical advice on topics related to **water**, considered both as resource and support of the biosphere



- Promote working in a coordinated and interdisciplinary way, through the **integration** of research groups from different knowledge areas

- Become a **reference center** for private companies and public administration at local, national and international levels

10 Research Groups

- Water Quality
- Environmental Impact Assessment
- Water Chemistry and Microbiology
- Hydraulics and Hydrology
- Hydraulic Networks and Pressure Systems
- Water Resources Engineering
- Groundwater Hydrology
- Mathematical Modelling of Subsoil
- Hydrological and Environmental Modelling
- Forest Science and Technology

OUTLINE

- **Introduction**
- **Role of economics in WRPM**
- **Hydroeconomic models (HEM)**: concept, characteristics, configuration, results, classification
- **Economic characterization of water demands**
- **Urban water demand**
- **HEM applications**: some practical examples
- **Limitations, challenges and conclusions**

INTRODUCTION

Context. Integrated modelling of D and S.

What's the most **undervalued** natural resource & **underpriced** service ?

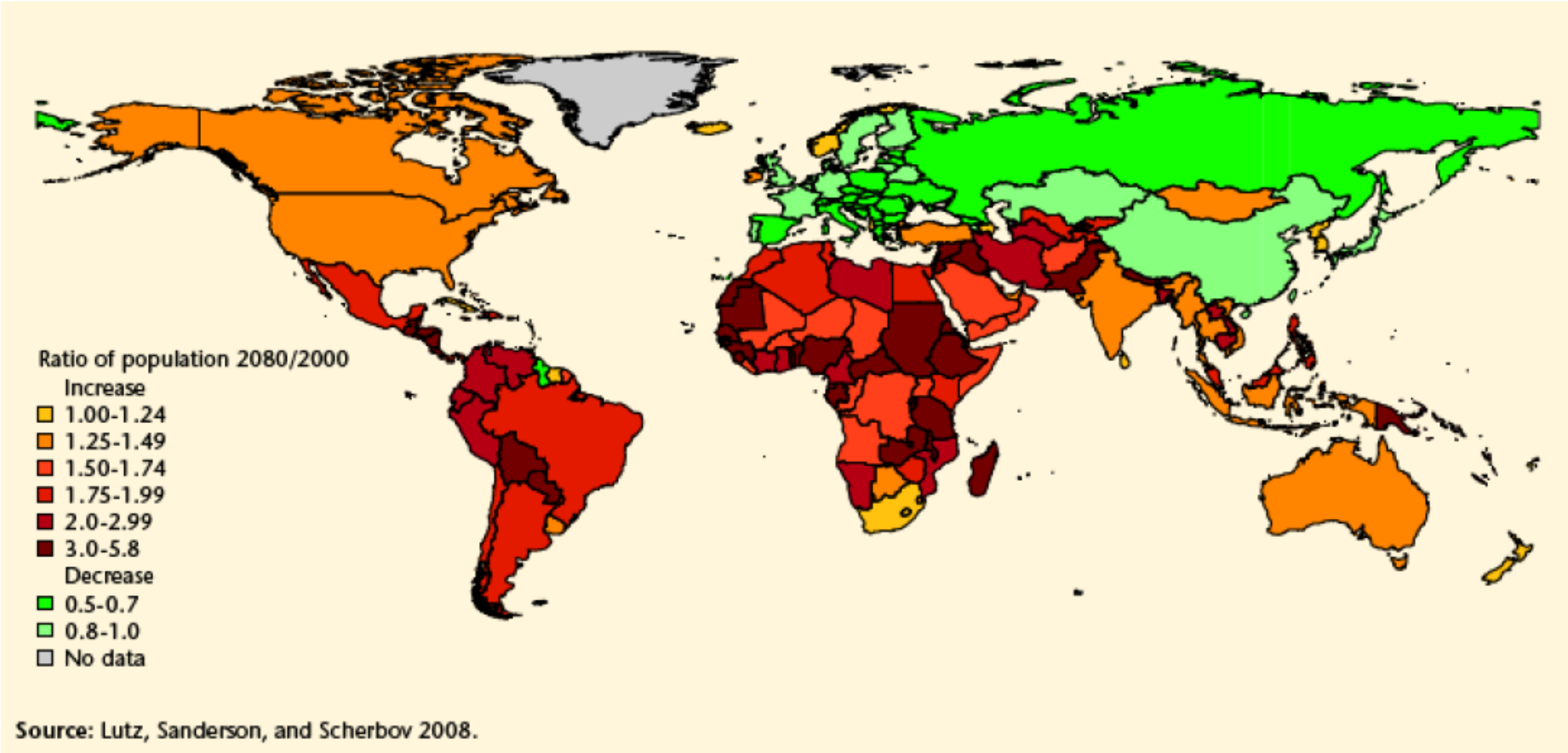
Mismanaged; pollution, depletion, ….

What can we offer from the scientific community?

The Economist cover, January 12th 2013

CONTEXT

POPULATION GROWTH [7 billion people in 2011]

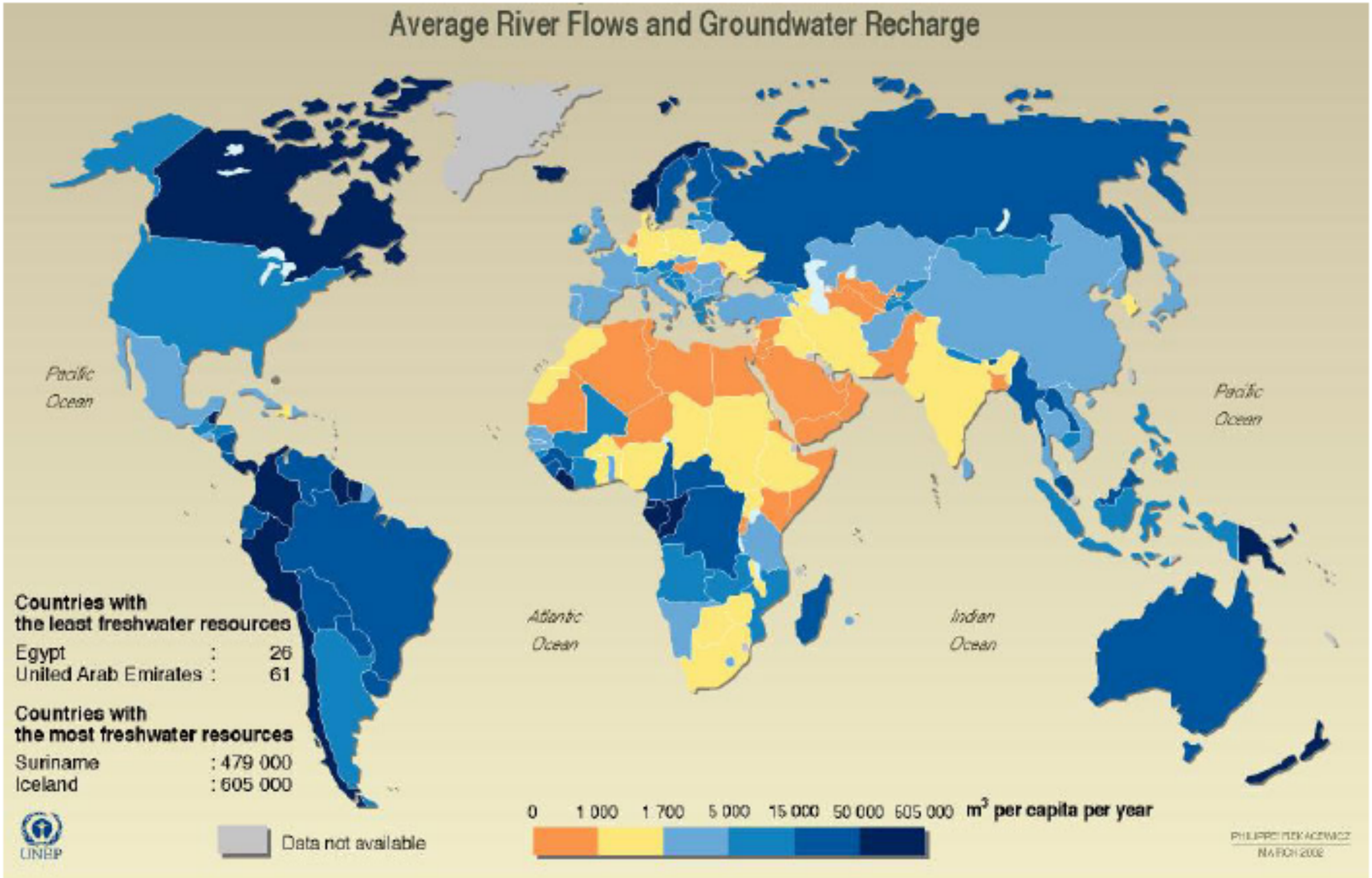


Continuing population growth and urbanization are projected to add **2.5 billion people** by 2050, with nearly **90 %** of the increase concentrated in Asia & Africa *(UN World Urbanization Prospects, 2014 update)*

ONTEXT

WATER SCARCITY

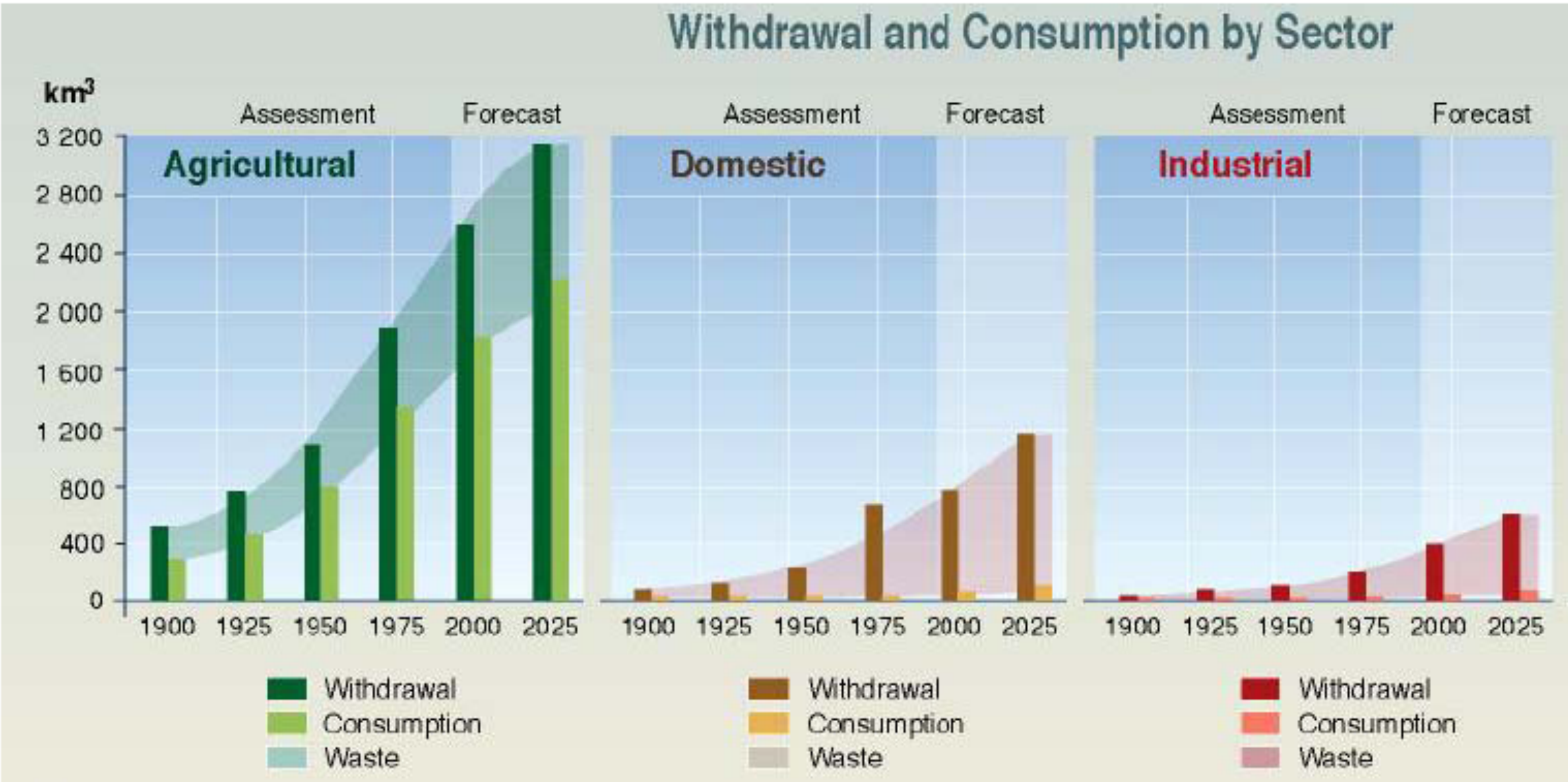
Global Water Availability



Source: *World Resources 2000-2001, People and Ecosystems: The Fraying Web of Life*, World Resources Institute (WRI), Washington DC, 2000.

ONTEXT

GROWING AGRICULTURE, DOMESTIC & INDUSTRIAL DEMANDS



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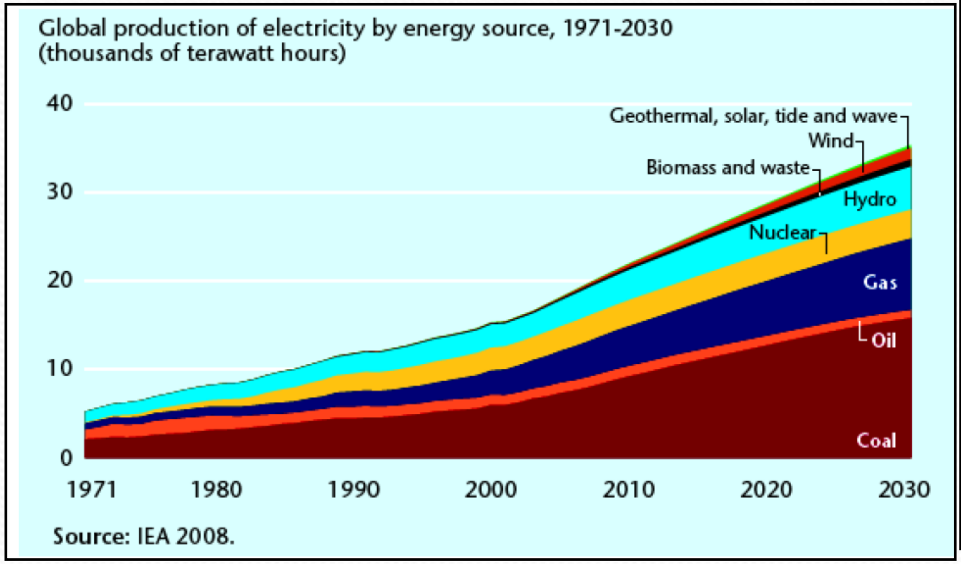
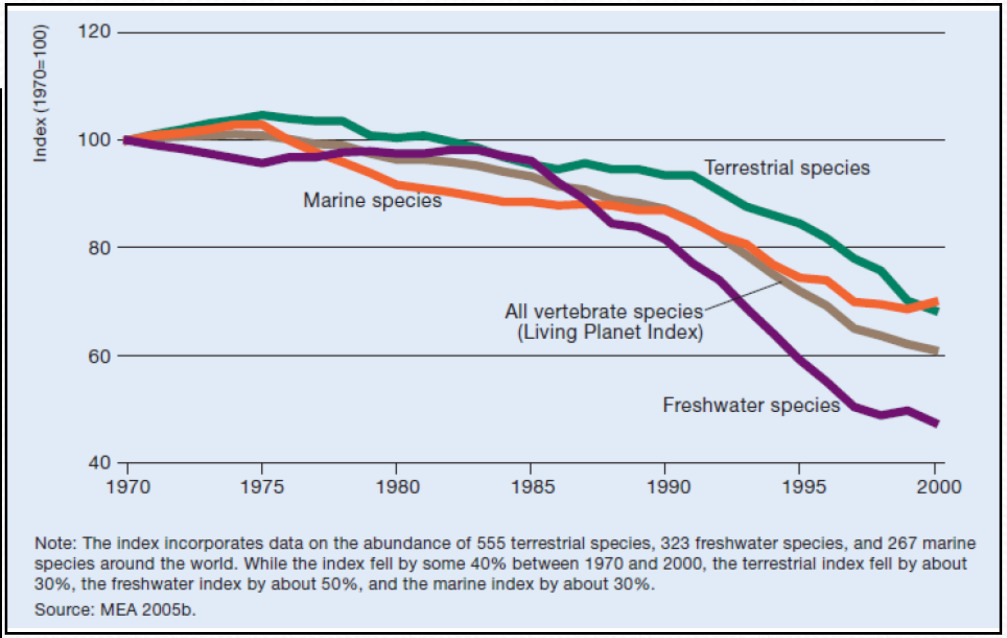
GROWING ENERGY DEMAND

WATER-ENERGY NEXUS



- In the US, 39% of water withdrawals for cooling
- Pumping, treatment, processing of raw water = 7% E_production (UNESCO, 2008)

DECLINING ECOSYSTEMS



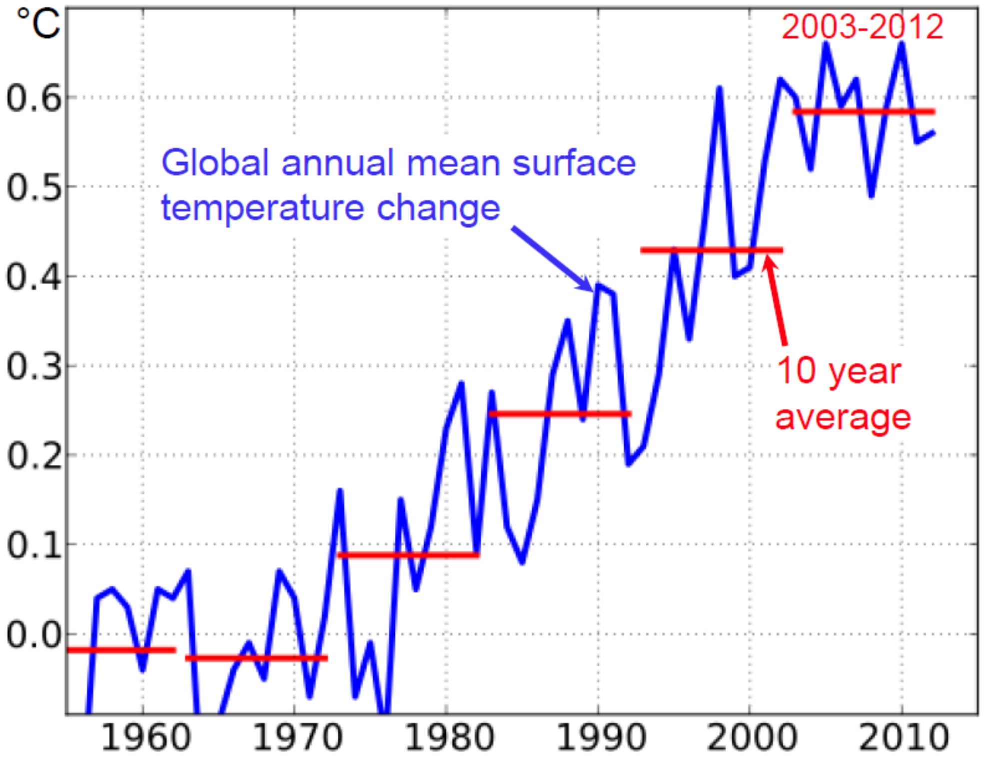
Millineum Assessment Report

- Last 50 years, ecosystems changed more than in any previous period

…RTAINTY ON FUTURE WATER AVA… / CLIMATE C…ANGE

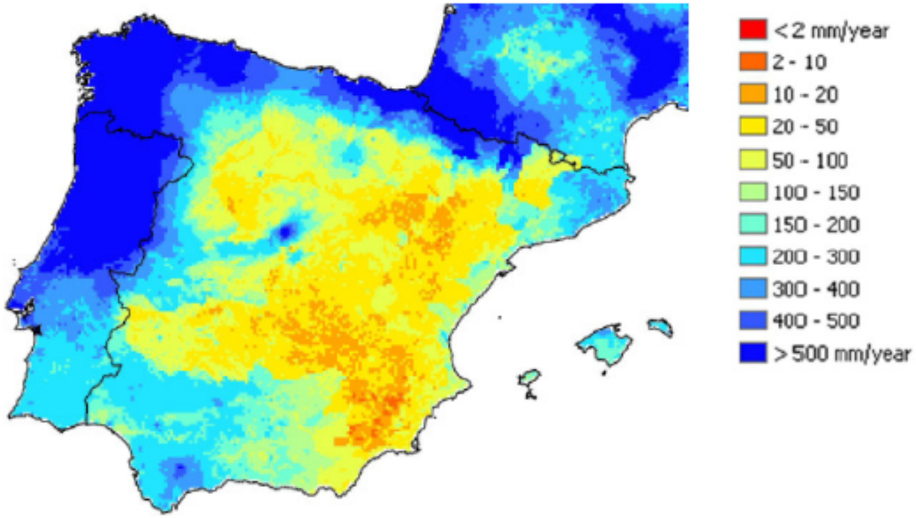
IPCC's AR5 – Physical Report

http://www.ipcc.ch/report/ar5/

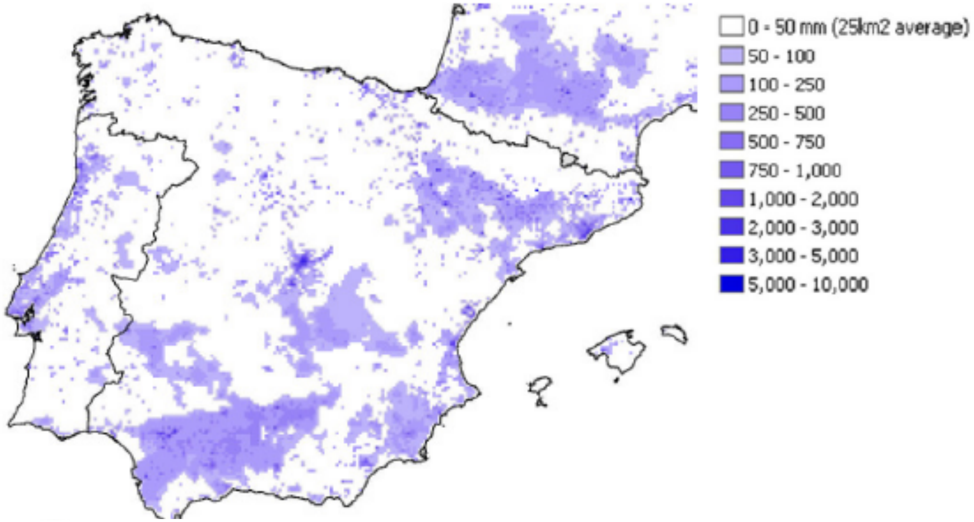


Plot: www.climate.be/pendules (2013) Reference period (0°C): 1951 - 1980
Data: NASA GISS, http://data.giss.nasa.gov/gistemp/graphs_v3 , method in Hansen et al. PNAS 2006

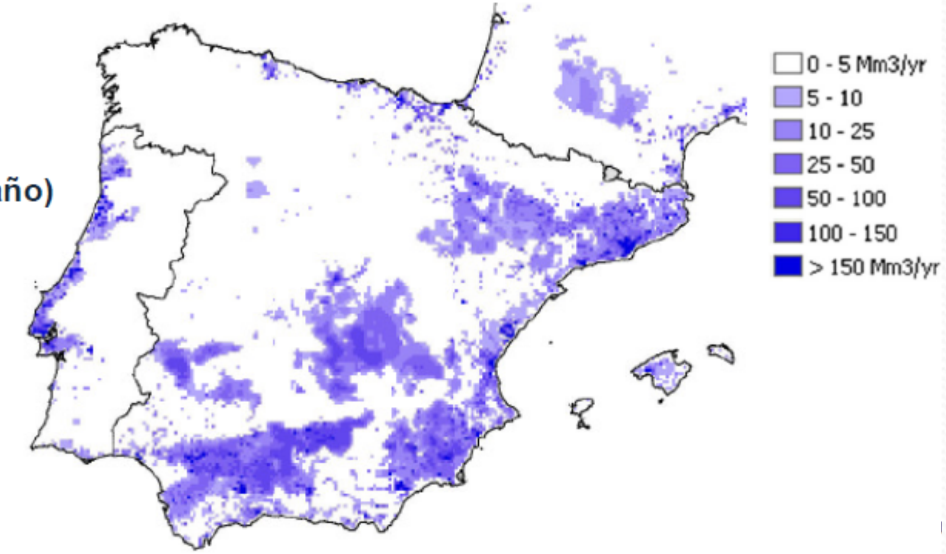
1. Escorrentía, mm/año (recursos renovables disponibles)



2. Demanda, mm/año



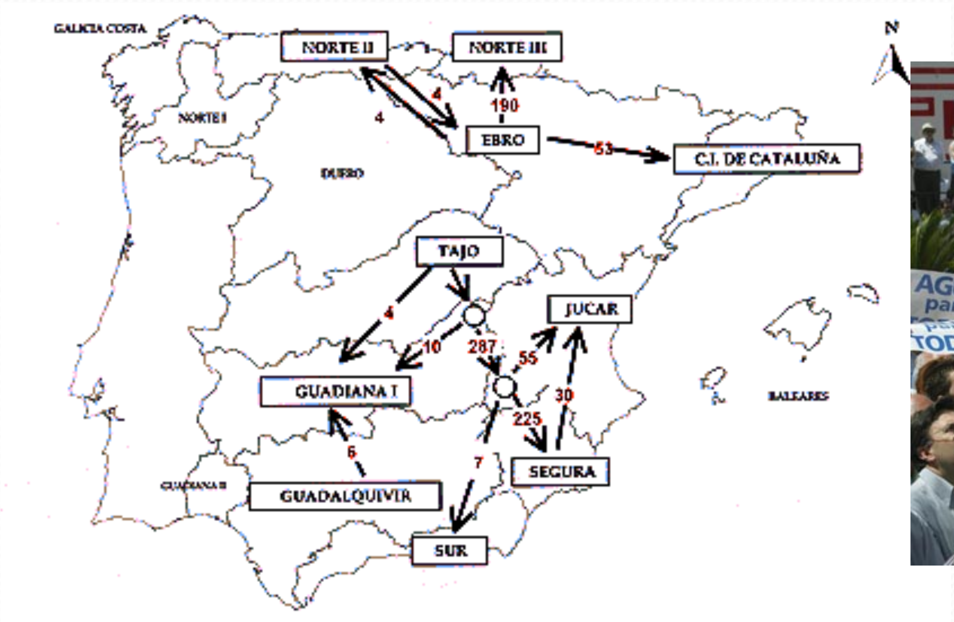
3. Déficit hídrico (hm³/año)



One of the most arid countries in the EU / 1st EU country in irrigated area (3.4 M ha.;75% consumptive uses)

WATER MANAGEMENT IN SPAIN - OTHER FEATURES:

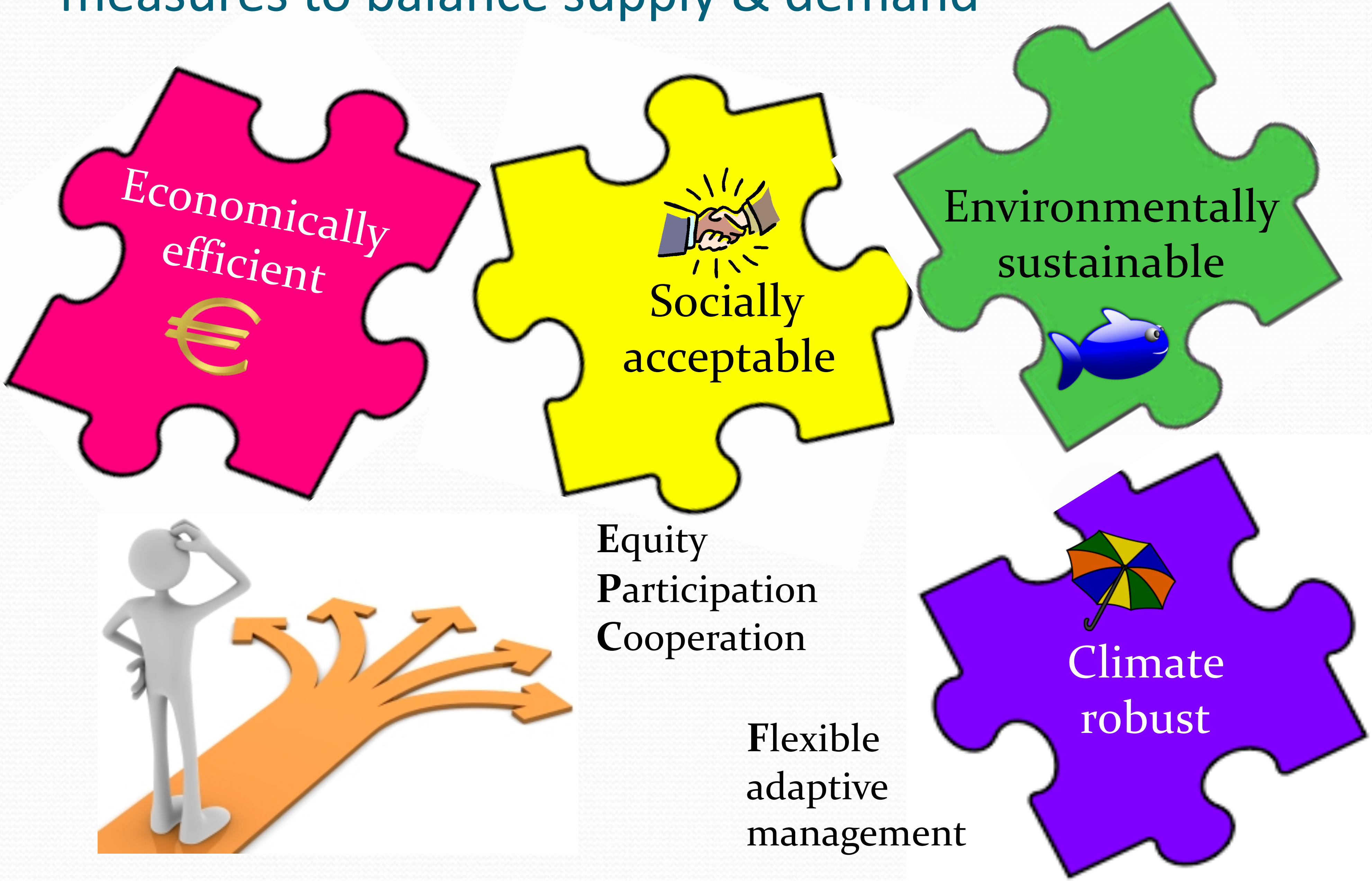
- Long tradition of RBM (since 1927)
- Interbasin water transfers
- High water reuse (water exploitation index Segura basin: 2.3)
- High social sensitivity to water issues (social & political confrontation)



LICY MEASURES

- **Supply enhancement**: limited resources & costly
- **Demand management**: *economic instruments* (water markets, pricing, etc) & other D management options; within resource availability *(e.g. water conservation);* economics, essential role
- **Re-allocation** (people, sectors, etc.): socially-politically difficult

Challenge: optimal combination (**PORTFOLIO**) of measures to balance supply & demand

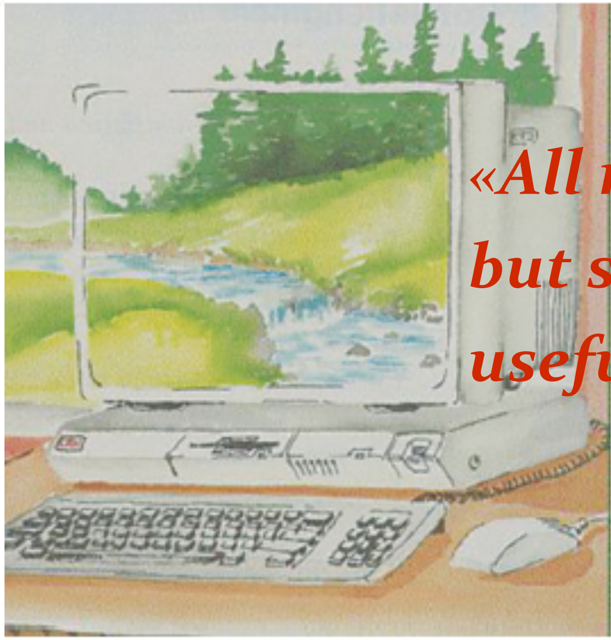


MO in conflict, many alternatives, uncertainty over future S & D, high impacts & costs

Design / **Management** } of **WRS** ⇒ **predict impact** of ≠ alternatives on objectives ⇒ **MODELS**

[*Source: Loucks y van Beek, 2005]*

. Using mental models for prediction.



. Using computer models for prediction.

«All models are wrong, but some of them can be useful» (*G.E.P. Box, 1978*)

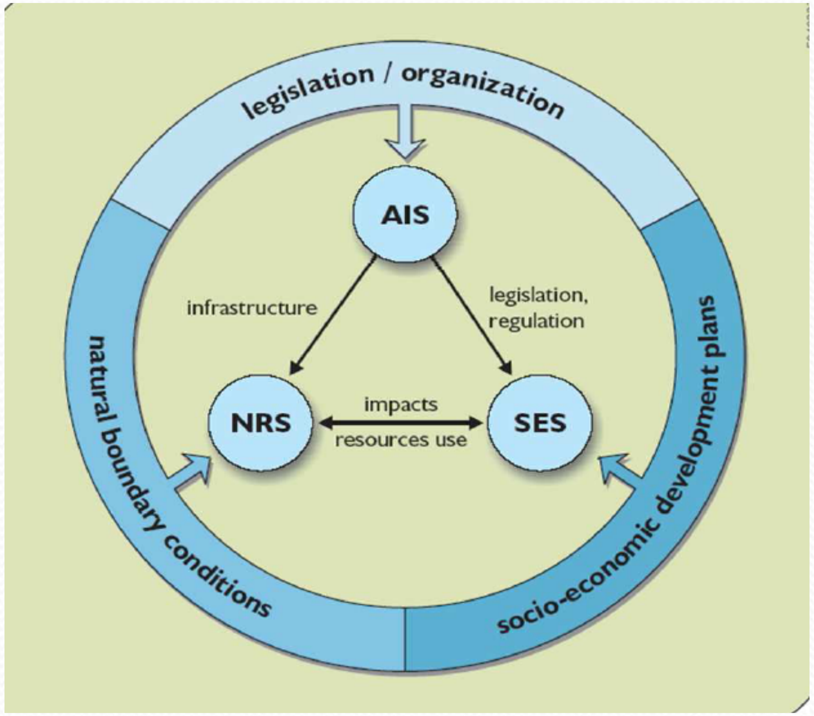
Integrated analysis *(water quantity, quality, economics, etc.)* of the performance of the system

Hydroeconomic models

WRM - interactions among:

- **Natural** system
- **Socio-economic** system
- **Legal-institutional** system

HEM - models representing those interactions



Combination of ***Economic-Engineering-Environmental*** aspects of WRS → results more relevant to policy !

ROLE OF ECONOMICS IN WRM

The EU WFD

Role of *Economics* in RBM:

- Increasing *water scarcity - water quality issues*; growing environmental concerns - competition
- Inelastic supply of 'new' water

➡ **need for ec. efficient water allocation & managmt.**

- Water management, *multipurpose. Multiple objectives,* many stakeholders ⇒ ≠ units. Lots of trade-offs !!!

➡ **simplify the problem: a common unit (money) / tradeoffs and opportunity costs (solving conflicts)**

Role of Economics in RBM

A bit of History …

- Economic & science-eng. concepts/tools, long usefully combined for WRM in a wide range of domains
- Modern engineering & microecs. - common ancestors in the French engineering schools in 19th century (water eng.)

One of the earliest definition of ***ec demand curve,*** for urban water supply (1853, J. Dupuit):

> … the enemy comes, blockades the city, diverts the stream; the inhabitants have now at their disposal only the drops that escape from the works of the enemy or that of a few wells that dry up easily; there is no longer any more available for all usages, everyone is more or less deprived; water then has a value. … If the enemy, perfecting its works, succeeds in progressively diminishing the quantity of water that enters the city, its price is going to rise more and more, and one will not care to exchange a liter of it for a diamond (Dupuit 1853, translated by Elelund and Hebert 1999).

Applications of Economics to **WRM:**

- **Water demand** estimation & forecast
- **Multipurpose** water resources development
  - **planning** and **design** (CBA, CEA analysis)
  - **finance** & **cost** allocation
- Water management/**allocation** decisions
- **Economic Policy Instruments** (pricing, taxes, water markets, etc)
- **Policy analysis** (changes in legal & institutional system)

Some LANDMARKS ....

- 1936, US fed requirement of ***CBA*** (**Flood Control Act**) to ensure that *the benefits*, "to whomsoever they accrue", *exceed the costs*
- Academics: **Harvard Water Program** (50's): system analysis for WRPM; multidisciplinary: engineers (ej. *Fair, Rogers*), economists (ej. *Dorfman, Eckstein*), political scientists (ej. *Maass*)
- **1st applications of HEM,** 60 and 70's, semiarid regions. *Samuelson* (1952), competitive mkt as opt. problem. *Vaux and Howitt* (1984), market to mitigate water scarcity in California. *Booker and Young* (1994), HEM with flow network, Colorado river. *Booker* (1995), droughts. Etc.
- **WFD, EU** (2000): integration of economics into water policy

EU Water Framework Directive (WFD), 2000

Main Goal: ***good status of water bodies***, preventing further deterioration & promoting LT sustainable water use

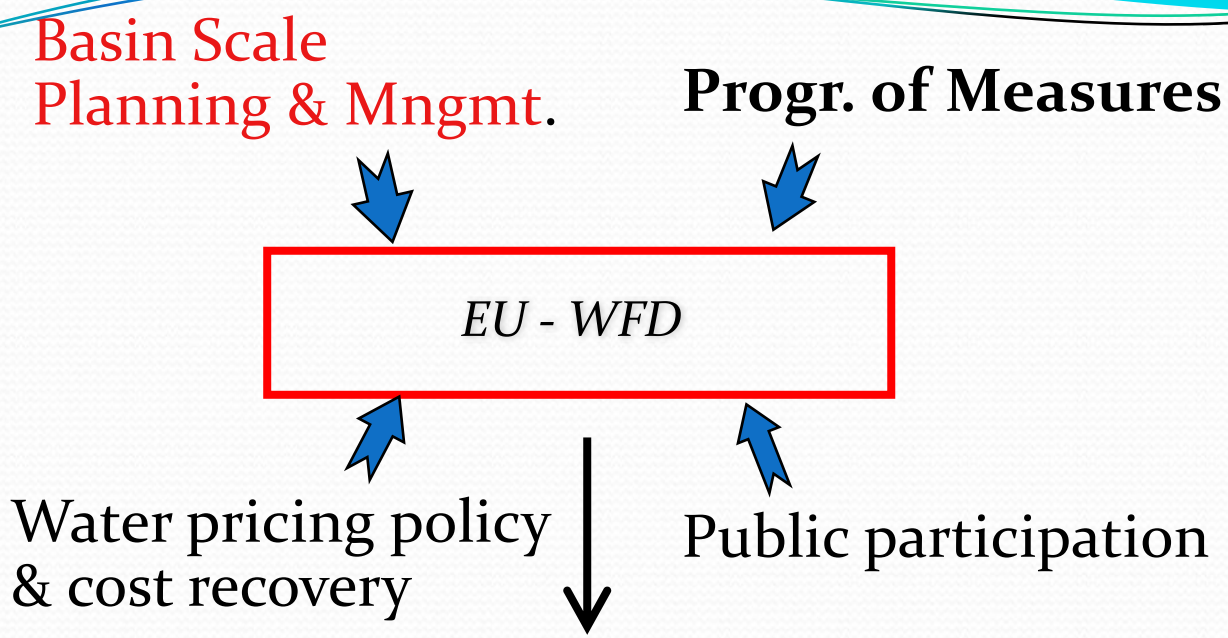
✓ *Key elements:*

- ❑ Aquatic ecosystems & env. protection
- ❑ River basin planning & management
- ❑ **Economic principles & instruments**
- ❑ Public participation

✓ The EU-WFD & Economics

- Economic Principles (e.g. *polluter pays principle*)
- Economic Tools & Methods: CEA - *Prog. Measures;* CBA - *Exemptions*
- Economic Instruments - New **water pricing policy** that provides:
  - incentive for *efficient water use*
  - contribution to *cost recovery*

" .... including **environm. and resource costs** ..." ??



INTEGRATED RB MODELLING


Water Resour Manage (2007) 21:1103–1125
DOI 10.1007/s11269-006-9101-8

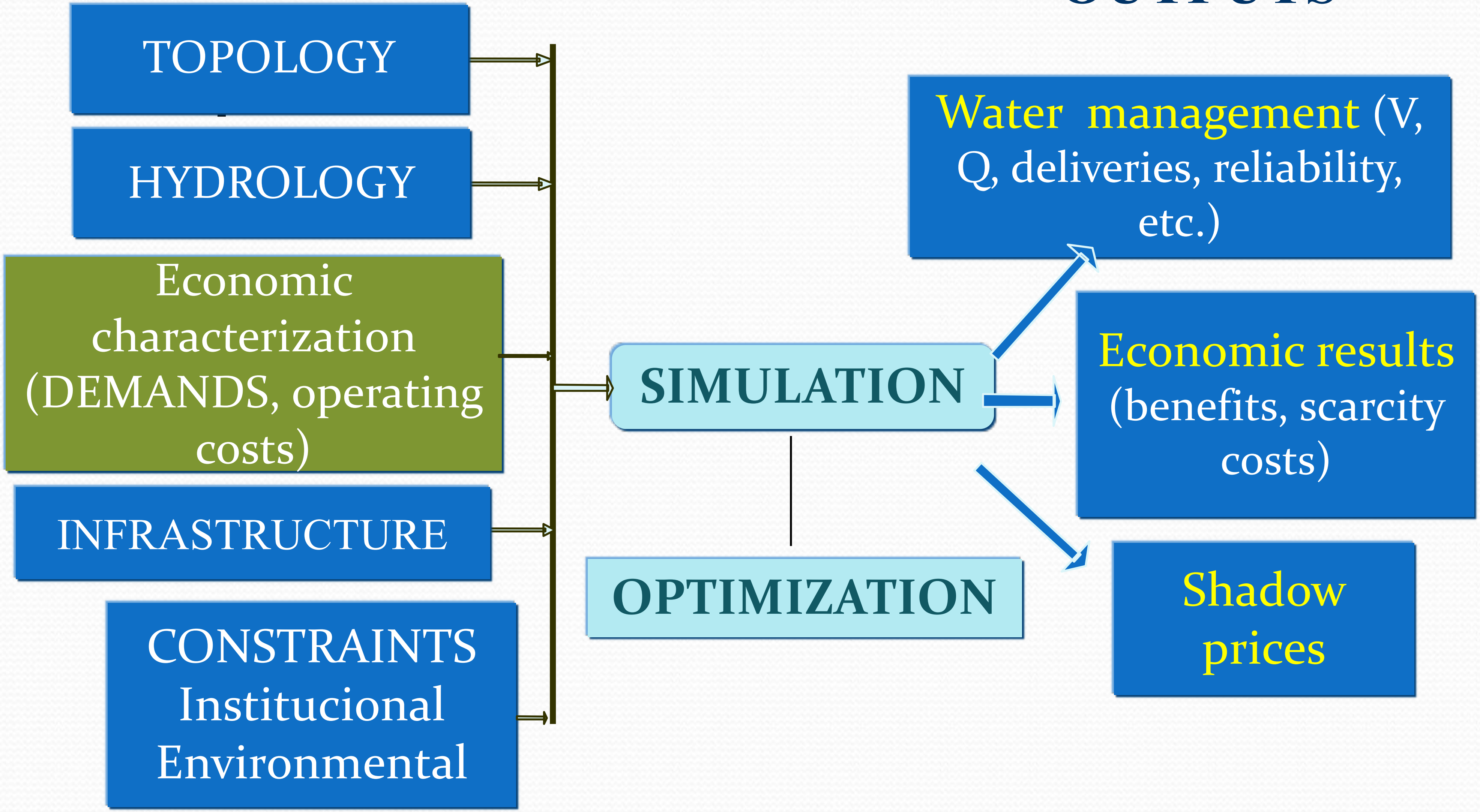
Hydro-economic Modeling in River Basin Management: Implications and Applications for the European Water Framework Directive

I. Heinz · M. Pulido-Velazquez · J. R. Lund · J. Andreu

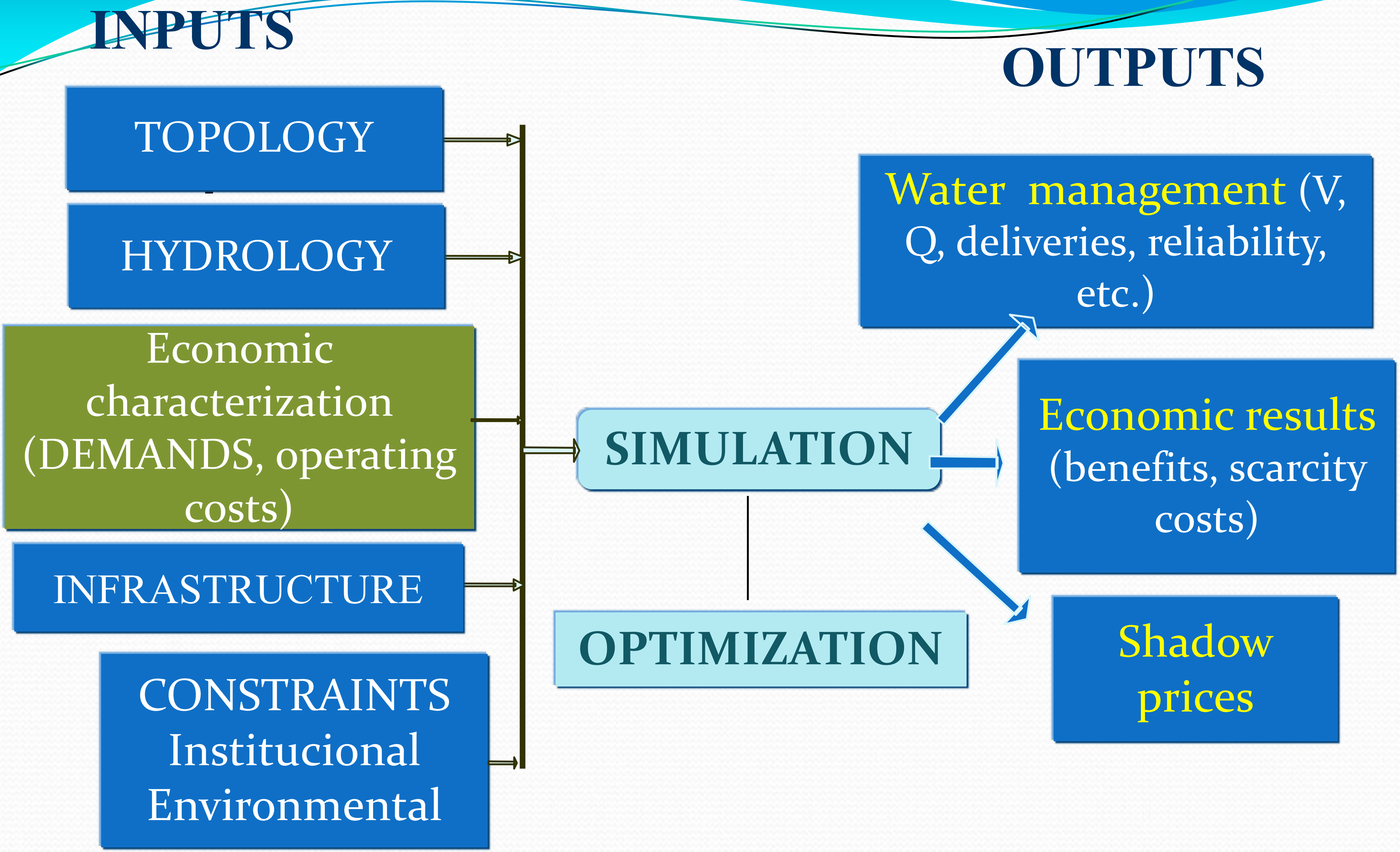
HYDRO-ECONOMIC MODELS

INPUTS

OUTPUTS



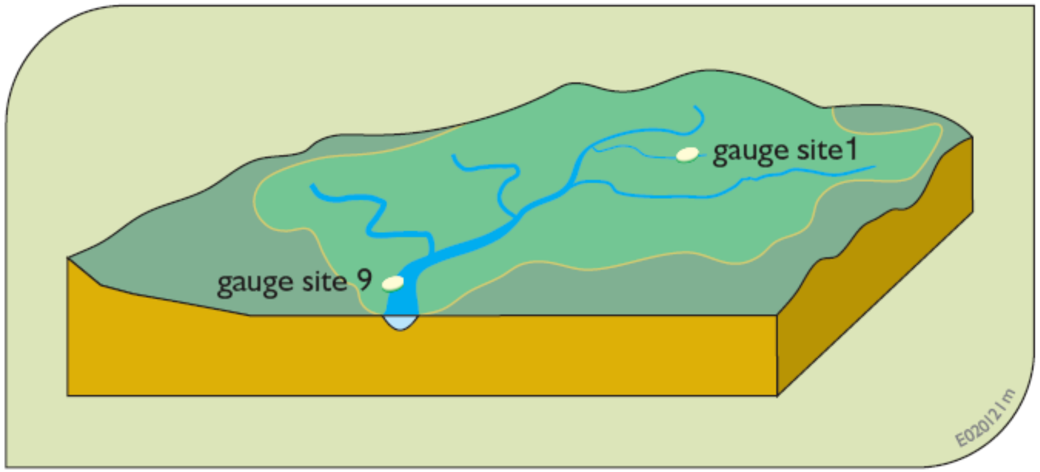
Flow Network: nodes & links


INPUTS
OUTPUTS
TOPOLOGY
HYDROLOGY
Economic characterization (DEMANDS, operating costs)
INFRASTRUCTURE
CONSTRAINTS Institucional Environmental
SIMULATION
OPTIMIZATION
Water management (V, Q, deliveries, reliability, etc.)
Economic results (benefits, scarcity costs)
Shadow prices

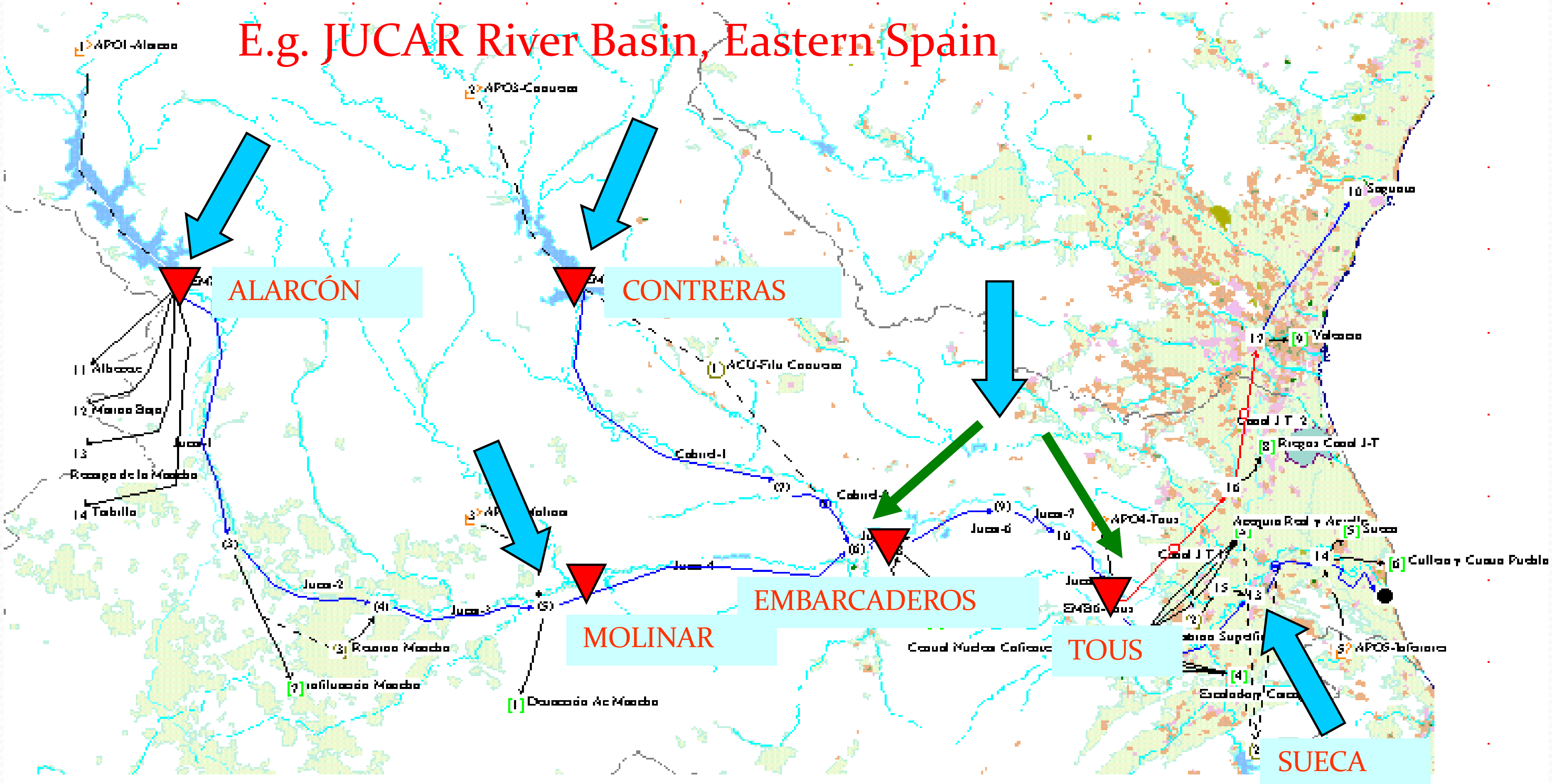
Surface hydrology:

- Surface-flow modelling :
  mass balance at the nodes, with monthly time step
  (avoid flow routing)

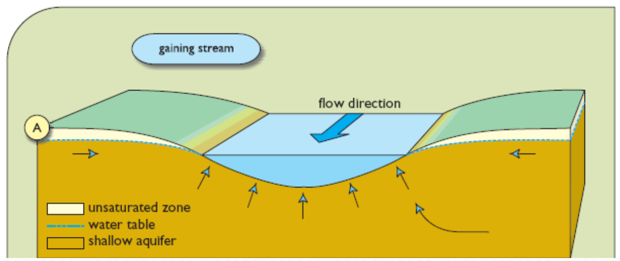
- *Long time series of streamflows* (historical records / synthetic streamflow series)



NATURAL INFLOW TIME SERIES



Groundwater Hydrology

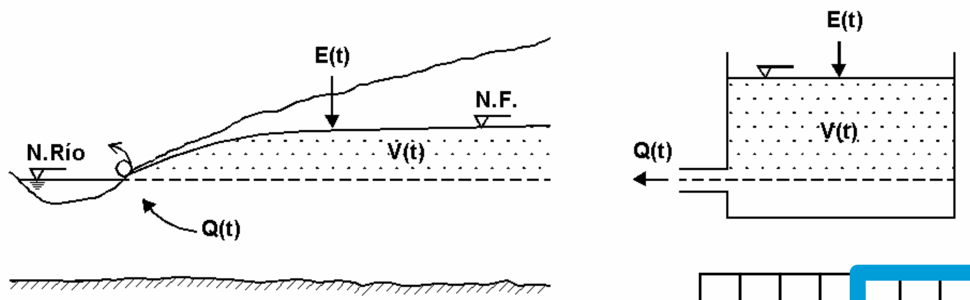


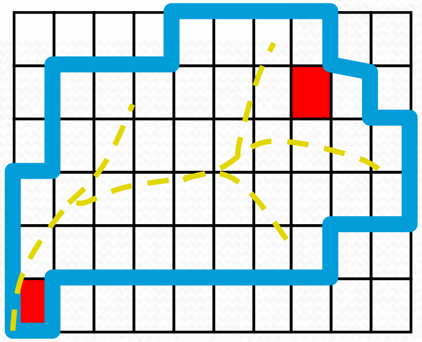
▪ Groundwater flow / SAI:

Complex integration in RB models. Efficient methods.

- ✓ Lumped-parameter models:
- ✓ Analytical solutions

Linear-reservoir model





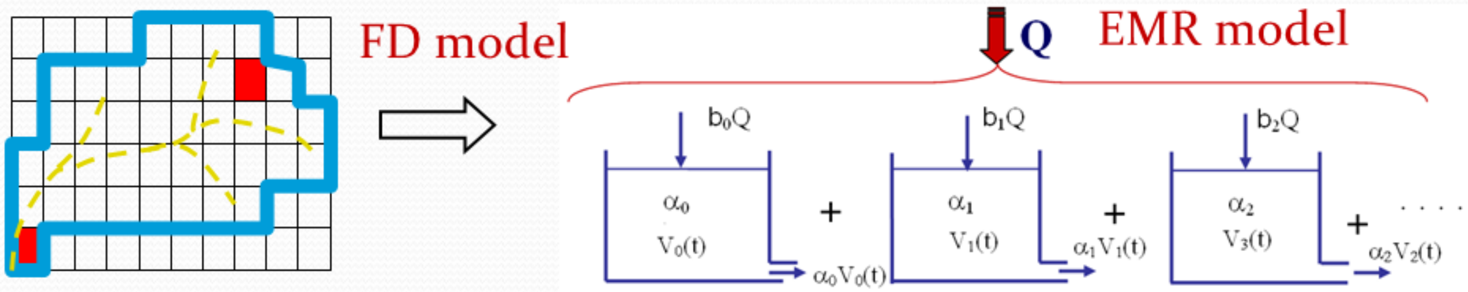
Parameter-distributed modelling

e.g. Response matrices / Eigenvalue Method

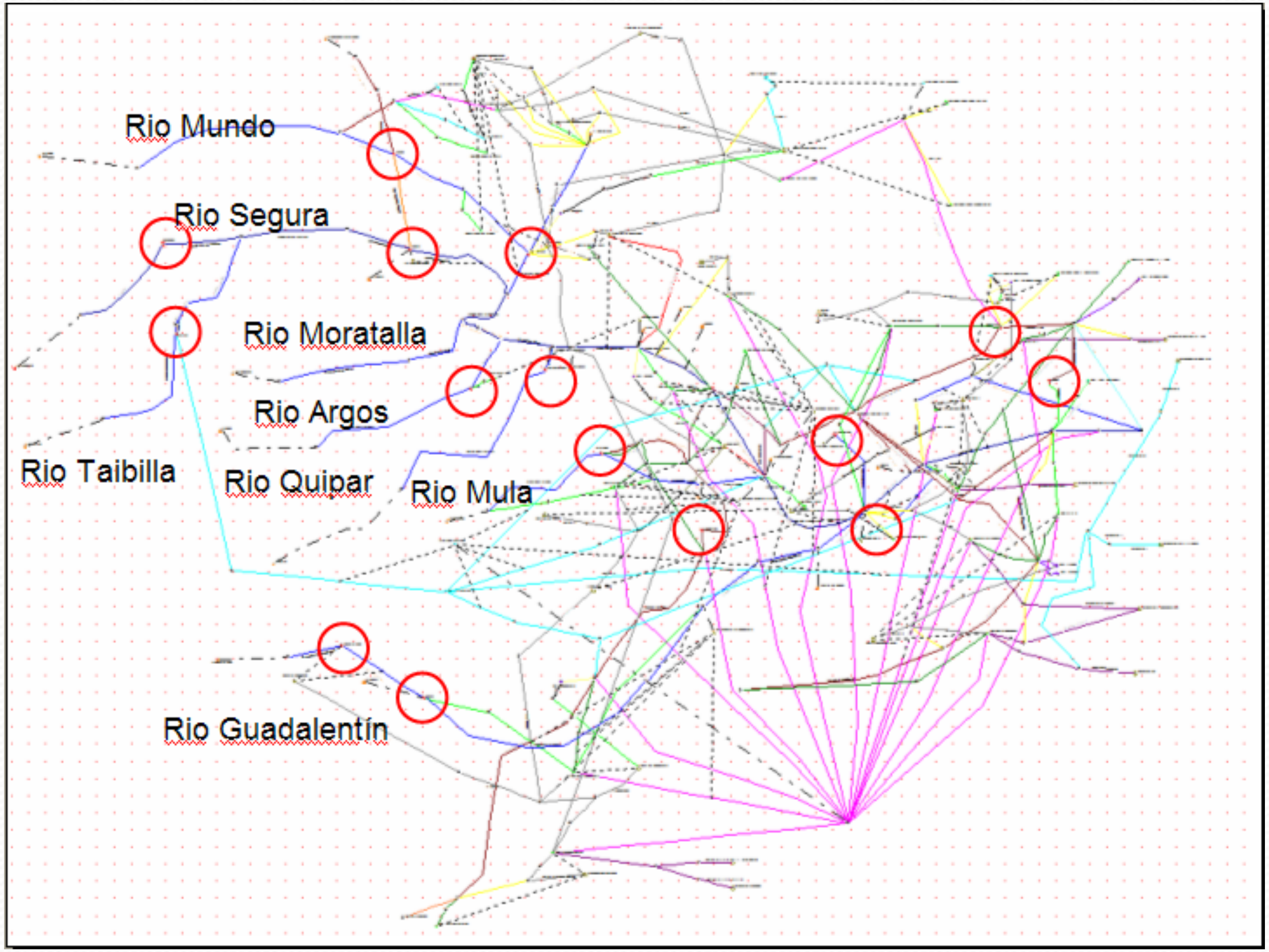
Stream-aquiter interaction

e.g. Embedded Multireservoir Model

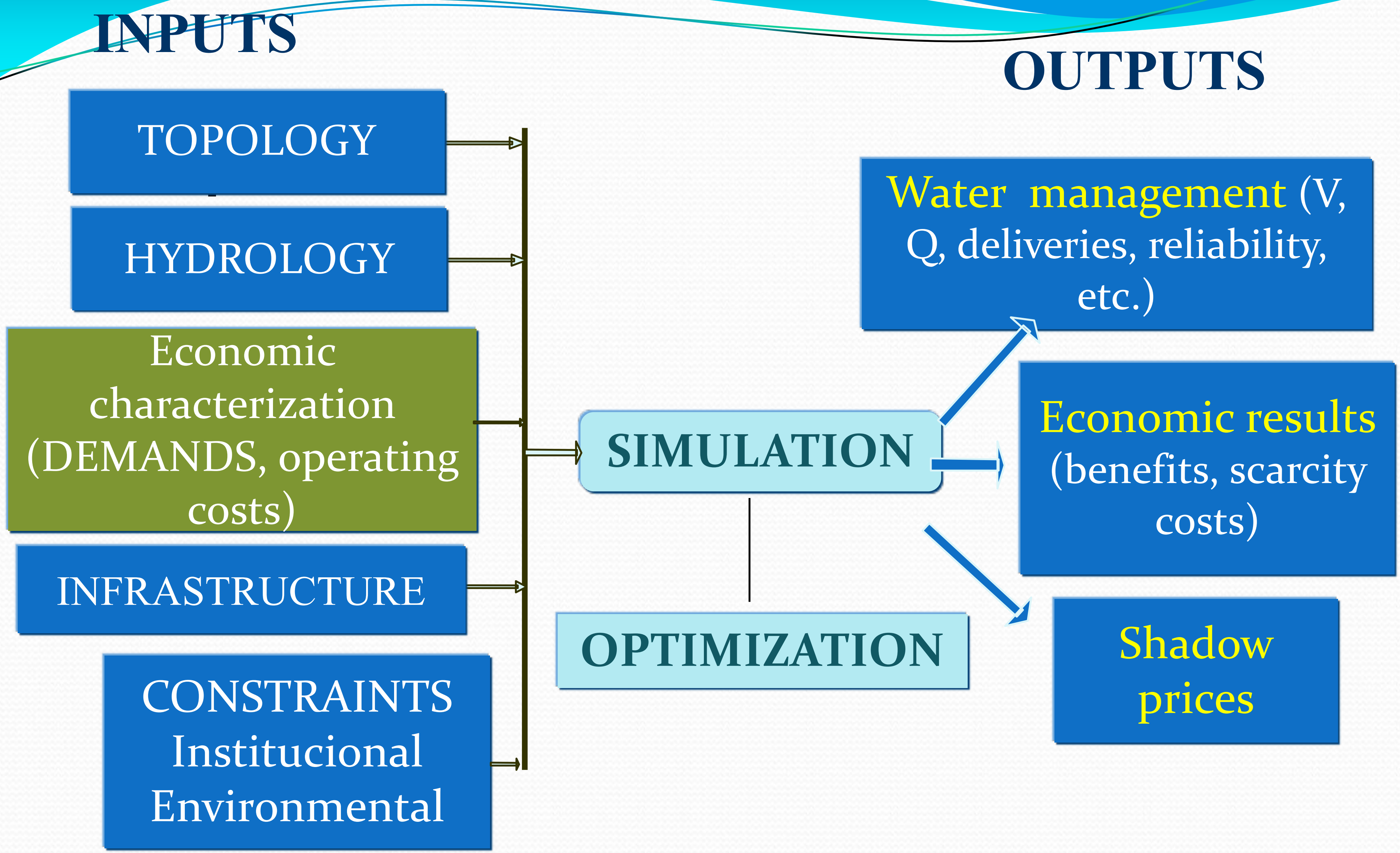
Pulido-Velazquez et al., 2005



E.g. Segura river basin (eastern Spain)



28 reservoirs
26 aquifers
152 canals
90 demands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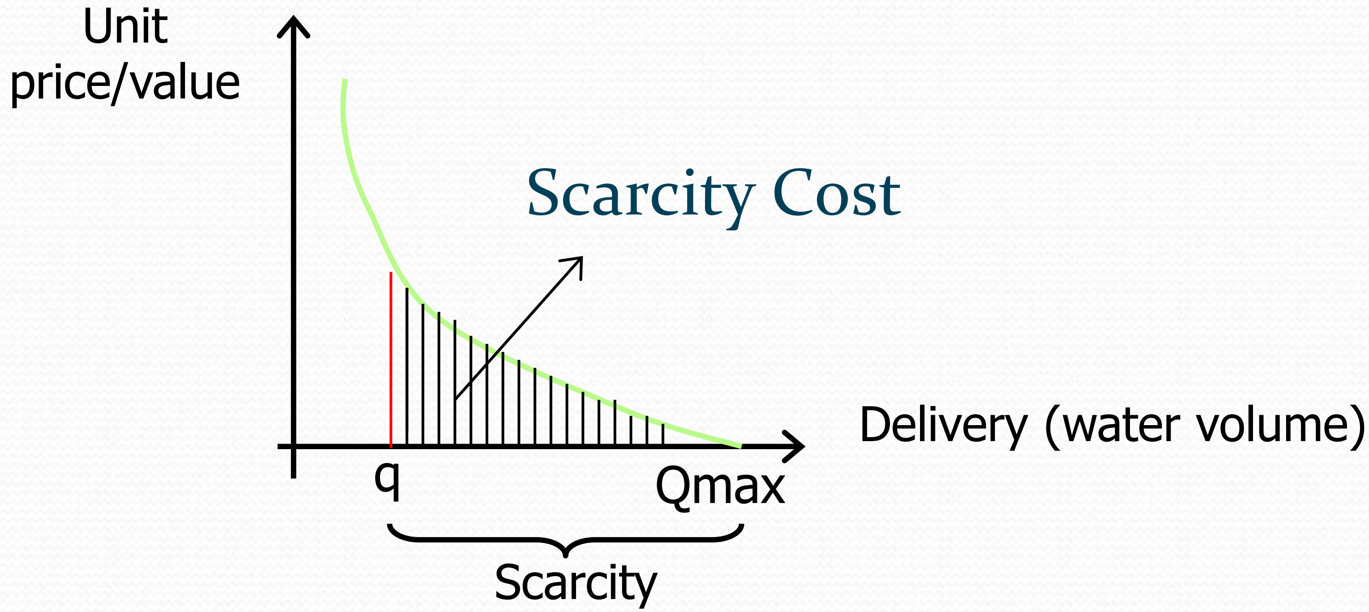
Economic characterization

Caracterization of the economic value of water for the different uses
⇨ DEMAND CURVES



Demand Curve —Integration⇒ Penalty function

marginal value = f(supply) scarcity cost =f(supply)

Optimization vs. Simulation

SIMULATION:

system managed following set of **a-priori operating rules**. *Positive valuation* (*modus operandi*)

What if … ?

OPTIMIZATION

optimal operation / max net economic benefit of water use. *Normative approach*

What's best ?

Ad-Hoc vs. Generalized DSS

AD-HOC models

More flexibility / time-consuming, skills requirement (computer programming knowledge, e.g. GAMS)

DSS tools

Interactive computer-based tools that assist in decision-making for complex management problems, integrating:

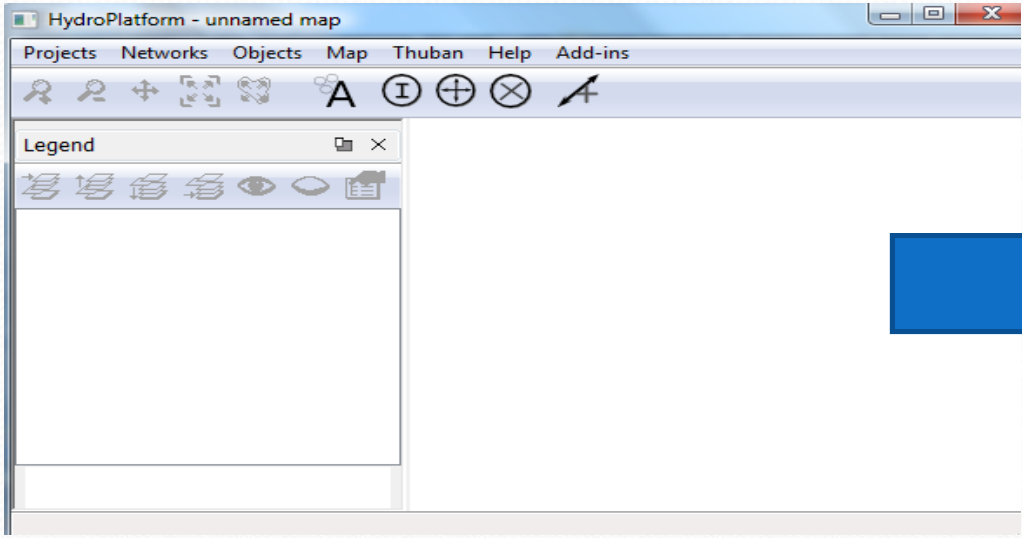
- ... Simulation and Optimization modules
- ... Computer assisted graphical design
- ... Geographically referenced data bases
- ... Graphical tools for results display and analysis

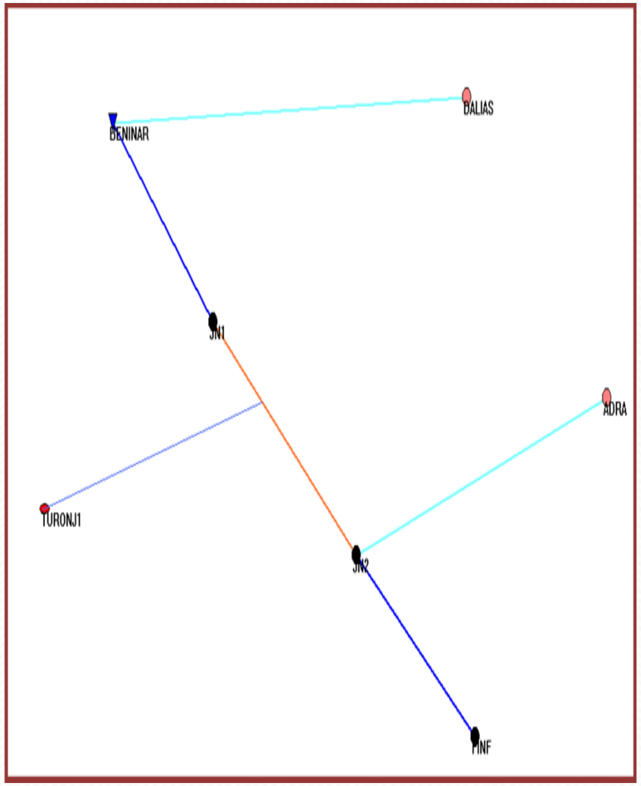
e.g. UPV tools

Preprocessing Tools

HydroPlatform (Harou et al., 2010)

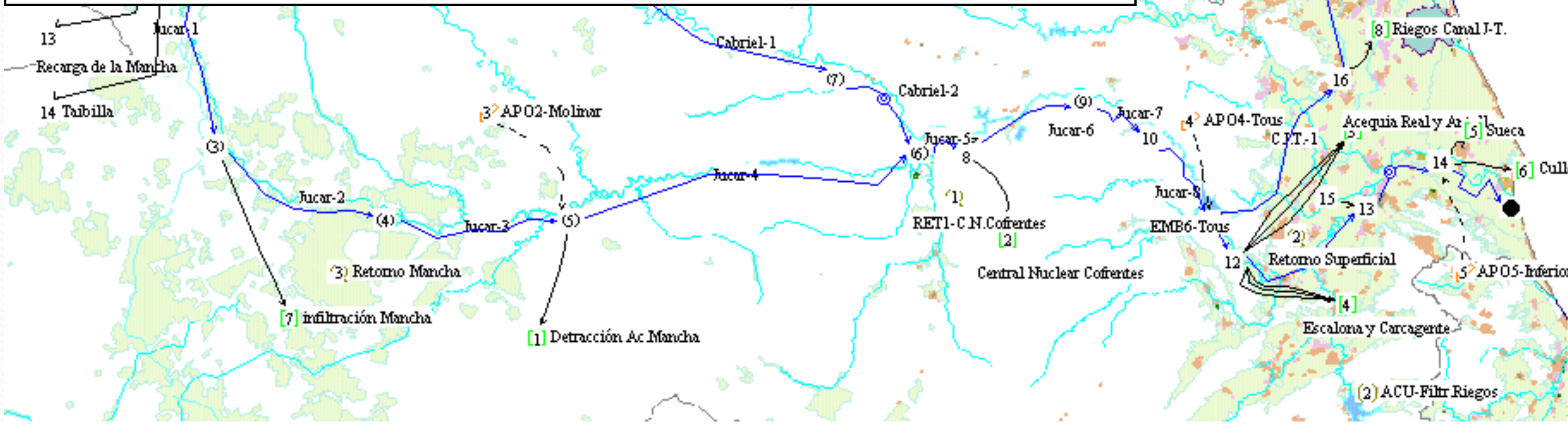
- Open-source platform for network (node-link) systems
- Input, store, display & export model data (conectivity matrix, etc)



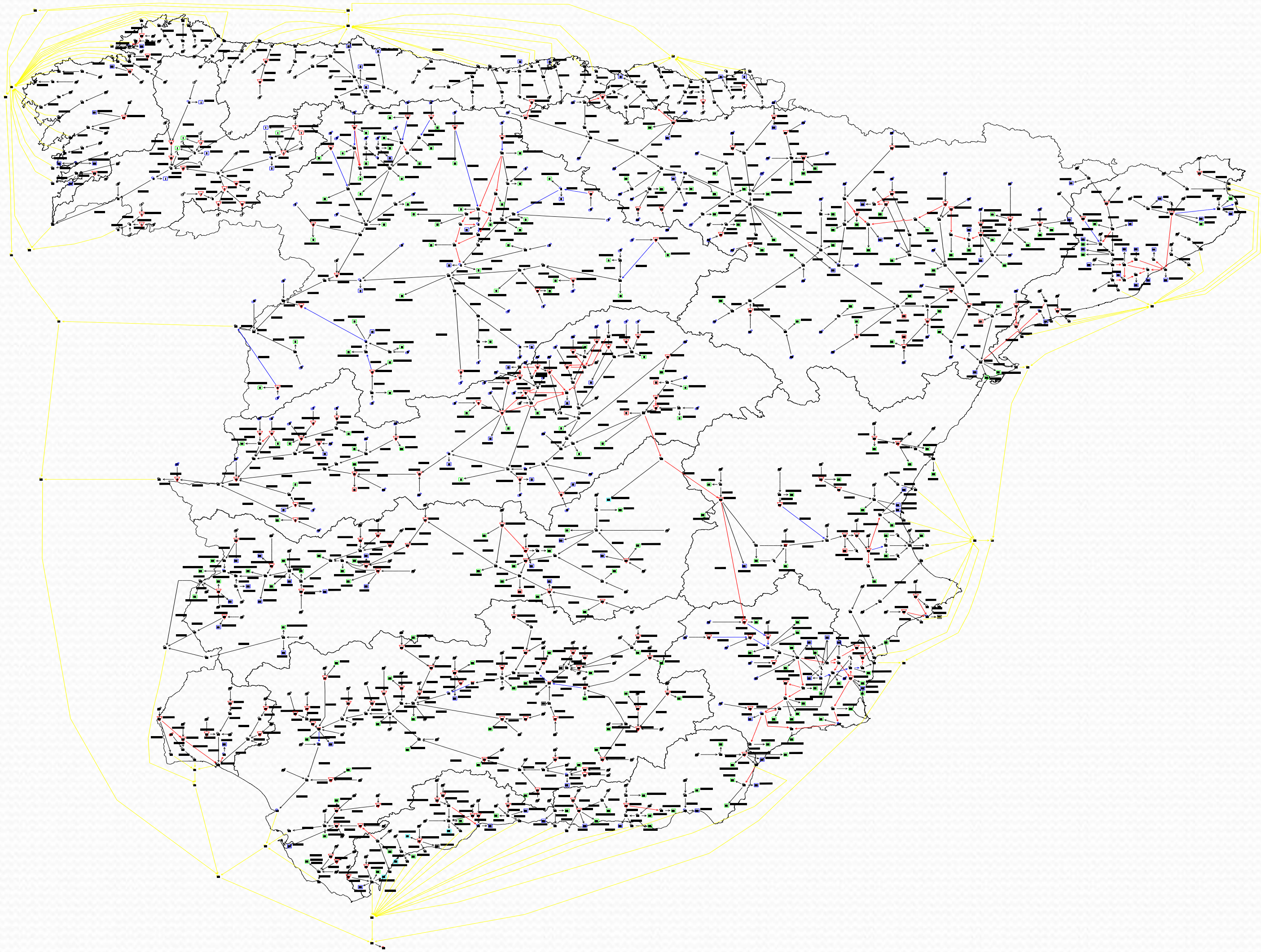


DSS AQUATOOL

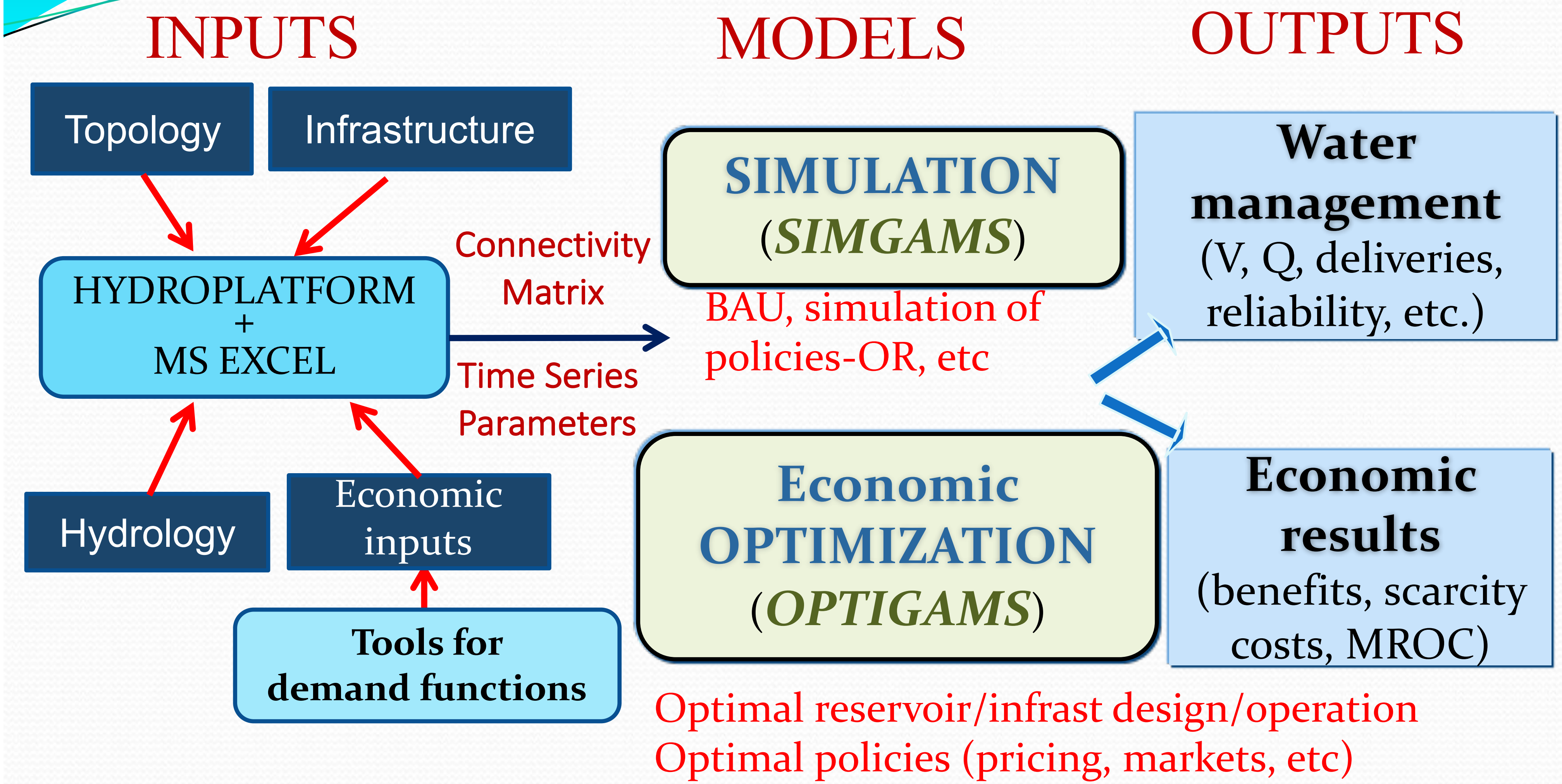
- Surface / GW hydrology
- Hydraulic Infrastructure
- Demands / Water rights
- Operating Rules
- Water quality
- Environmental flow assessments
- Economics



Spanish National Water System (*CEDEX*)



THODS & TOOLS –



SDP_GAMS

(Héctor Macián and Pulido-Velázquez, 2013)

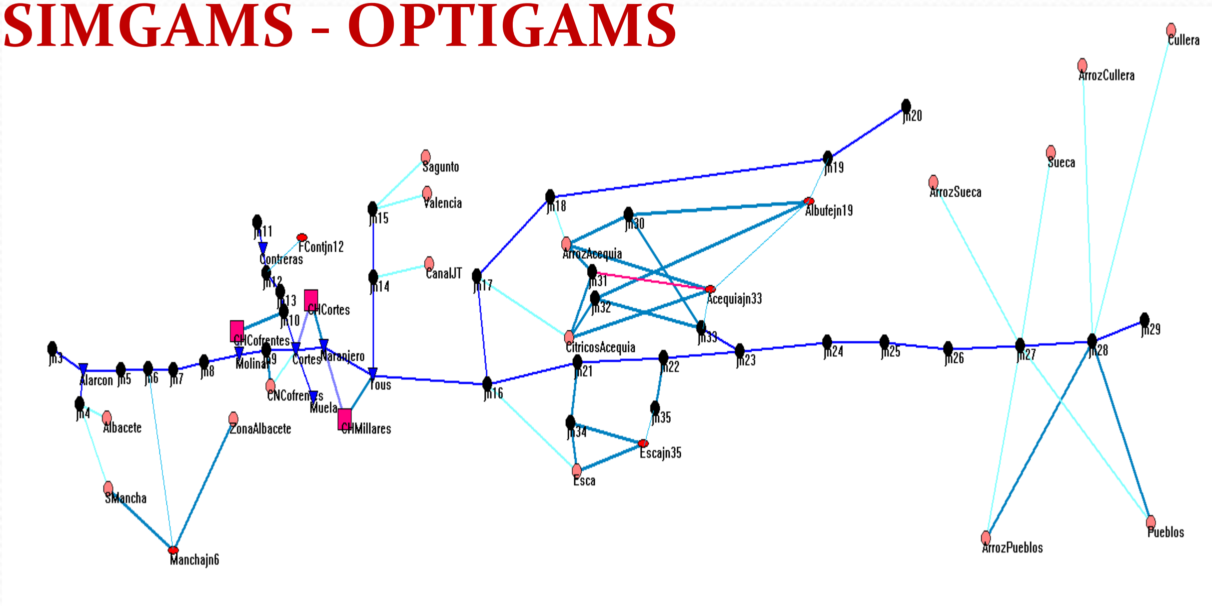
GENERALIZED SDP-SDDP TOOL

[avoid perfect foresight of deterministic opt.]

Case study: Jucar river basin

HEM TOOLS - UPV

SIMGAMS - OPTIGAMS



Demands	Water scarcity costs over 29 year period (M€)
Acequia Real Cítricos	29.04
Escalona	0
Sueca Cítricos	3.88
Cuatro Pueblos Cítricos	1.14
Cullera Cítricos	7.2
Canal Júcar-Turia	45.3
Regadíos Mancha Oriental	0.038
Valencia	0
Sagunto	0
Albacete	0
Acequia Real Arroz	0.1
Sueca Arroz	1.64
Cullera Arroz	0.23
Cuatro Pueblos Arroz	0.12

Combined use of *Optimization* & *Simulation*

- **ECONOMIC OPTIMIZATION** ⇒ ec/ optimal ideal policies (max efficiency)

- **SIMULATION** ⇒ economic impacts of different policies /management alternatives/scenarios

…me applications:

Journal of Hydrology 375 (2009) 627–643

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Review

Hydro-economic models: Concepts, design, applications, and future prospects

Julien J. Harou [a,*], Manuel Pulido-Velazquez [b], David E. Rosenberg [c], Josué Medellín-Azuara [d], Jay R. Lund [d], Richard E. Howitt [e]

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[b] Departamento de Ingeniería Hidráulica y Medio Ambiente, Universidad Politécnica de Valencia, Cami de Vera, s/n. 46022, Valencia, Spain
[c] Department of Civil and Environmental Engineering, Utah Water Research Laboratory, Utah State University, UT, USA
[d] Department of Civil and Environmental Engineering, University of California, Davis, CA, USA
[e] Department of Agricultural and Resource Economics, University of California, Davis, CA, USA

List of over 80 hydro-economic modeling efforts dating back 45-years from 23 countries [early applications, 60s and 70s in arid regions: Israel & south-western US]

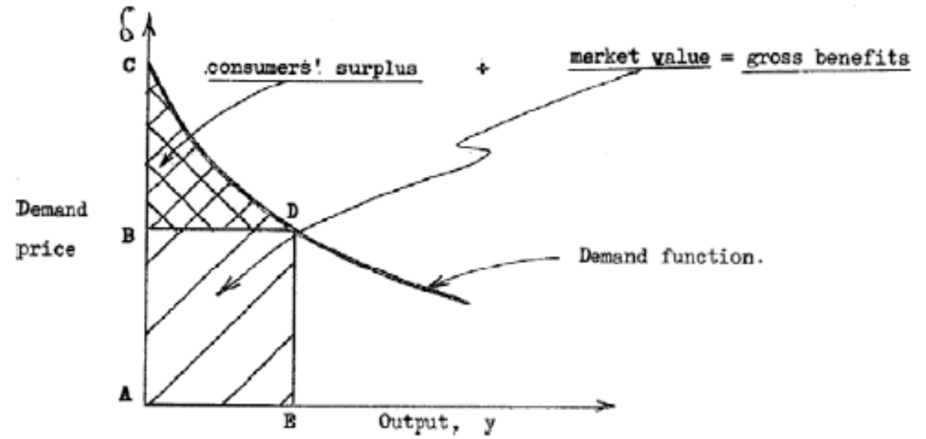


Fig. 1. Demand function consisting of the price (willingness to pay) for water at different quantities. Note that for a small quantity of water ("Output", y), the price is high (C). (Bear et al., 1964). N.B. market value alternatively named producer surplus.

ECONOMIC CHARACTERIZATION OF WATER DEMANDS

Approaches for determining the economic value of water

Non-productive uses (residential, rec. and env. uses)

water, final good ⇒ ***Consumer Theory***

UTILITY ↔ consumers' tastes/preferences; WTP

Assessment:

- Econometric methods (I); Nonmarket valuation (D)

Productive uses (ag., ind., commercial, hydropower, etc.)

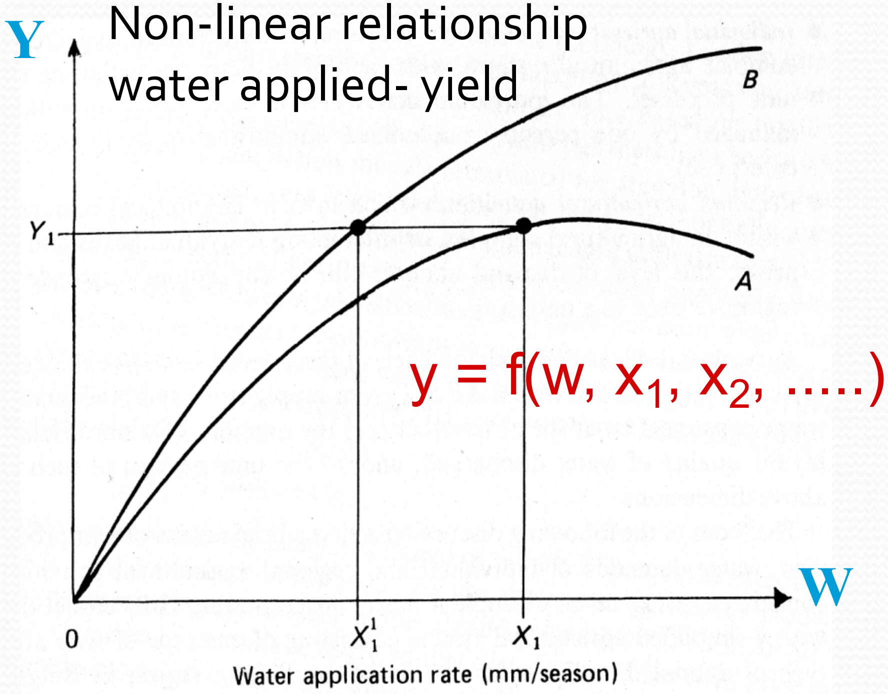
water, intermediate good (*derived D*) ⇒ ***Production Th***

Ec value of water ↔ residual value over final product ↔ *technology* & *final product D*

Assessment:

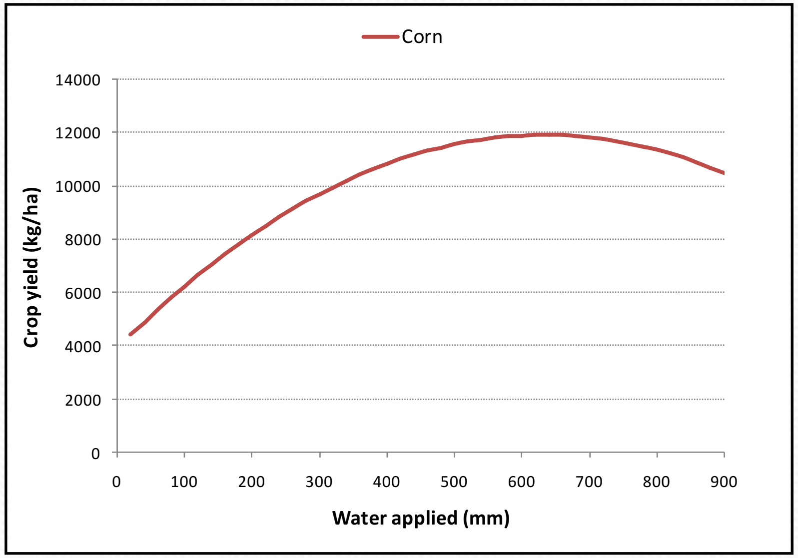
- Production functions (I); Math programming (D)

PRODUCTION FUNCTIONS for irrigated agriculture



Fuente: Kindler & Russel, 1984.
Modelling water demands. Academic Press.

E.g. Crop production function for corn.
Mancha Oriental. EPIC (Pulido-Velazquez et al., 2015)

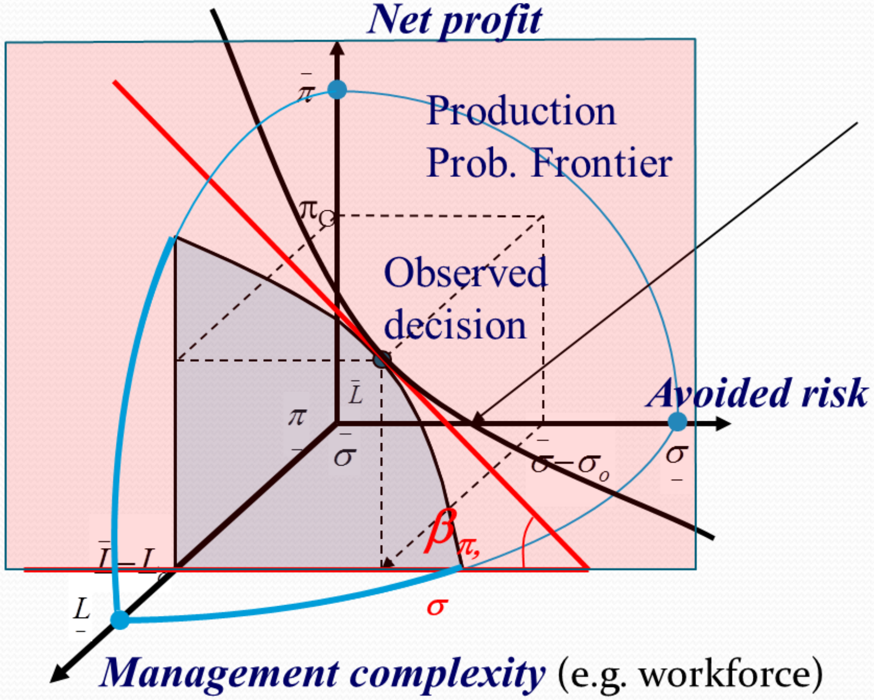


- Controlled experiments
- Statistical regressions on experimental data
- Agronomic simulation models (EPIC, CERES, COTMOD, ...)

Demand curves in AGRICULTURE

- **Profit-maximization models**
- **PMP** – perfect calibration to observed decisions (Howitt, 1995)
- **Multicriteria revealed-preference approach**

Multi-Objective Utility Function



$$U(\pi, \sigma_e, L_e) = \pi^{\alpha_1} \sigma_e^{\alpha_2} L_e^{\alpha_2}$$

Assessment of impact of different policy scenarios

Modern portfolio theory
(Markowitz, 1952)

Gomez, C.M., C. Gutiérrez-Martín, A. Lopez-Nicolas, M., Pulido-Velazquez. *What lies behind farmers decisions? Coming to terms with revealed farmers' preferences*.
Submitted to *American Journal of Ag Ec*.

URBAN WATER DEMAND

URBAN WATER USE

Includes:

- **Residential** use
  Indoor (e.g. drinking, cooking, hygiene) vs Outdoor (e.g., private gardens, swimming pools, car washing)
- Small **industries** supplied by local network
- **Public & municipal** uses (landscape irrigation, street cleaning, public fountains, schools, hospitals,...)
- **Commercial** uses
  (hotels, restaurants, other commercial uses, ...)

URBAN DEMAND

Most demanding water use !

- **High quality**
- **High supply reliability**

(*Spain*: monthly deficit < 10% monthly D)

- **t distribution ± uniform**

(except touristic zones; high hourly variability)

- Point **returns** w/ **constant** features, ≈ 80% **–>** reclaimed WWT ***reuse***

- ***Economics***:
  - ➢ high supply cost but low opportunity cost
  - ➢ Inelastic demand / normal good

URBAN WATER DEMAND **MYTHS**

(adapted from Baumann et al. 1998)

1) Water is a necessity

Myth: water, fixed requirment; no subject to tastes, desires, etc.

Response: only few l/day actually necesary for life

2) Myth of pcwu

Myth: Future W requirement = Pop x PCU (*per-capita approach*)

Response: limited account of determinants of water use other than pop (socioeconomic, geographic, climatic, etc). Alternative: *disaggregated water use forecast*

SOME FACTORS affecting urban water use:

- **Climate** (T, rainfall)
- **Urban configuration** (pop density, housing type, size, ...)
- **Income** (> elasticity when low income, > % family budget)
- **Water price**
- **Season** (Summer, ↑ outdoor uses ⇨ > price-elasticity)

✓ ***> consumption if:***

warmer climate, Summer, ↑ income, ↓ pop density

URBAN WATER DEMAND **MYTHS**

- 1) Water is a necessity
- 2) Myth of pcwu
- **3) Water users do not respond to price !**

Myth*:* necessity - matter of habit, water bill just small % of household budget, … !

Response: <u>water use does, in fact, respond to changes in price</u> *(empirical studies)*

- **Indoor** D, quite **inelastic** (no substitutes) but **outdoor** D can be quite **elastic** (inelastic $\not\Rightarrow$ no reaction)
- ε will likely **increase** at **higher prices**

URBAN WATER DEMAND **MYTHS**

- 1) Water is a necessity
- 2) Myth of pcwu
- 3) Water users do not respond to price !
- **4) Water conservation will lead to negative financial impacts on water supply agencies**

Lower revenues (cost) but also
lower operating cost and deferred cost of future facilities (benefit)

Require correct user charges !

Approaches

Since *Howe & Linaweaver (1967)*, empirical studies of urban water demand. Most, econometrics.

- **ECONOMETRIC ANALYSIS** / META-ANALYSIS
- RESIDUAL IMPUTATION (single value)
- **POINT-EXPANSION METHOD**
- NONMARKET VALUATION TECHNIQUES
- MATH PROGRAMMING

ECONOMETRIC ANALYSIS

1) Postulate functional form: water = F(factors affecting consumption) + r
2) Data from time series – different locations (panel)
3) Fit parameters by statistical regression
4) Goodness-of-fit analysis
5) Interpret findings

Limitation: getting enough amount of reliable data

E.g. Econometric model of residential water demand in Valencian region

(García-Valiñas, 2005)

Time series from 2000 to 2003, 125 municipalities

$$\ln Q_{it} = \alpha + \beta \ln P_{it} + \delta X_{it} + \gamma Z_i + \eta_i + \mu_{it}$$ Random disturbance

Q = water use, time t municipality i

P_{it} = variable price

X_{it}, Z_{it} = explanatory variables

η_i = other factors

Price-elasticity of demand

Variable	Valor estimado del coeficiente	Error estándar
PRECIO	-0,6451	0,0455
RENTAPC	0,00004	$6{,}5\ 10^{-6}$
VIVUNIFP	1,6695	0,9742
VIV2P	0,7167	0,2784
ZLIT	0,1620	0,1093
TAMHOG	-0,7653	0,2645
EINDUS	0,3283	0,3129
HABTUR	0,5779	0,2468
Término indep.	5,2107	0,7578

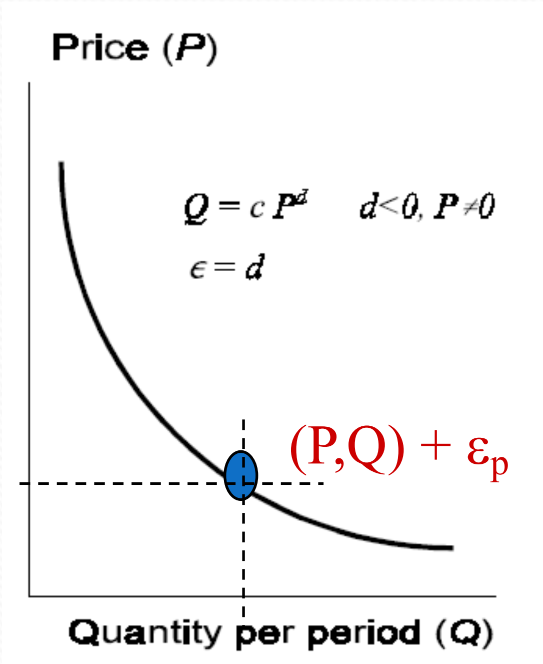
Problem: lack of data !!

Use of easy functional form like Cobb-Douglas (constant elasticity)

→ POINT-EXPANSION METHOD

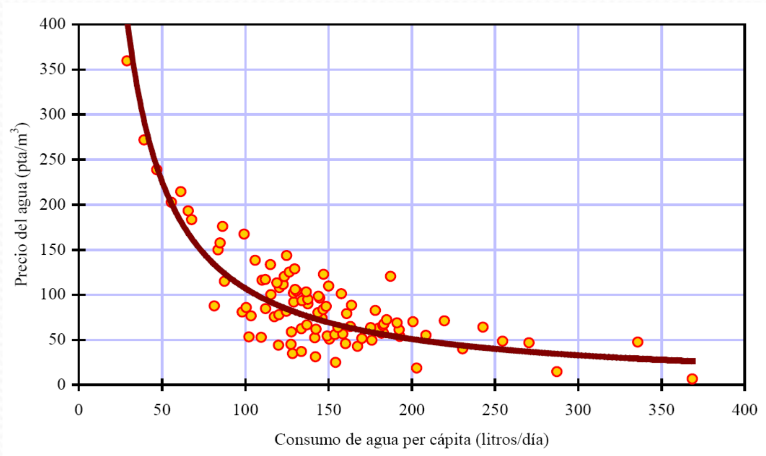
Point-expansion method

(James and Lee, 1971; Jenkins et al, 2003, JAWWA)



Constant price-elasticity curve

Econometric assessment of ε_p



$$Q = cP \quad \Rightarrow \quad c_i = q_1\, p^{\ \ i}$$

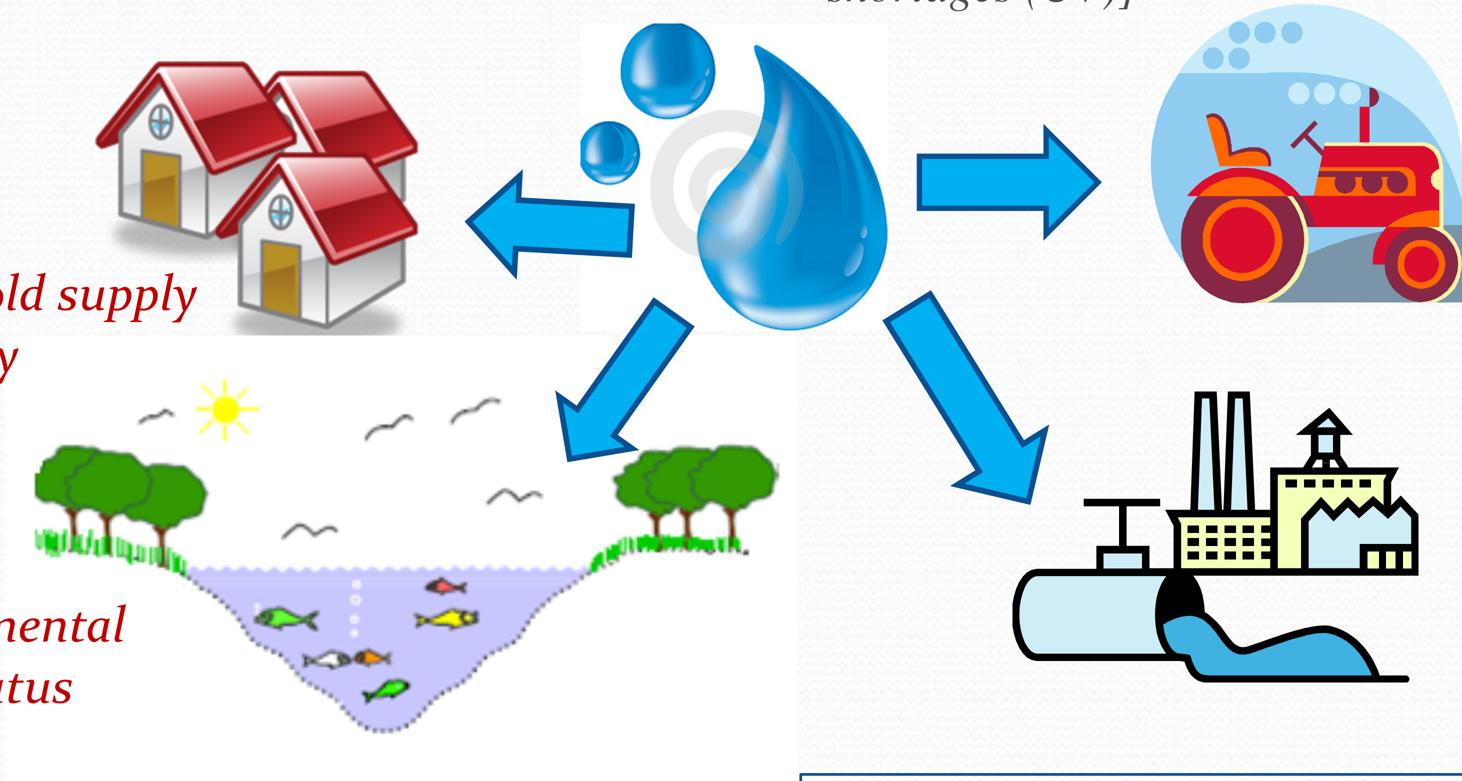
- Easy to apply / entire D function
- Simplification *(deviations when far from known point)*

Non-market valuation (CV, CE, hedonic pricing, travel cost, ….)

Opportunity cost of water use under increasing scarcity conditions in South Europe / Transferability

[Griffin and Mjelde, 2000 – WTP to avoid shortages (CV)]

Household supply reliability

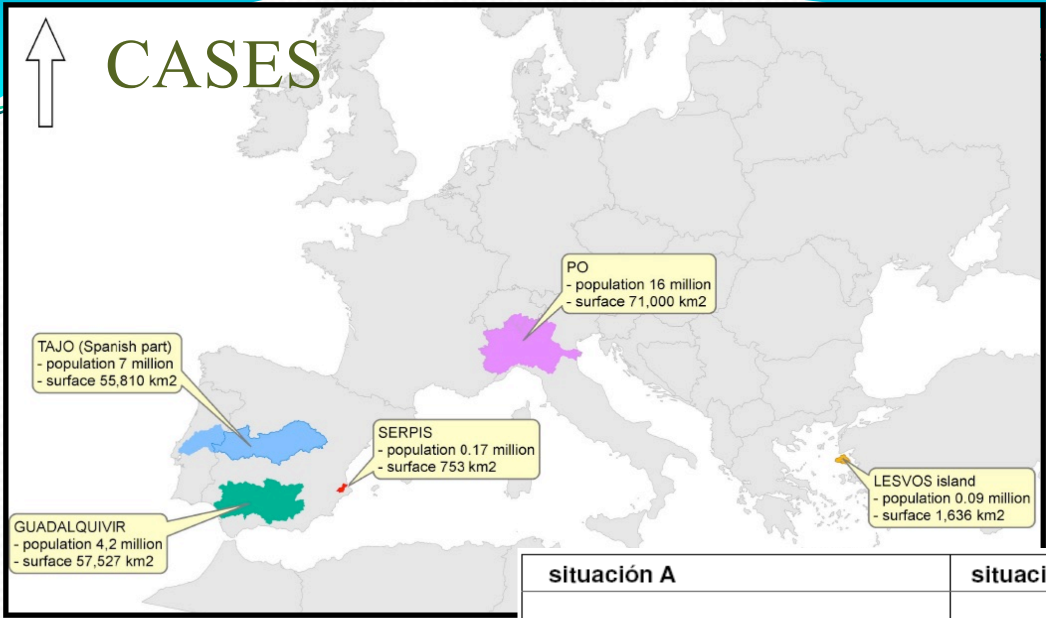


Environmental water status

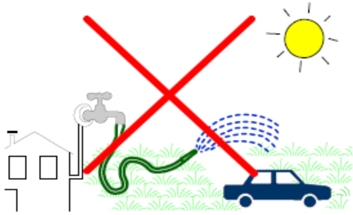
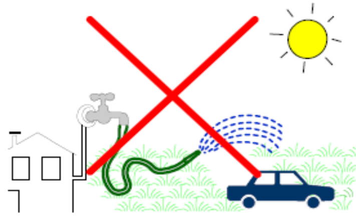
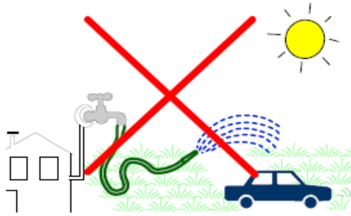
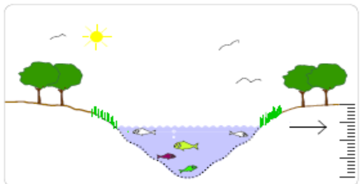
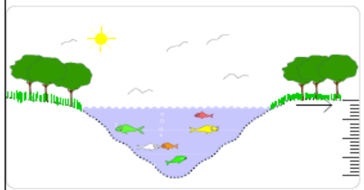
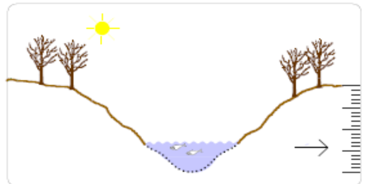
Brouwer, R., et al. 2015. Improving value transfer through socio-economic adjustments in a multicountry choice experiment of water conservation alternatives. *Australian J. of Ag. Resource Economics* 59, 1 -21.

Glenk, K., Martin-Ortega, J., Pulido-Velazquez, M., Potts, J., 2015. Inferring attribute non-attendance from stated choice data: implications for benefit transfer. *Environmental and Resource Economics* 60: 497–520.

CASES



CHOICE EXPERIMENT

situación A	situación B	Situación actual
3 años de 10 	2 año de 10 	4 años de 10 
buena 	muy buena 	mala 
20 €	40 €	0 €

Math Programming

Water conservation options */ water-energy nexus*

- Each household, set of actions:
  - *Long-term*: Tech improvements (indoor retrofits, outdoor savings)
  - *Short-term*: Behavioral changes

[Alcubilla and Lund, 2006; Rosenberg et al., 2007; Cahill et al., 2013]

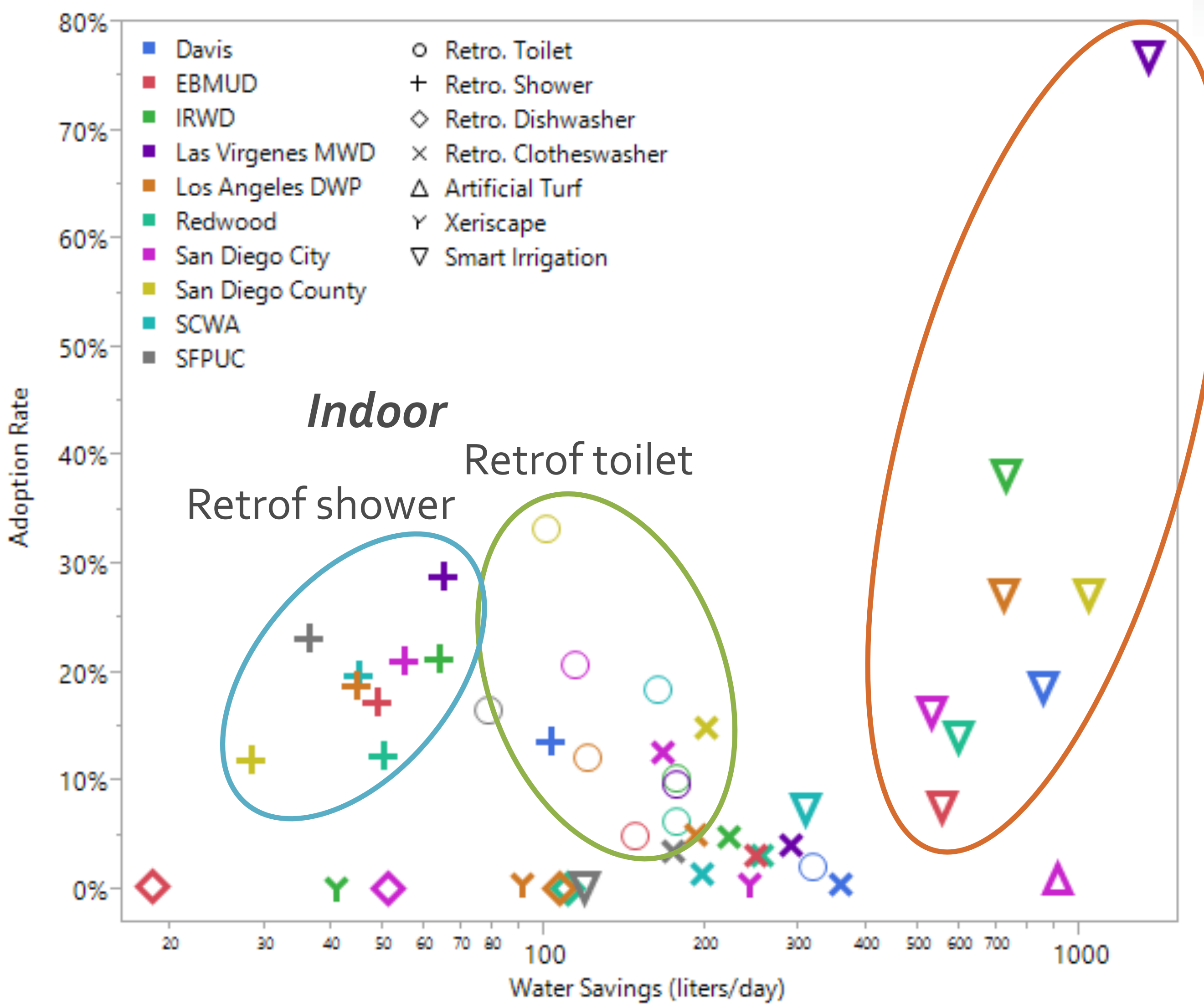
- Each ***action*** has:
  - Cost
    - Annualized costs for retrofits
    - "Hassle costs" for behavioral changes
  - Effectiveness (water/energy savings)

Escriva-Bou, A., J.R. Lund, M. Pulido-Velazquez, 2015. Optimal residential water conservation strategies considering related energy in California. *Water Resour. Res.*, 51

Escriva-Bou, A., J.R. Lund; M. Pulido-Velazquez, 2015. Modeling residential water and related energy, carbon footprint and costs in California. *Env. Science & Policy* 50, 270-281.

Results: Water Savings for Long-Term Actions

Escriva-Bou et al., WRR, 2015



Outdoor (smart irrigation)

PPIC

Optimal Combination of Conservation Actions considering Action Costs and Water and Energy Bills

2-stage stochastic optimization model

Cost of LT tech improvements

$$Minimize\ TOTAL\ COST = \sum_{wlt} C_{wlt} \cdot X_{wlt} + \sum_{elt} C_{elt} \cdot X_{elt} +$$

$$B \cdot \left[\sum_{we} p_{we} \cdot \left(\sum_{ee} p_{ee} \cdot \left\{ D \cdot \left(\sum_{wst} C_{wst} \cdot X_{wst_{we,ee}} + \sum_{est} C_{est} \cdot X_{est_{we,ee}} \right) + B_{W_{we}} + B_{E_{ee}} \right\} \right) \right]$$

Prob water & energy prices **Cost of ST behavioral modifcations** **Monthly water & energy bills**

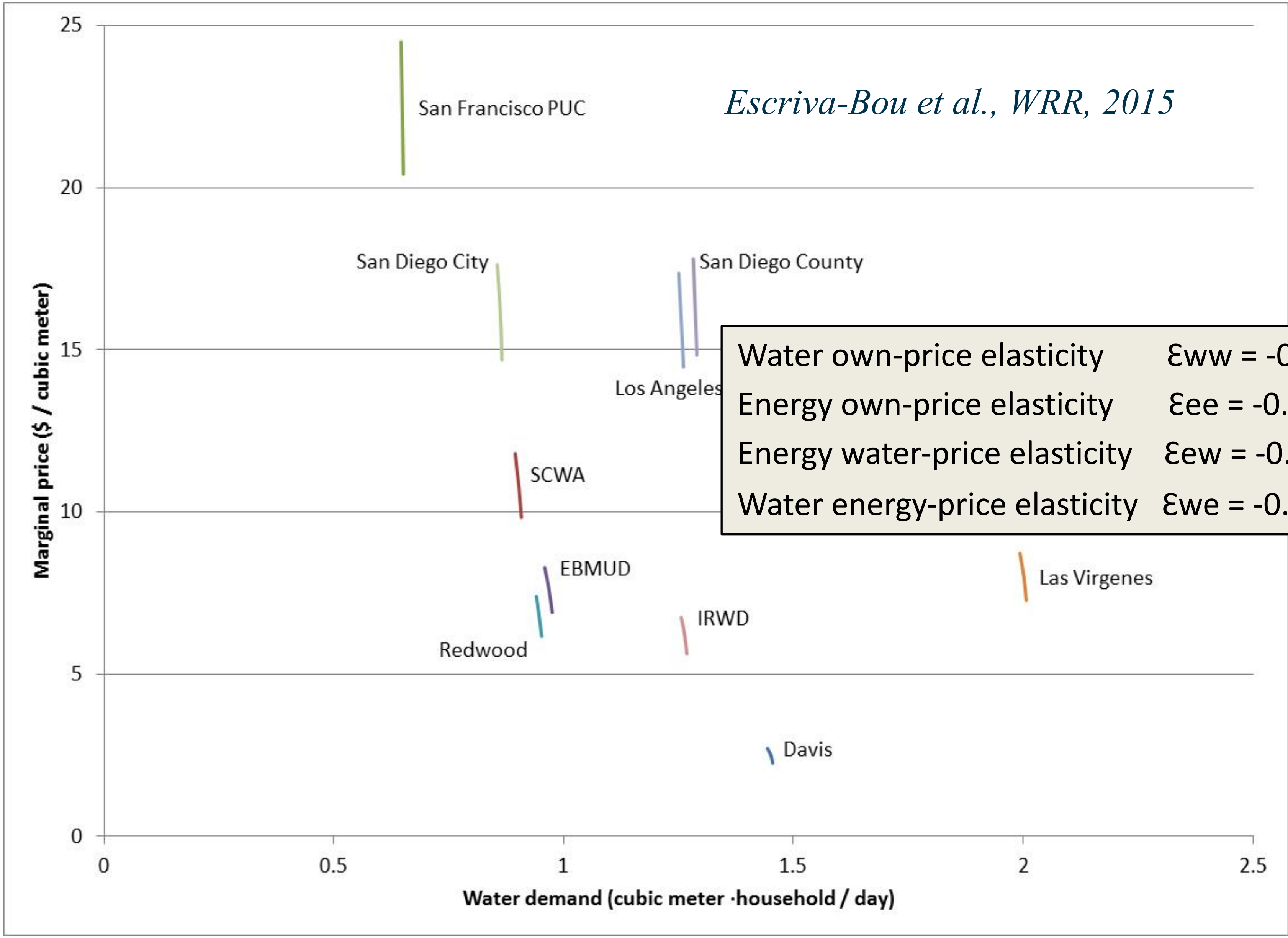
- Subject to:
  - Decision variables are binary
  - Savings are less than initial use (upper bound)
  - Mutually exclusive actions
  - Interdependence among actions

[adapted form Rosenberg et al., 2007]

Escriva-Bou et al., WRR, 2015

10,000 Monte Carlo simulations for water, water-related energy and costs for households in 10 cities in California (prob distribution of parameters affecting water use)

Results: demand function and elasticities



Water own-price elasticity	Ɛww = -0.05
Energy own-price elasticity	Ɛee = -0.03
Energy water-price elasticity	Ɛew = -0.02
Water energy-price elasticity	Ɛwe = -0.004

HEMs APPLICATIONS

APPLICATION 1:

PLANNING & MANAGEMENT: EC VALUE OF NEW INFRASTRUCTURE-OPERATION

Southern California – Adra River Basin (Spain)

WATER RESOURCES RESEARCH, VOL. 40, W03401, doi:10.1029/2003WR002626, 2004

Economic values for conjunctive use and water banking in southern California

Manuel Pulido-Velazquez
Department of Hydraulic and Environmental Engineering, Universidad Politécnica de

Marion W. Jenkins and Jay R. Lund
Department of Civil and Environmental Engineering, University of California, Davis,

ECOLOGICAL ECONOMICS 66 (2008) 51–65

available at www.sciencedirect.com

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www.elsevier.com/locate/ecolecon

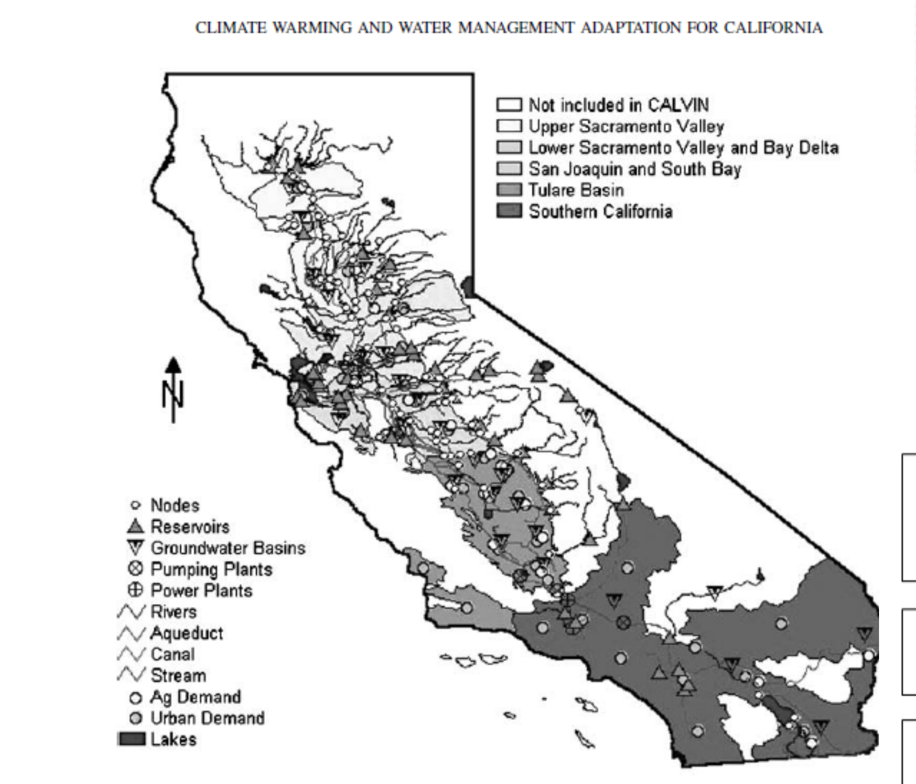
ELSEVIER

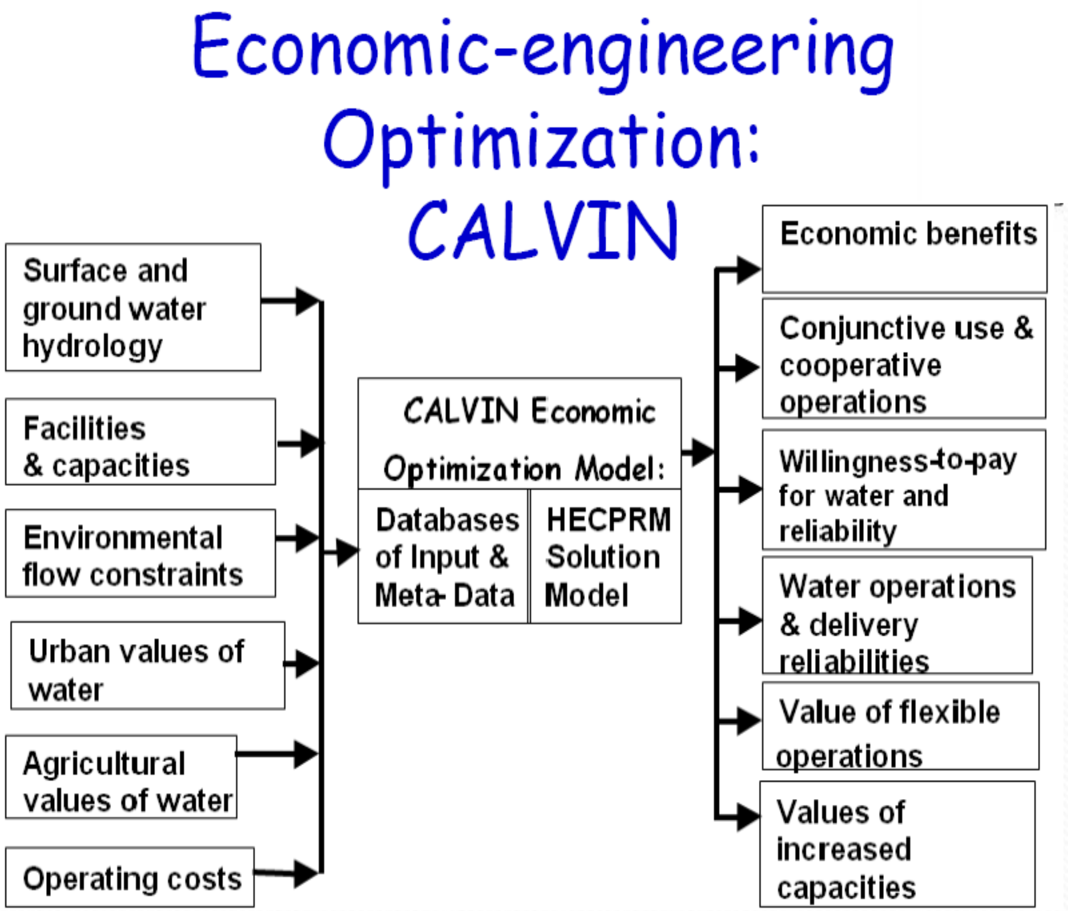
Hydro-economic river basin modelling: The application of a holistic surface–groundwater model to assess opportunity costs of water use in Spain

Manuel Pulido-Velazquez, Joaquín Andreu, Andrés Sahuquillo, David Pulido-Velazquez*
Institute for Water and Environmental Engineering (IIAMA), Technical University of Valencia, Cami de Vera s/n; 46022 - Valencia, Spain

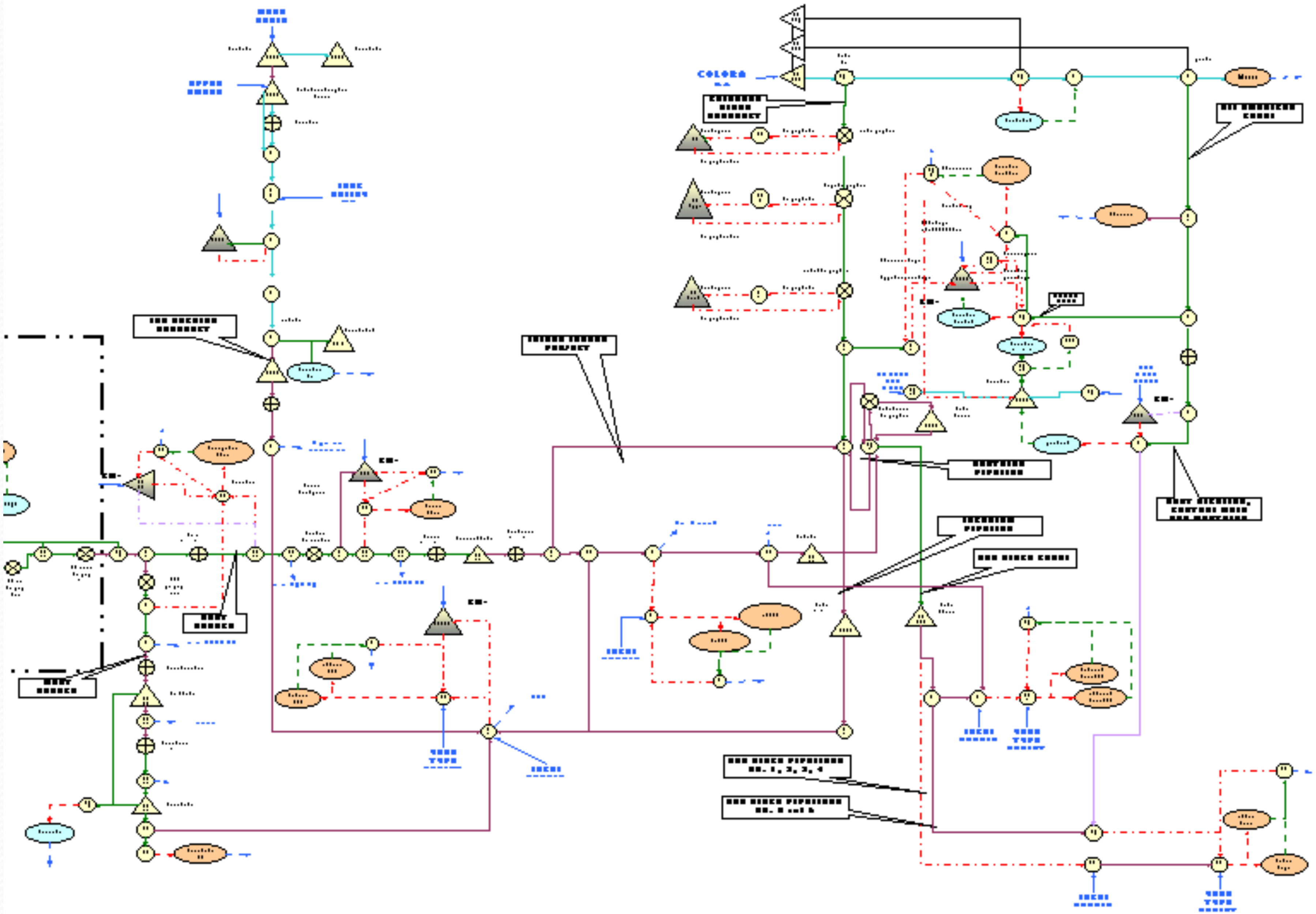
HEM for optimal Conjunctive Use - GW banking in Southern California

HYDRO-ECONOMIC MODELS





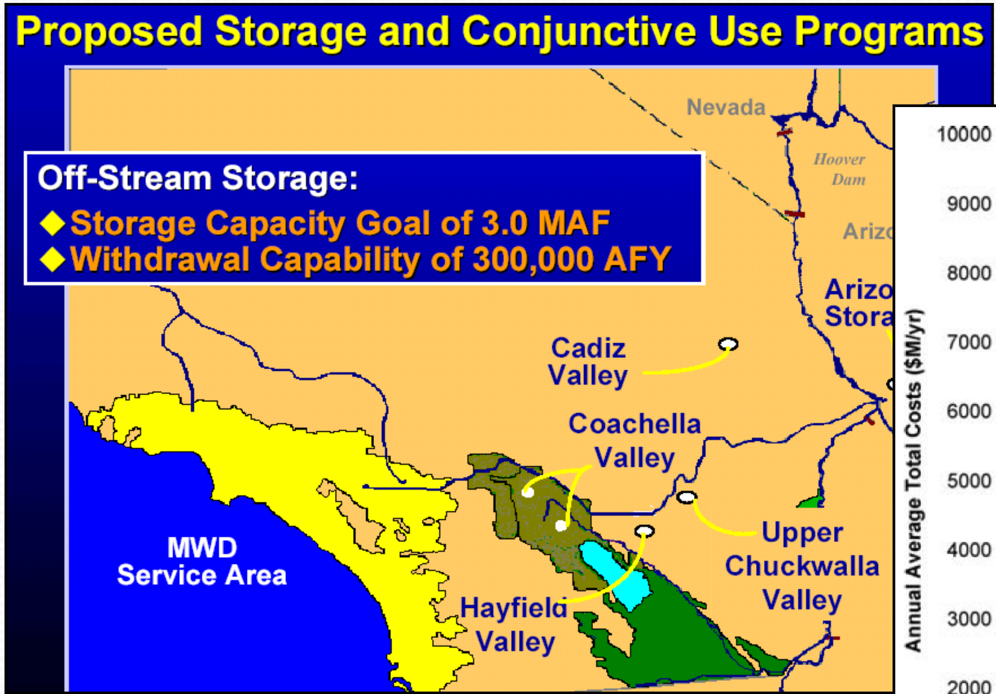
Southern California model (*Pulido-Velazquez et al., WRR, 2004*)

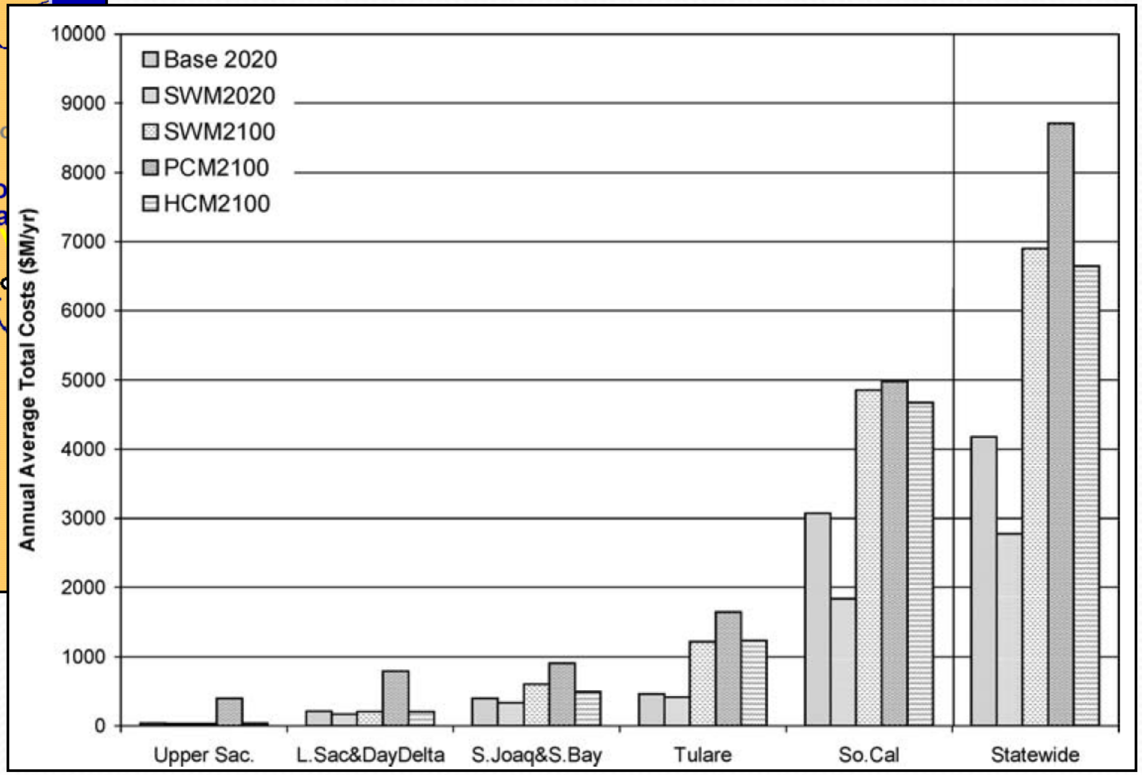


Significant adaptation capacity to reduced imports and climate & pop changes …

- Changes in CU operation & infrastr of GW storage (AR Mojave!)
- Significant transfers (**water markets**)

although at a significant cost …



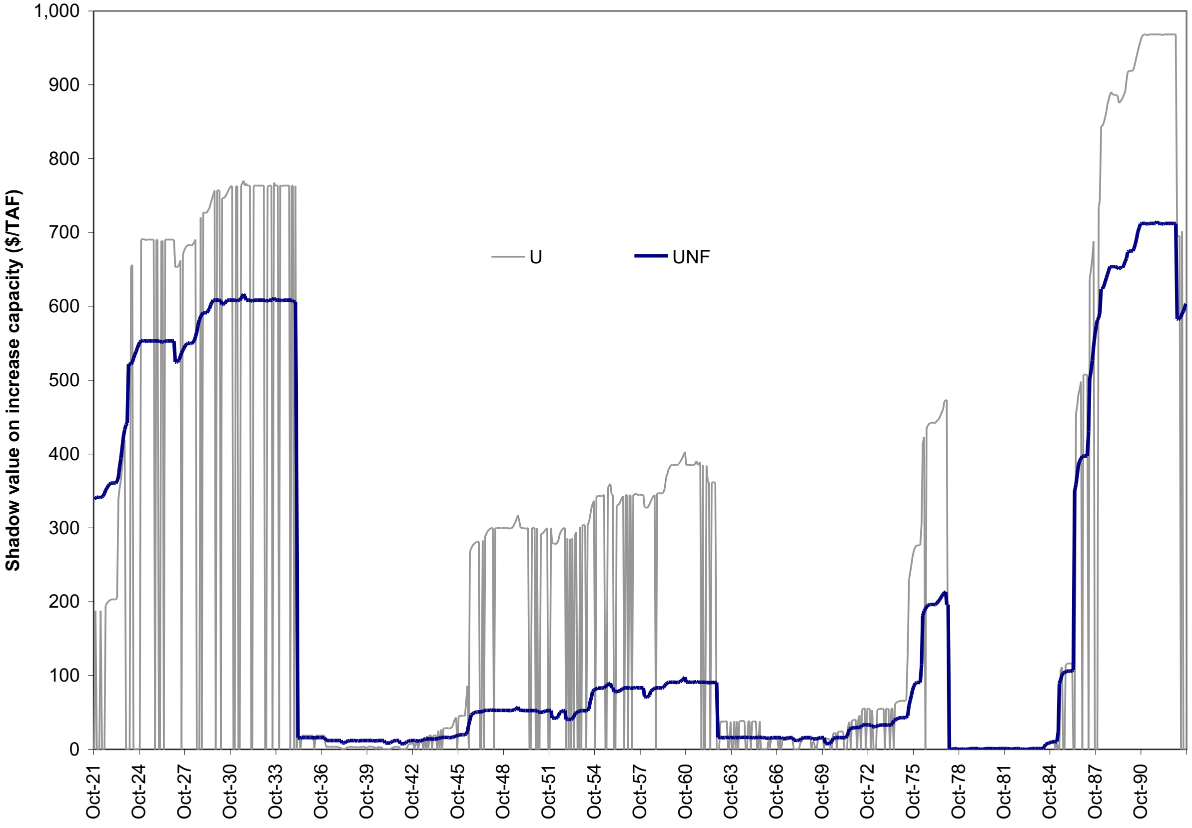


Tanaka et al., Climatic Change, 2006

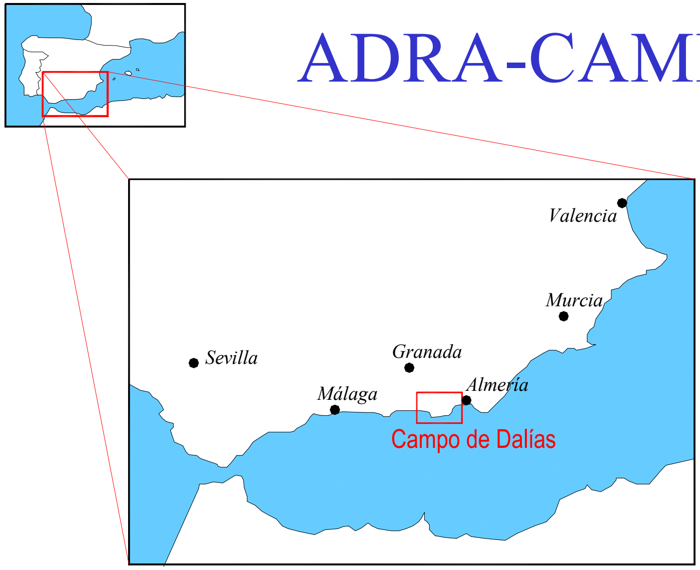
Marginal Economic Value of **Reservoir Capacity Expansion**

CALVIN name	*Surface Reservoir*	*Monthly Expected Value (K$/af)*		*Maximum (K$/af)*	
		U	*UNF*	*U*	*UNF*
SR-25	Silverwood Lake	4.5	3.1	323	242
SR-27	Lake Perris	4.4	2.8	322	241
SR-28	Pyramid Lake	3.9	2.6	322	241
SR-29	Castaic Lake	3.6	2.3	323	242
SR-LA	Aggregated Los Angeles Reservoir	15.4	13.1	358	356
SR-GL	Grant Lake	16.1	14.3	533	536
SR-LC	Long Valley Reservoir (Lake Crowley)	14.5	12.7	358	355
SR-LM	Lake Mathews of MWDSC	7.7	5.8	319	238
SR-LSK	Lake Skinner	10.6	8.6	317	268
SR-ER	Eastside Reservoir (Diamond Valley Lake)	4.1	2.9	322	241

Shadow Values of Capacity constraint in **Colorado River Aqueduct**

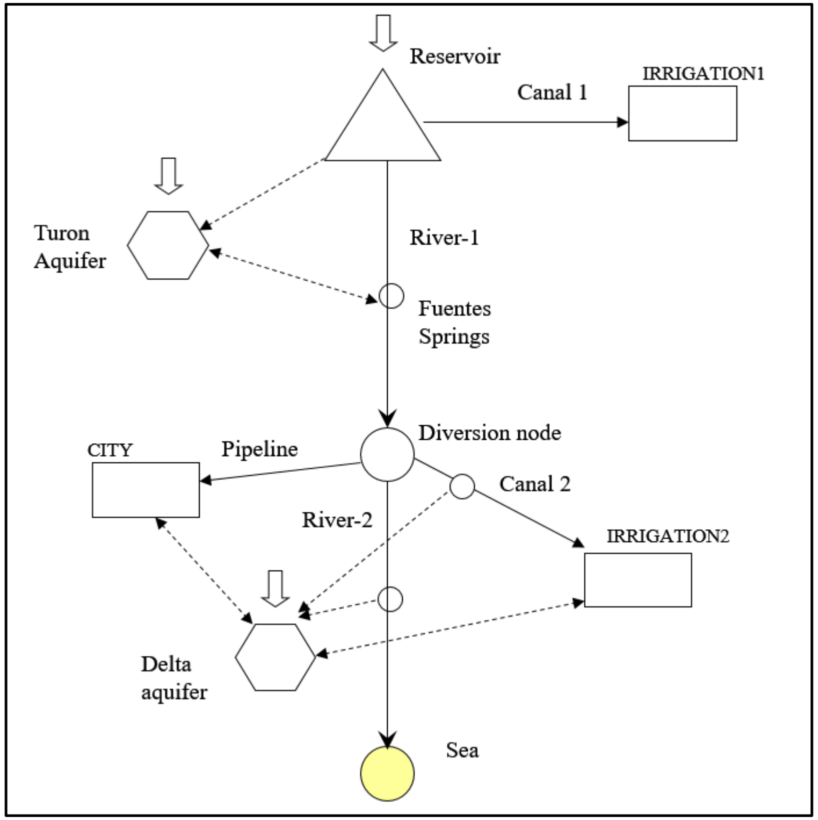


ADRA-CAMPO DE DALIAS SYSTEM

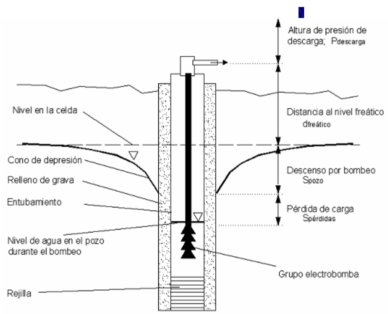


C. Dalías

"Sea of plastic"
(greenhouses)

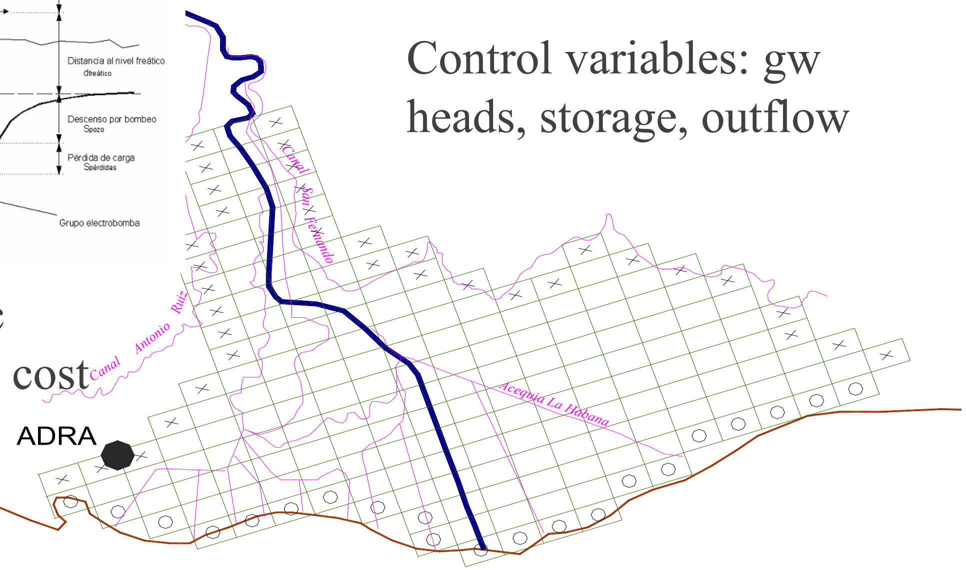


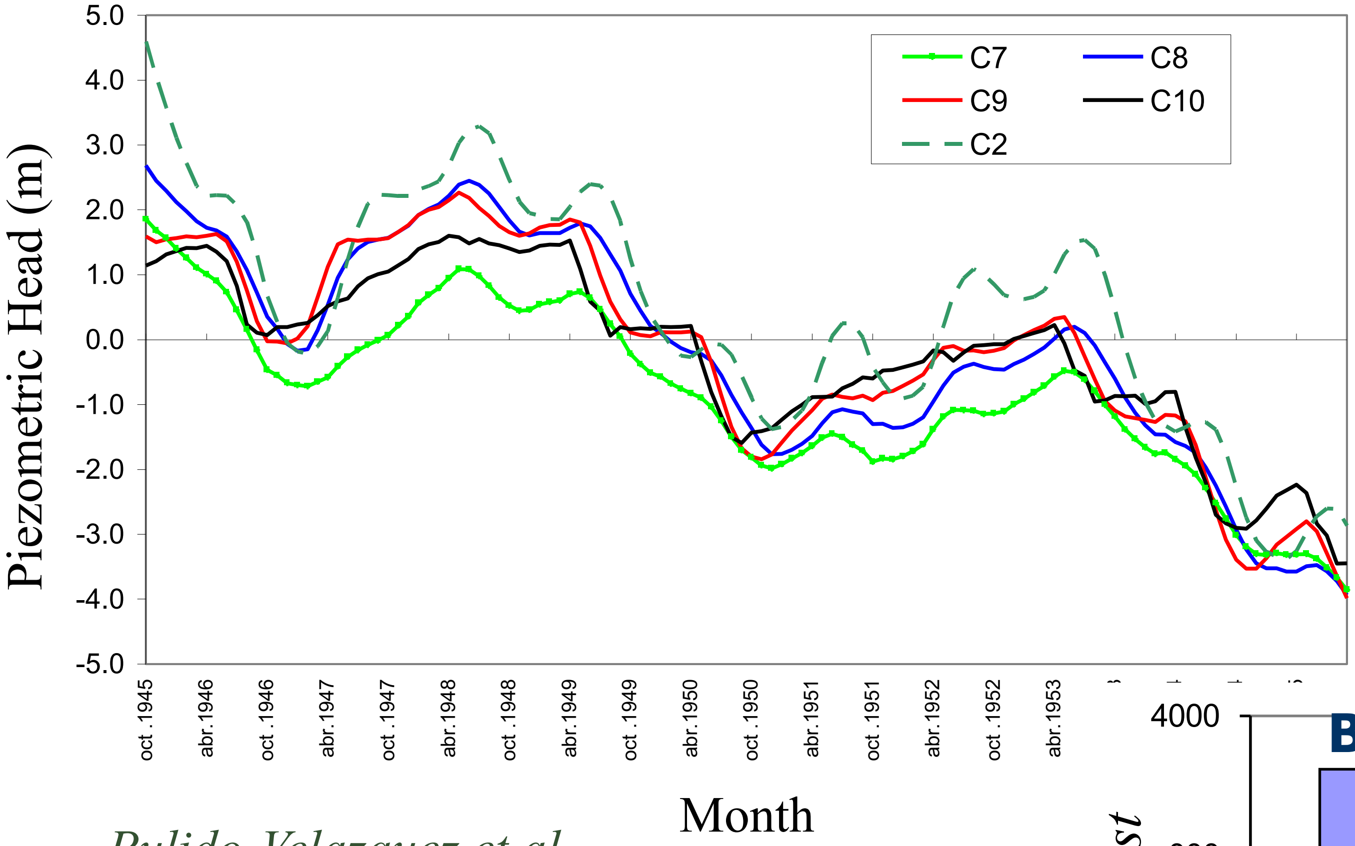
Distributed model of Adra aquifer



Control variables: gw heads, storage, outflow

Dynamic pumping cost

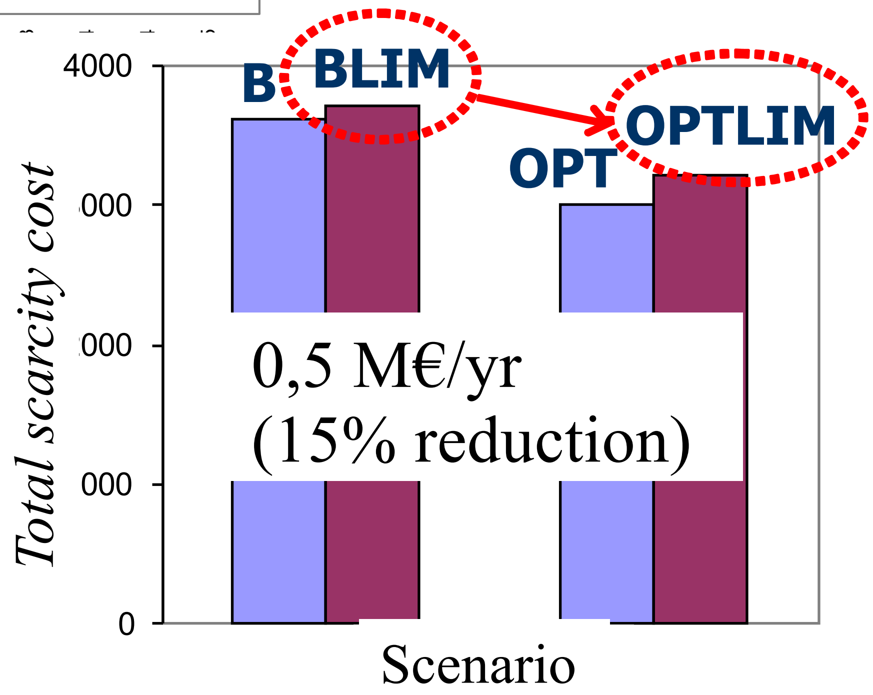




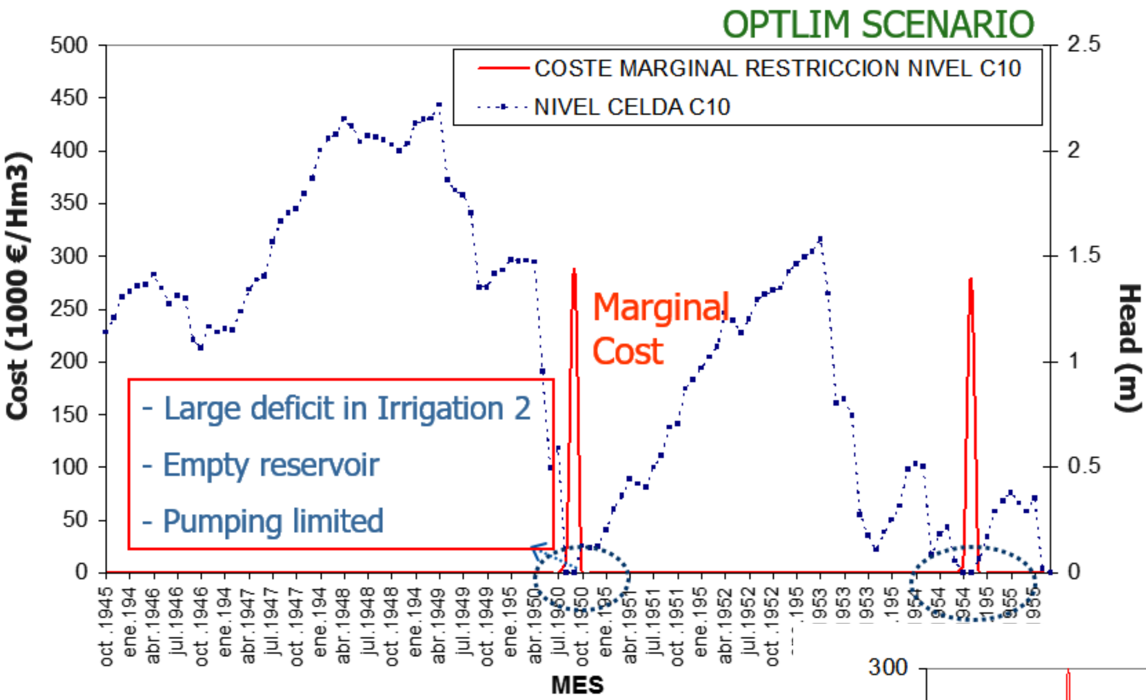
Avoid intrusion !!

CU optimization with pumping limitations based on dynamic GW heads

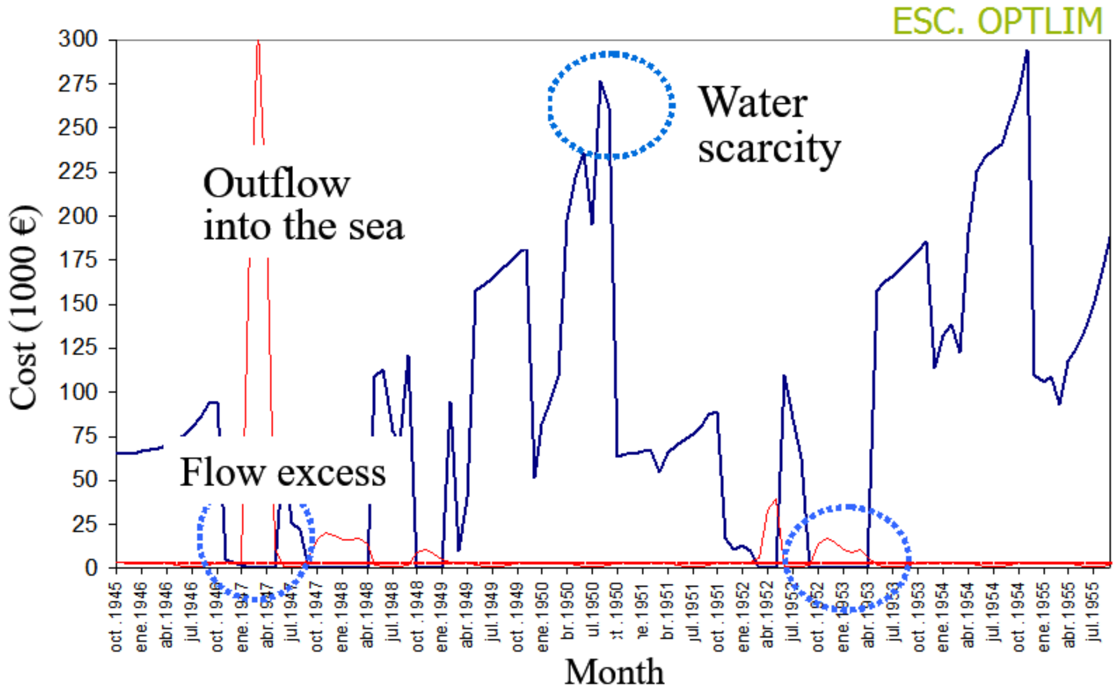
Pulido-Velazquez et al., JWRPM, 2006



MC of min head constraints in DELTA aquifer to avoid seawater intrusion



MC of min streamflow, last reach of Adra river



APPLICATION 2:

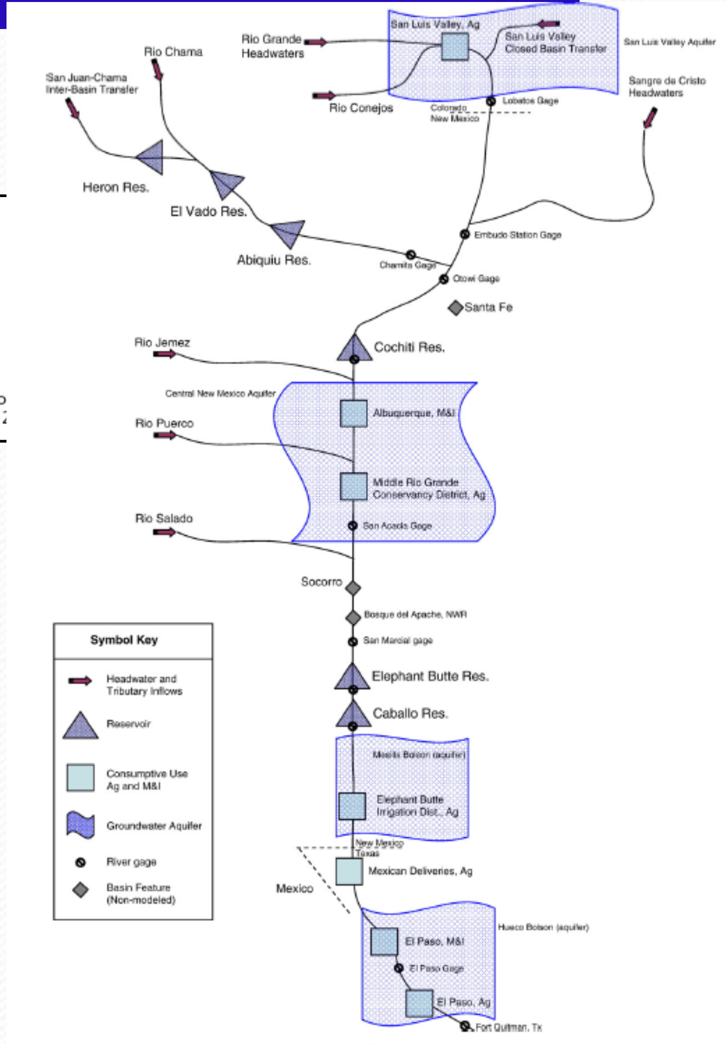
Value of water conservation in agriculture.
Rio Grande, US.

Ward and Pulido, PNAS, 2008

Water conservation in irrigation can increase water use

Frank A. Ward[a,1] and Manuel Pulido-Velazquez[b]

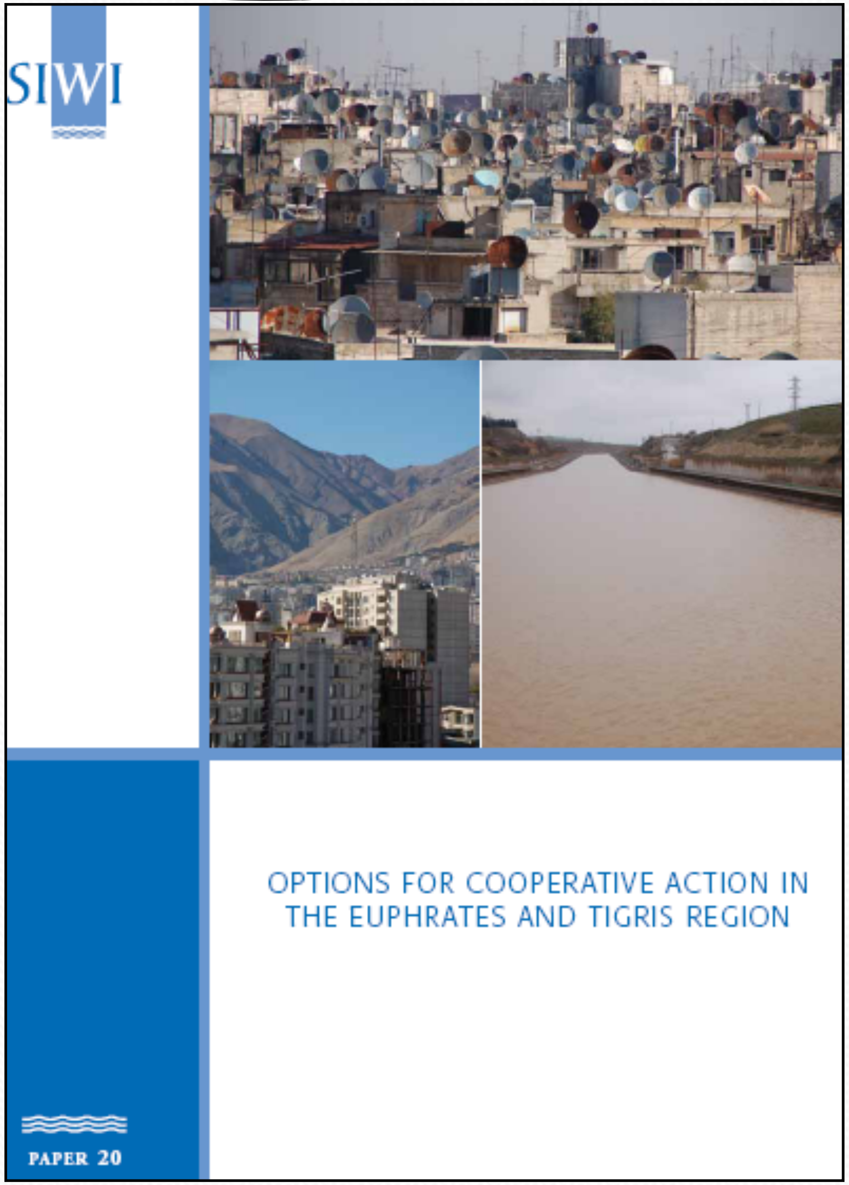
[a]Department of Agricultural Economics and Agricultural Business, New Mexico State University, Las Cruces, NM 88003; and [b]Department o
Environmental Engineering–Institute of Water and Environmental Engineering, Universidad Politécnica de Valencia, Cami de Vera s/n 461



- Policies of conservation can increase consumption !
- More efficient irrigation techniques: crop changes; ↓ valuable return flows; ↑ crop yields & ET

APPLICATION 3:

Benefits of cooperation. Tigris-Euphrates region



iiama

- HEM/ evaluate Bs from cooperation at basin scale
- Only public data and remote sensing (transparency)

ASSUMPTIONS:

Water savings in agriculture-> ↑ HP production, high-valued crops, env. flows

High value of cooperation

(from 200 to 1450 USD M$, depending on the scenarios)

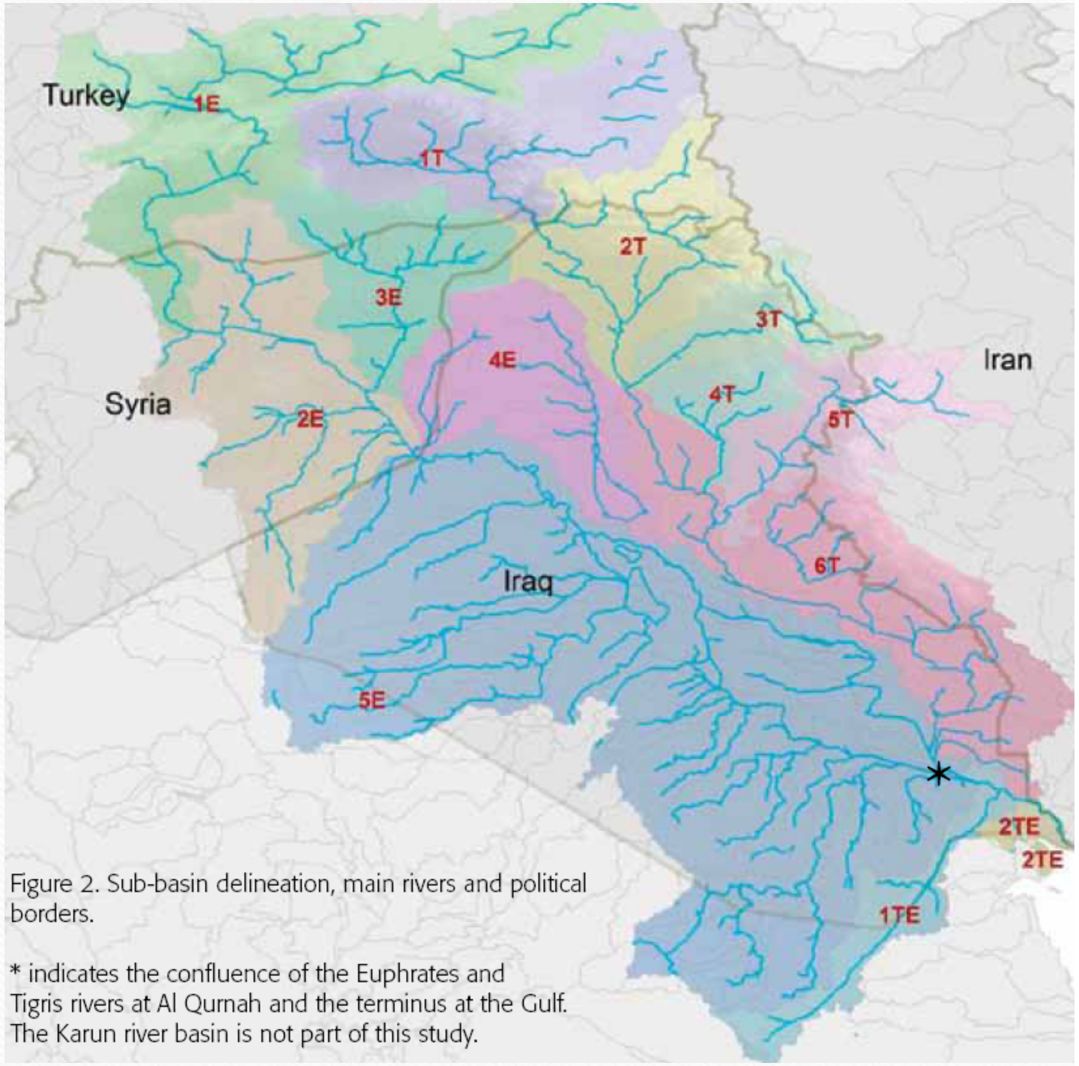


Figure 2. Sub-basin delineation, main rivers and political borders.

* indicates the confluence of the Euphrates and Tigris rivers at Al Qurnah and the terminus at the Gulf. The Karun river basin is not part of this study.

APPLICATION 4

DESIGN / ASSESSMENT OF ECONOMIC INSTRUMENTS

- OPTIMAL CONTROL OF GW POLLUTION. QUOTAS vs. PRICES (PhD thesis, S. Peña)
- EFFICIENT SCARCITY-BASED WATER PRICING POLICIES (PhD thesis, E. Álvarez)
- WATER MARKETS. Júcar /California / Nuevo México

OPT CONTROL OF GW NITRATE POLLUTION
Fertilizers' quotas vs. prices

Journal of Hydrology 392 (2010) 174–187

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Fertilizer standards for controlling groundwater nitrate pollution from agriculture: El Salobral-Los Llanos case study, Spain

S. Peña-Haro [a,b,*], C. Llopis-Albert [b], M. Pulido-Velazquez [b], D. Pulido-Velazquez [c]

Science of the Total Environment 499 (2014) 510–519

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Influence of soil and climate heterogeneity on the performance of economic instruments for reducing nitrate leaching from agriculture

Salvador Peña-Haro [a], Alberto García-Prats [b], Manuel Pulido-Velazquez [c]

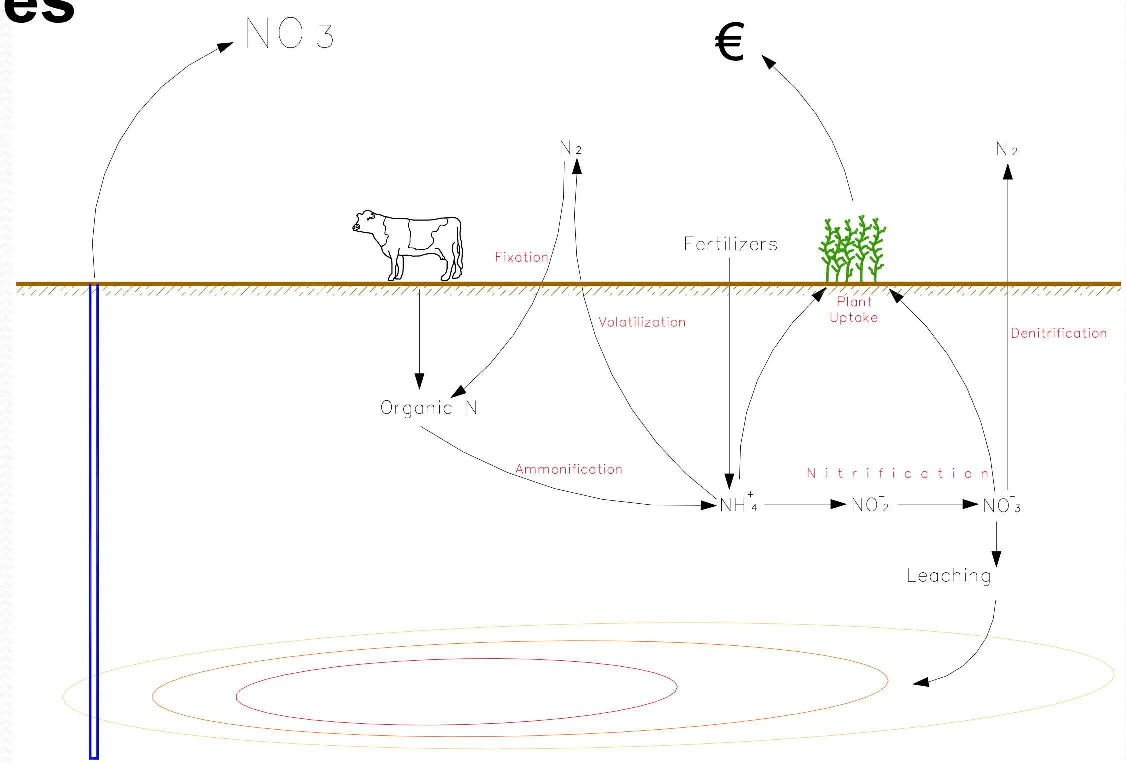
Groundwater Nitrate Pollution Control

EU ***WFD*** ⇒ CEA / PoM to reach ***good status***
(50 mg/l NO3 concentration)

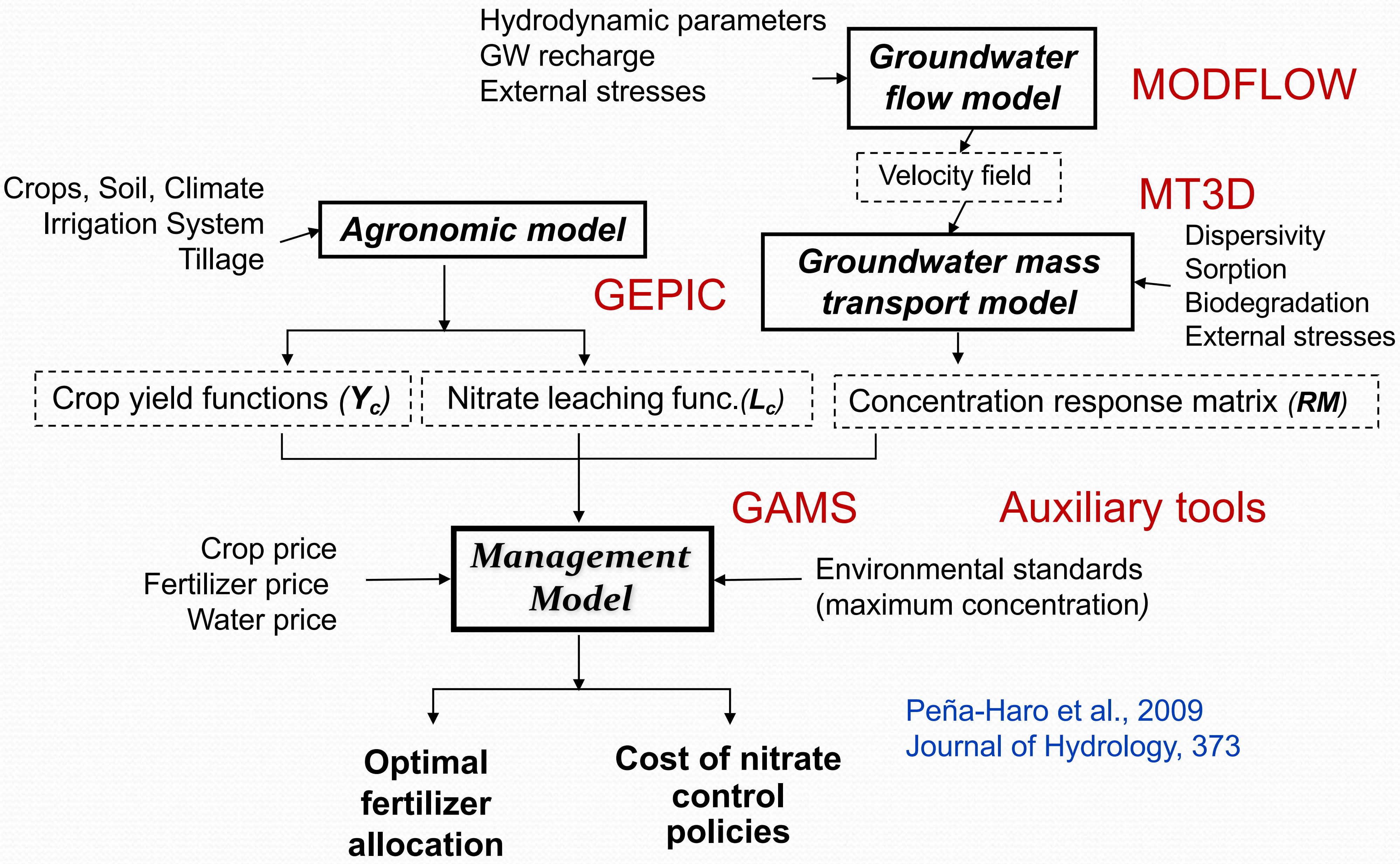
Opt management of GW nitrate pollution through **fertilizer quotas & prices**

HEM to find

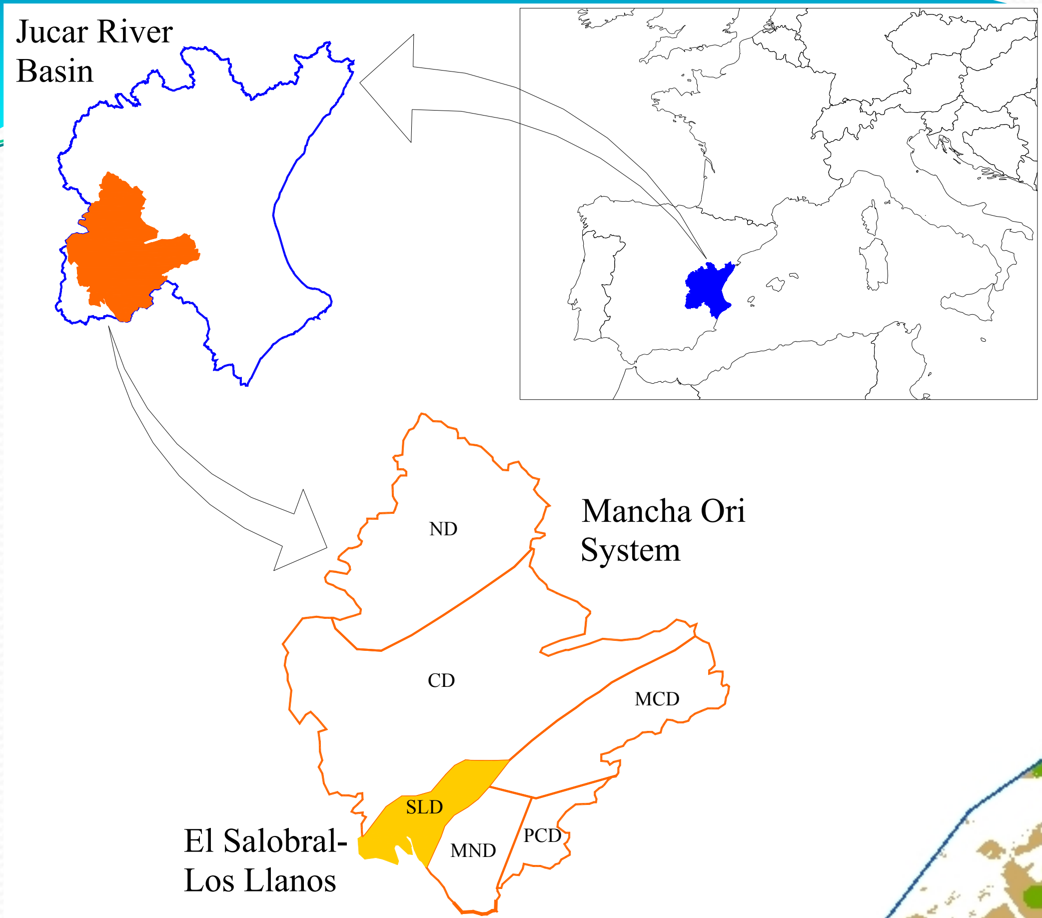
- ec/. optimal fertilizer applications (min agricultural income losses)
- / meets gw nitrate concentration limits



MODELLING FRAMEWORK ...

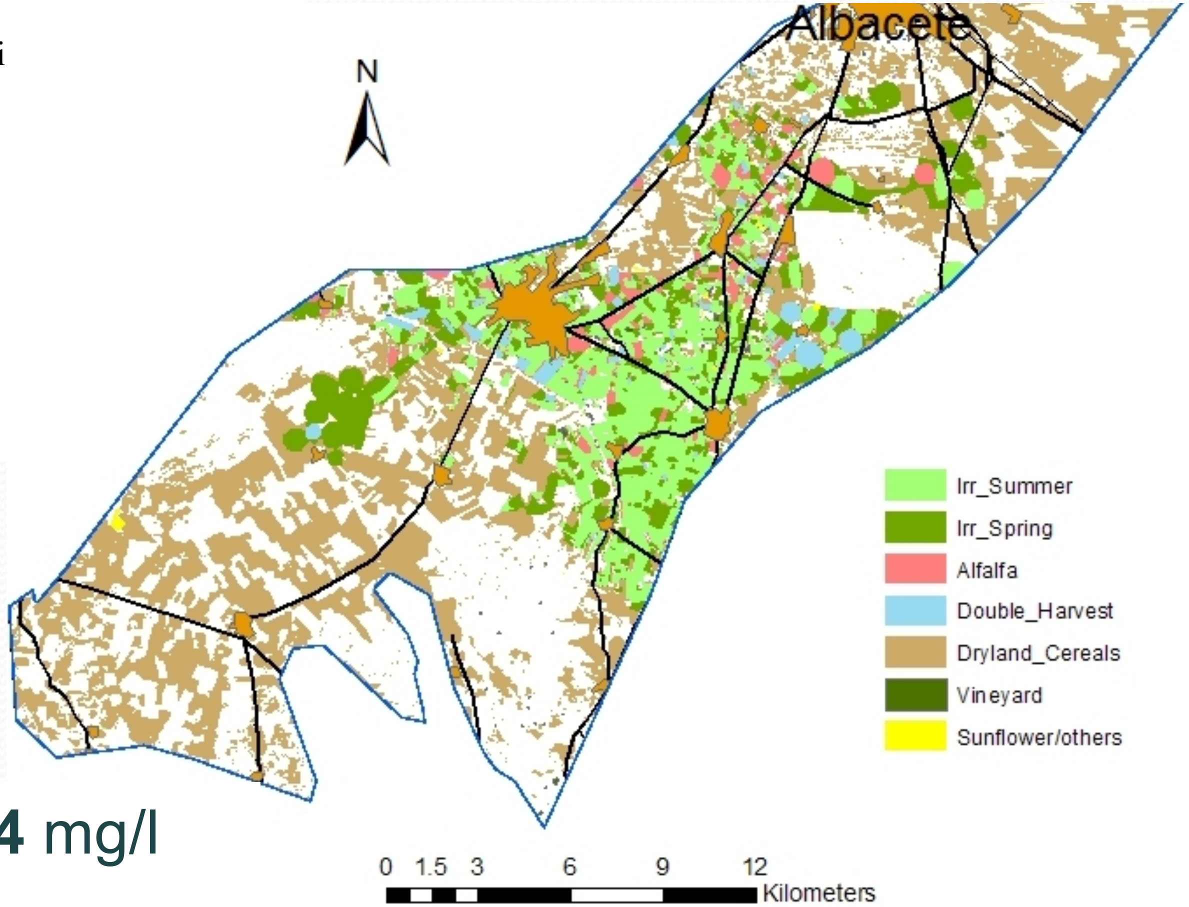


Peña-Haro et al., 2009
Journal of Hydrology, 373



El Salobral-Los Llanos

420 km^2 surface area
337 km^2 (80 %) agriculture
100 km^2 irrigated area

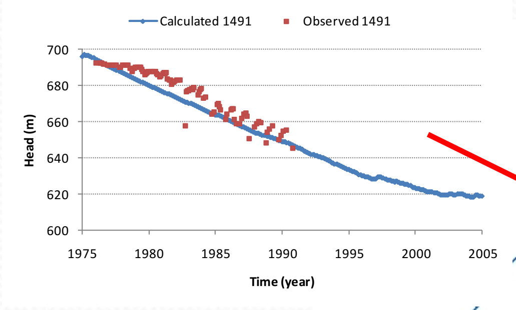


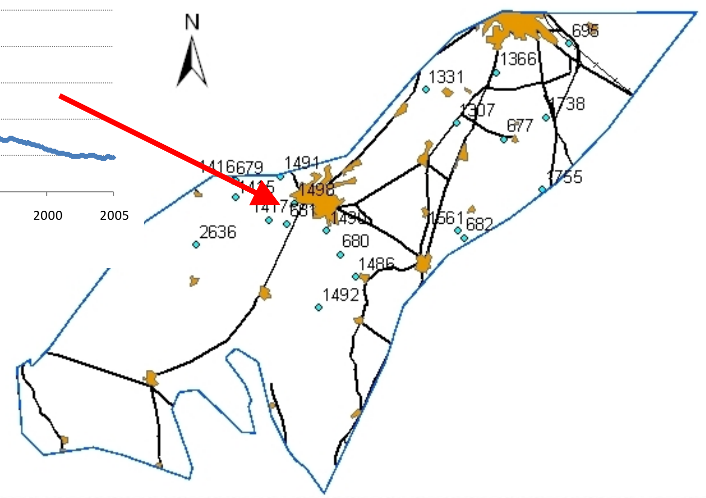
Nitrate concentrations of **54** mg/l under irrigated areas

Emissions (control) ↔ GW pollutant concentrations (targets)

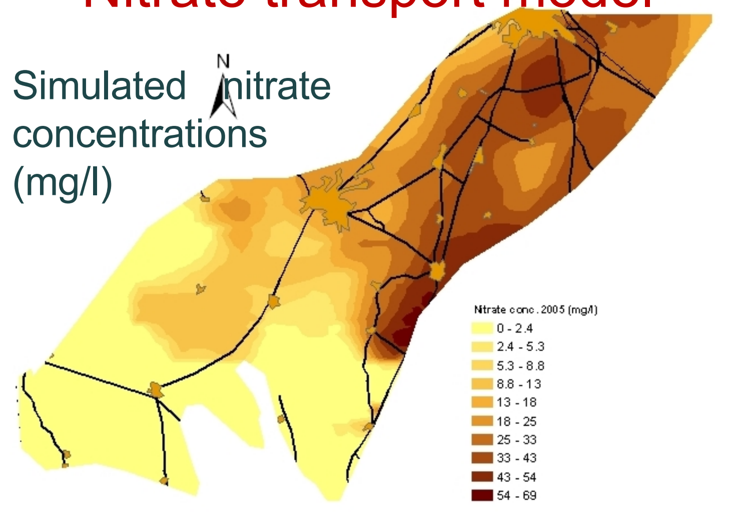
GW flow & transport model

GW flow model

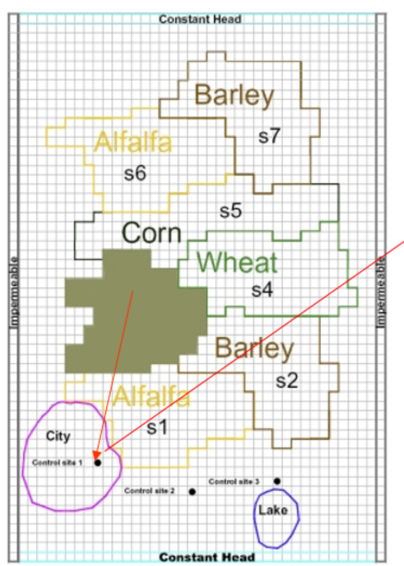




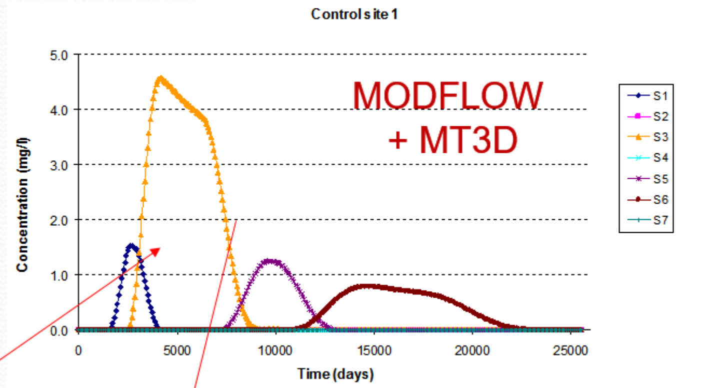
Nitrate transport model



Concentration Response Matrix



Requirement: linearity

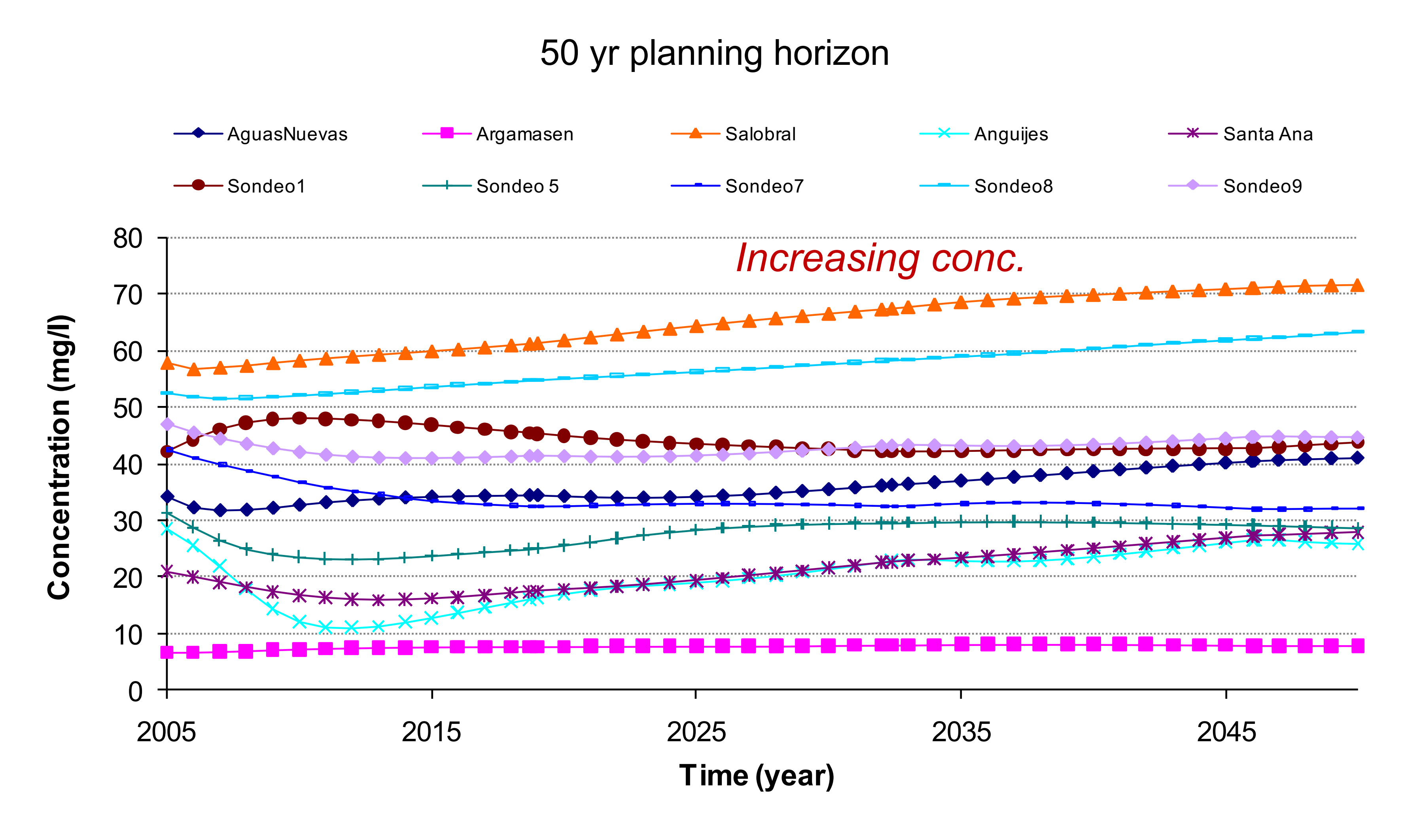


Sources x Planning horizons

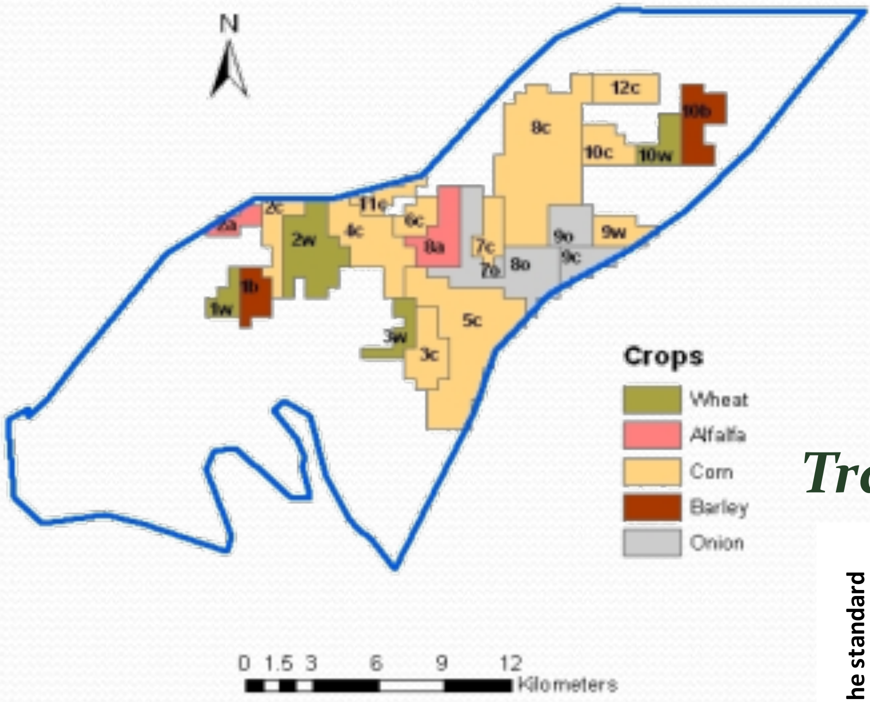
Control sites x Time

	$S_{1,1}$	$S_{2,1}$	…	$S_{s,1}$	$S_{1,2}$	$S_{2,2}$	…	$S_{s,2}$	…	$S_{s,m}$
$O_{1,1}$	$C_{1,1,1,1}$	$C_{1,1,2,1}$		$C_{1,1,s,1}$	$C_{1,1,1,2}$	$C_{1,1,2,2}$		$C_{1,1,s,2}$		$C_{1,1,s,m}$
$O_{2,1}$	$C_{1,2,1,1}$	$C_{1,2,2,1}$		$C_{1,2,s,1}$	$C_{1,2,1,2}$	$C_{1,2,2,2}$		$C_{1,2,s,2}$		$C_{1,2,s,m}$
⋮	⋮	⋮		⋮	⋮	⋮		⋮		⋮
$O_{c,1}$	$C_{1,t,1,1}$	$C_{1,t,2,1}$		$C_{1,t,s,1}$	$C_{1,t,1,2}$	$C_{1,t,2,2}$		$C_{1,t,s,2}$		$C_{1,t,s,m}$
$O_{1,2}$	$C_{2,1,1,1}$	$C_{2,1,2,1}$		$C_{2,1,s,1}$	$C_{2,1,1,2}$	$C_{2,1,2,2}$		$C_{2,1,s,2}$		$C_{2,1,s,m}$
$O_{2,2}$	$C_{2,2,1,1}$	$C_{2,2,2,1}$		$C_{2,2,s,1}$	$C_{2,2,1,2}$	$C_{2,2,2,2}$		$C_{2,2,s,2}$		$C_{2,2,s,m}$
⋮	⋮	⋮		⋮	⋮	⋮		⋮		⋮
$O_{c,2}$	$C_{2,t,1,1}$	$C_{2,t,2,1}$		$C_{2,t,s,1}$	$C_{2,t,1,2}$	$C_{2,t,2,2}$		$C_{2,t,s,2}$		$C_{2,t,s,m}$
⋮	⋮	⋮		⋮	⋮	⋮		⋮		⋮
$O_{c,t}$	$C_{o,t,1,1}$	$C_{o,t,2,1}$		$C_{o,t,s,1}$	$C_{o,t,1,2}$	$C_{o,t,2,2}$		$C_{o,t,s,2}$		$C_{o,t,s,m}$

Scenario 1. Business-as-usual. Current N fertilizer rates

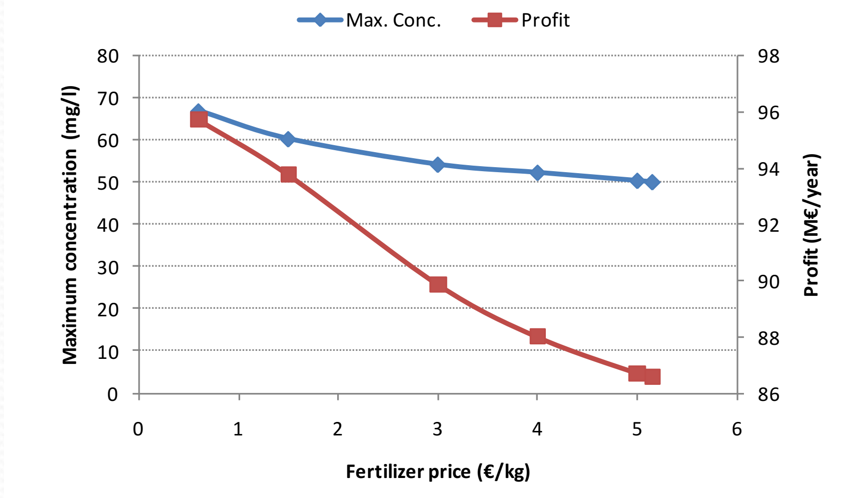


Optimal spatial allocation of fertilizer quotas

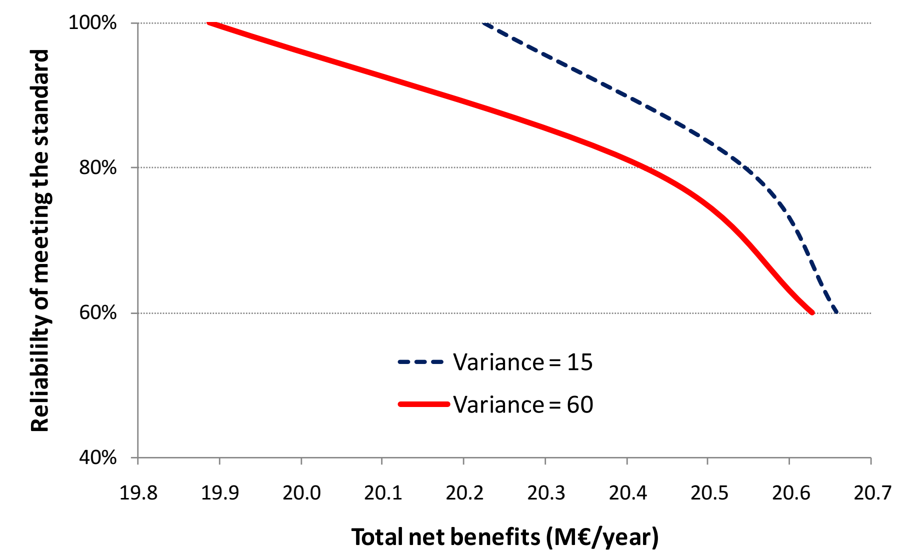


Peña-Haro et al., JH 2009
Peña-Haro et al., STOTEN, 2014

Fertilizer quotas vs. pricing



Trade-offs reliability vs. net benefits



EFFICIENT SCARCITY-BASED WATER PRICING

«Efficient water use is fundamentally about the recognition of water's opportunity cost» (Griffin, 2006)

Design of Efficient Water Pricing Policies Integrating Basinwide Resource Opportunity Costs

M. Pulido-Velazquez[1]; E. Alvarez-Mendiola[2]; and J. Andreu[3]

JOURNAL OF WATER RESOURCES PLANNING AND MANAGEMENT © ASCE / SEPTEMBER/OCTOBER 2013 / 583

J. Water Resour. Plann. Manage. 2013.139:583-592.

Hydrol. Earth Syst. Sci., 19, 3925–3935, 2015
www.hydrol-earth-syst-sci.net/19/3925/2015/
doi:10.5194/hess-19-3925-2015

Hydrology and Earth System Sciences
Open Access

Definition of efficient scarcity-based water pricing policies through stochastic programming

H. Macian-Sorribes[1], M. Pulido-Velazquez[1], and A. Tilmant[2]

[1]Research Institute of Water and Environmental Engineering (IIAMA), Universitat Politècnica de València, Valencia, Spain
[2]Department of Civil and Water Engineering, Université Laval, Québec City, Québec, Canada

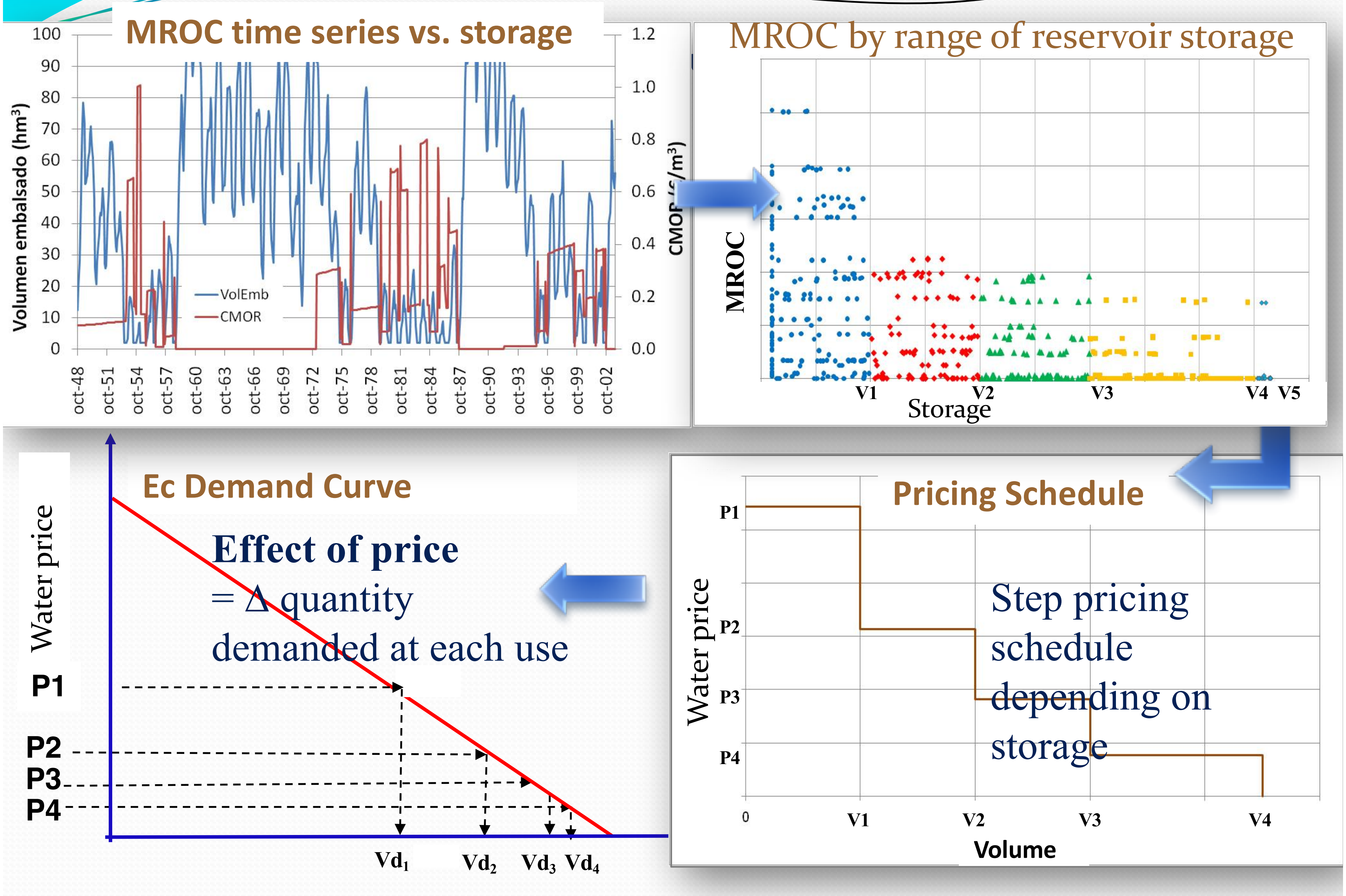
ROLE OF WATER PRICES (WFD)

- **Financial instrument** (cost recovery)
- **Ec instrument** / efficient water use (D management)

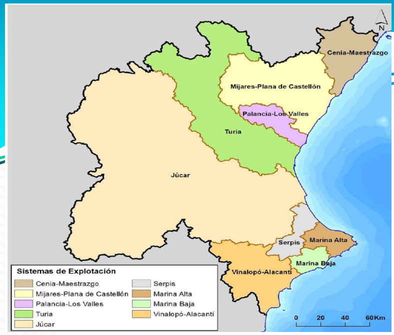
Cost of water = cost of provision + **opportunity cost**

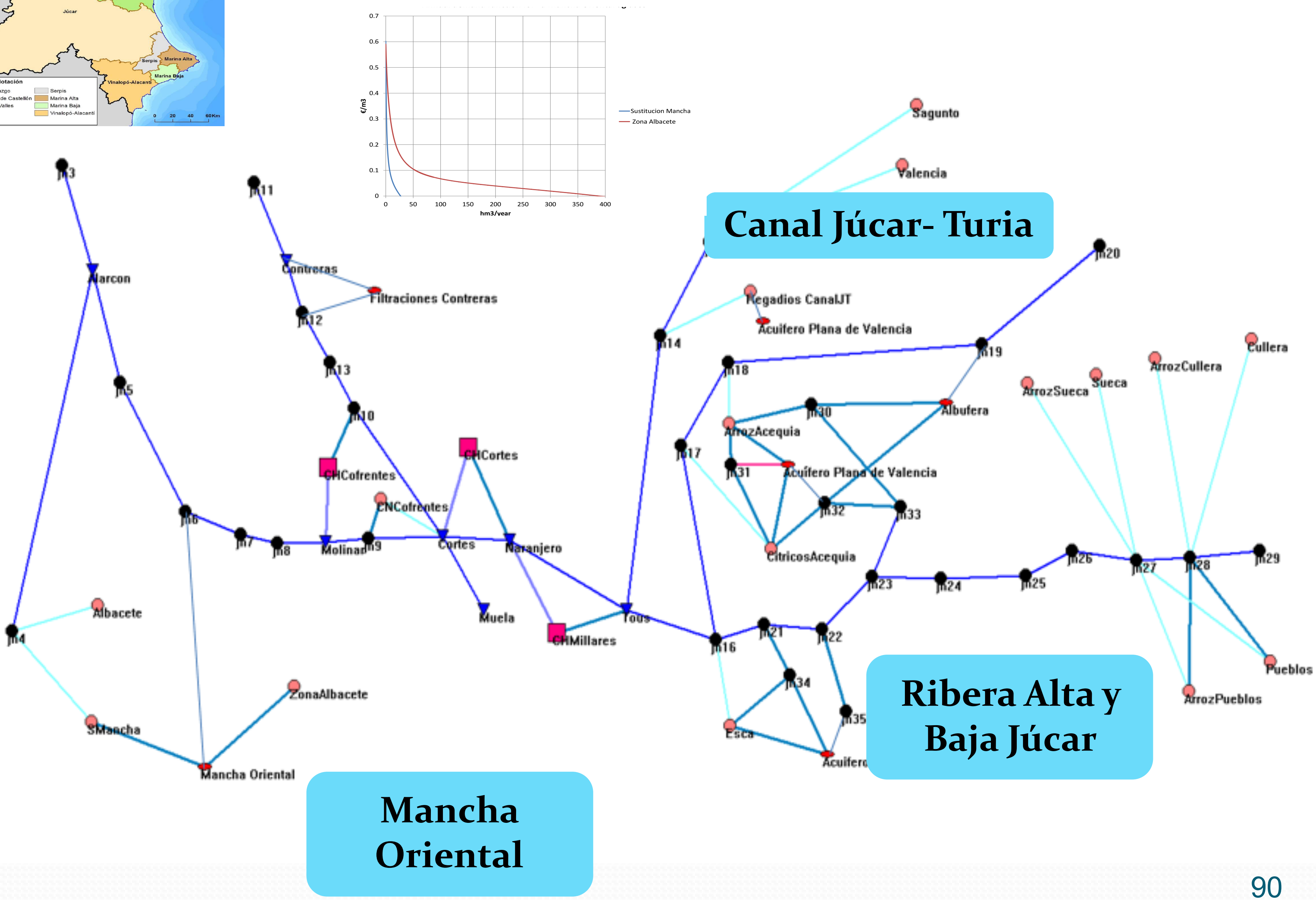
- Water, undervalued when RC ignored -> errors in investment & water allocation decisions. Price should include opp. costs !!
- Absent water market allocation, -> **ec value of water at the different uses & basinwide HEM**

Scarcity WP: MROC -> step pricing functions



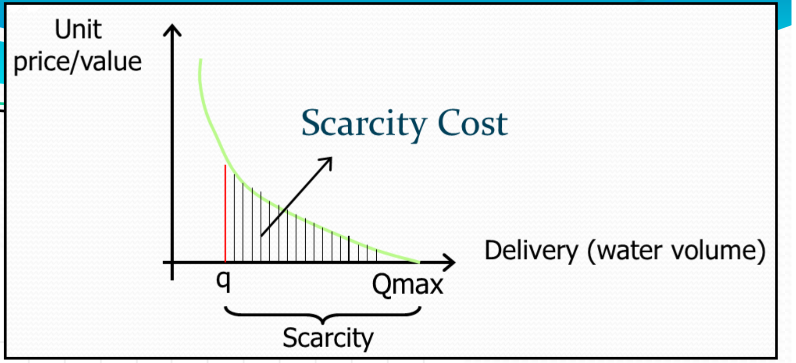
Case study: Jucar River Basin

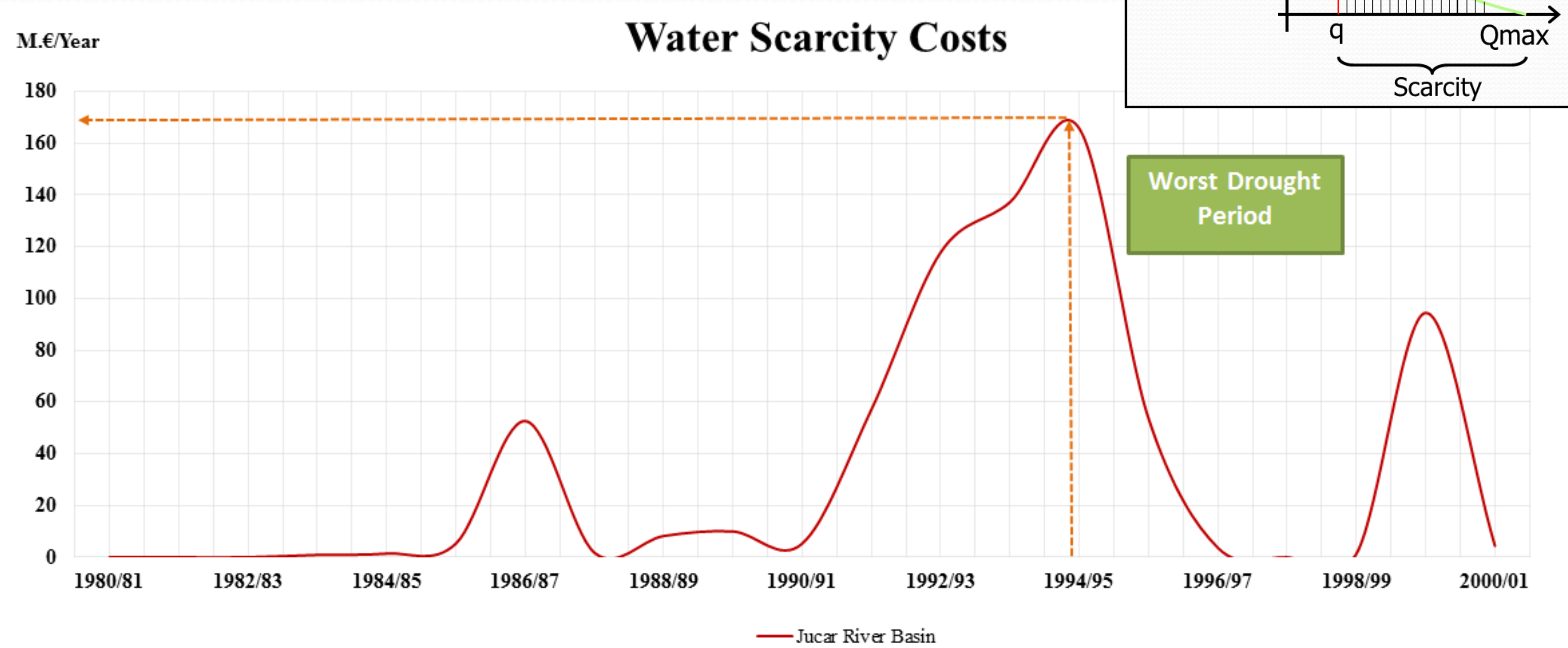


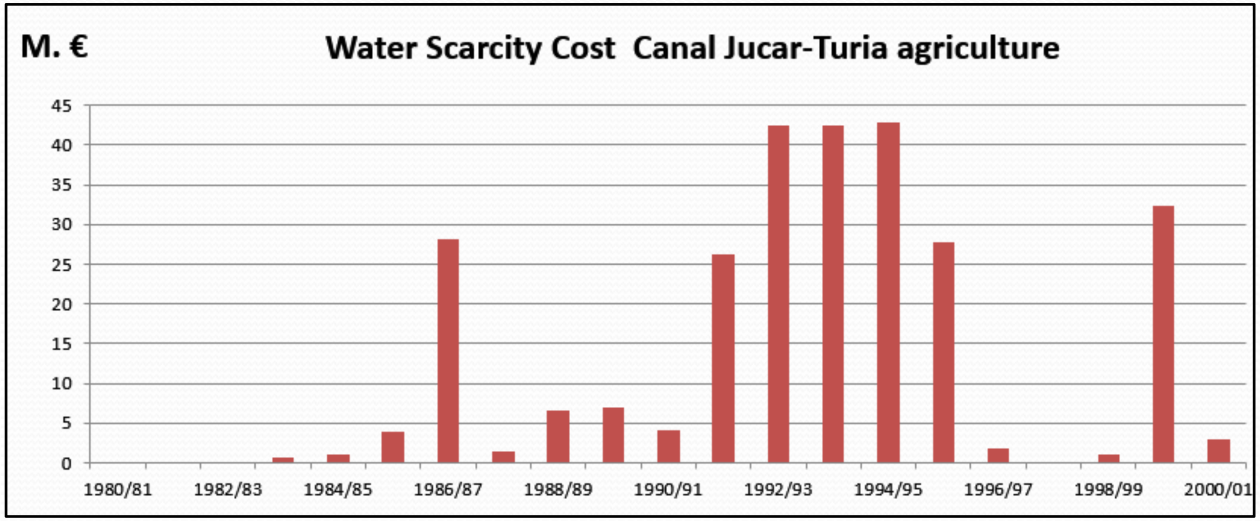


SCENARIO 1: BUSINESS-AS-USUAL

WATER SCARCITY COST



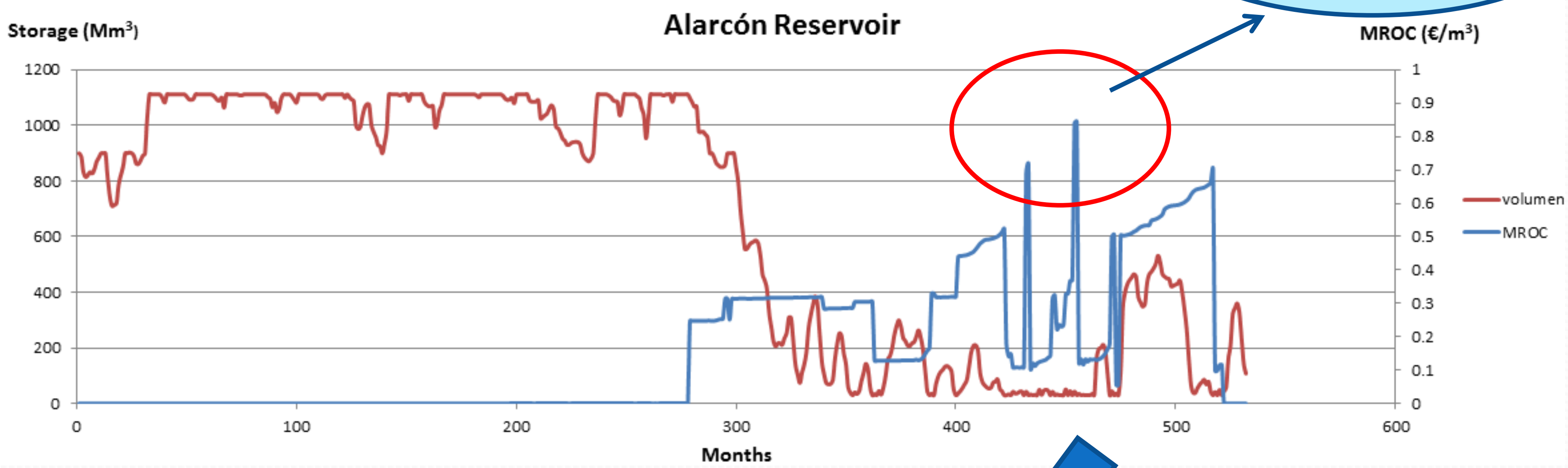


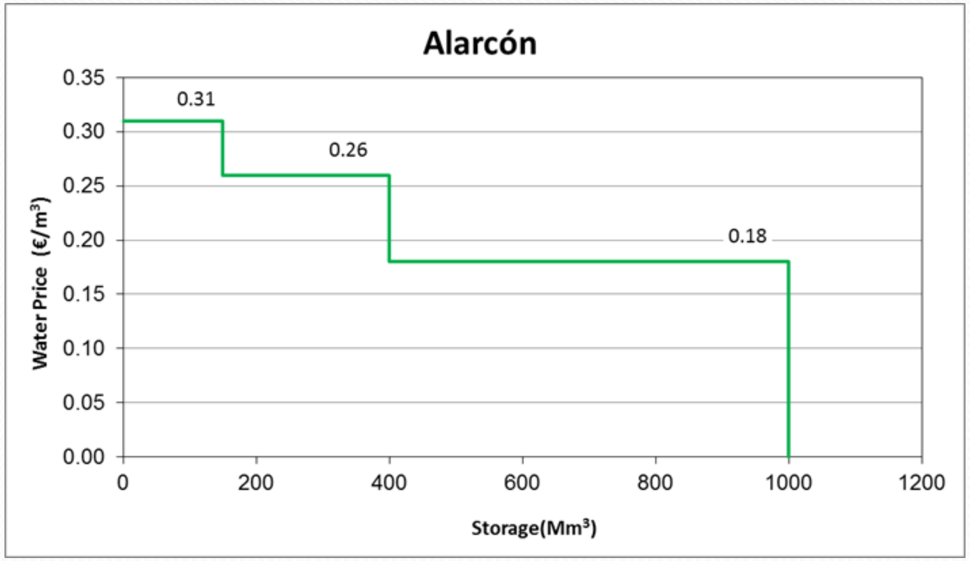


SCENARIO 2: Scarcity Water Pricing Policies

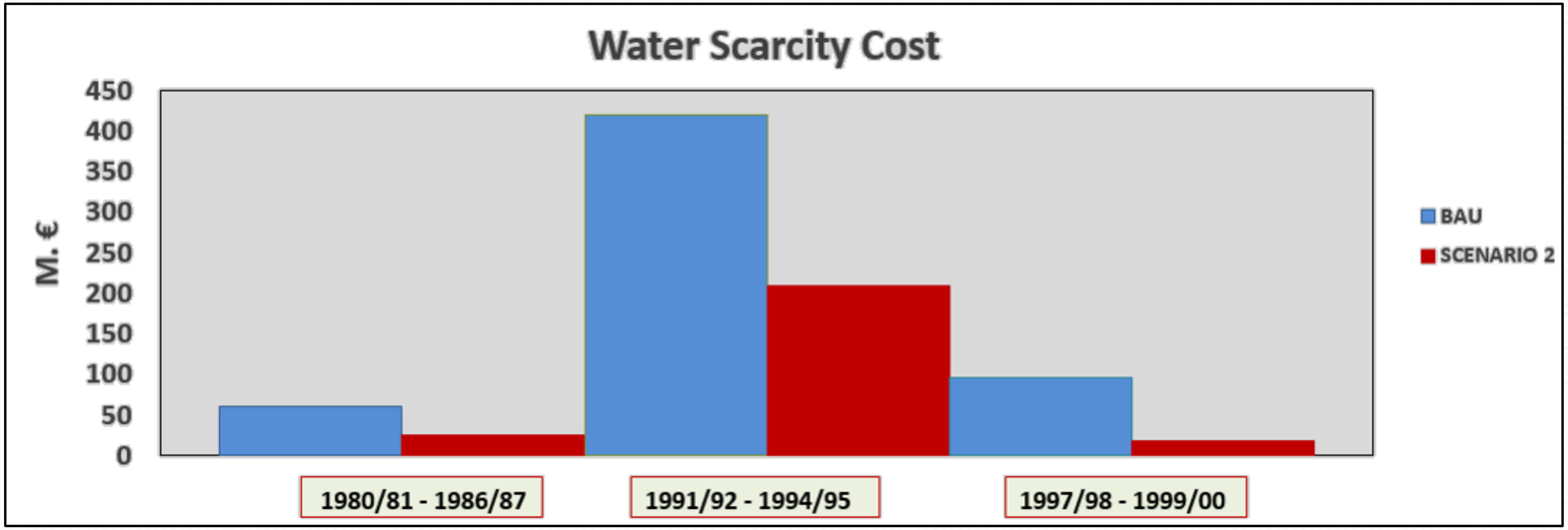
Drought period: higher values

Alarcón reservoir





SCENARIO 2: Scarcity-based Water Pricing Policies



- Reduced total economic losses during drought periods
- Reduced revenues of low-value crops during droughs with more water available for high-value crops

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SCENARIO 3: Water Markets

	Water Scarcity Costs (M.€)
Acequia Real Júcar orange trees	0
Mancha Oriental Irrigation District	1.78
Sueca orange trees	0
Cuatro Pueblos I.D. orange trees	0
Cullera orange trees	0
Canal Jucar-Turia	0
Acequia Real Júcar rice	18.03
Sueca rice	12.4
Cuatro Pueblos I.D. rice	0.88
Cullera rice	8.76
Escalona	0
Albacete	0
Valencia	0
Sagunto	0

↓ scarcity cost

Rice 0.05 €/m³ High opportunity cost
(without ⊂ environmental benefits)

Citrus 0.8 €/m³ Low opportunity cost

APPLICATION 5:

IMPACTS & ADAPTATION to Climate Change

Application to Jucar River basin (Spain) – Orb River Basin (France)

Global Environmental Change 34 (2015) 132–146

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

Integrating top–down and bottom–up approaches to design global change adaptation at the river basin scale

Corentin Girard[a,*], Manuel Pulido-Velazquez[a], Jean-Danie
Yvan Caballero[b]

Environmental Modelling & Software 69 (2015) 42–54

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

An interdisciplinary modelling framework for selecting adaptation measures at the river basin scale in a global change scenario

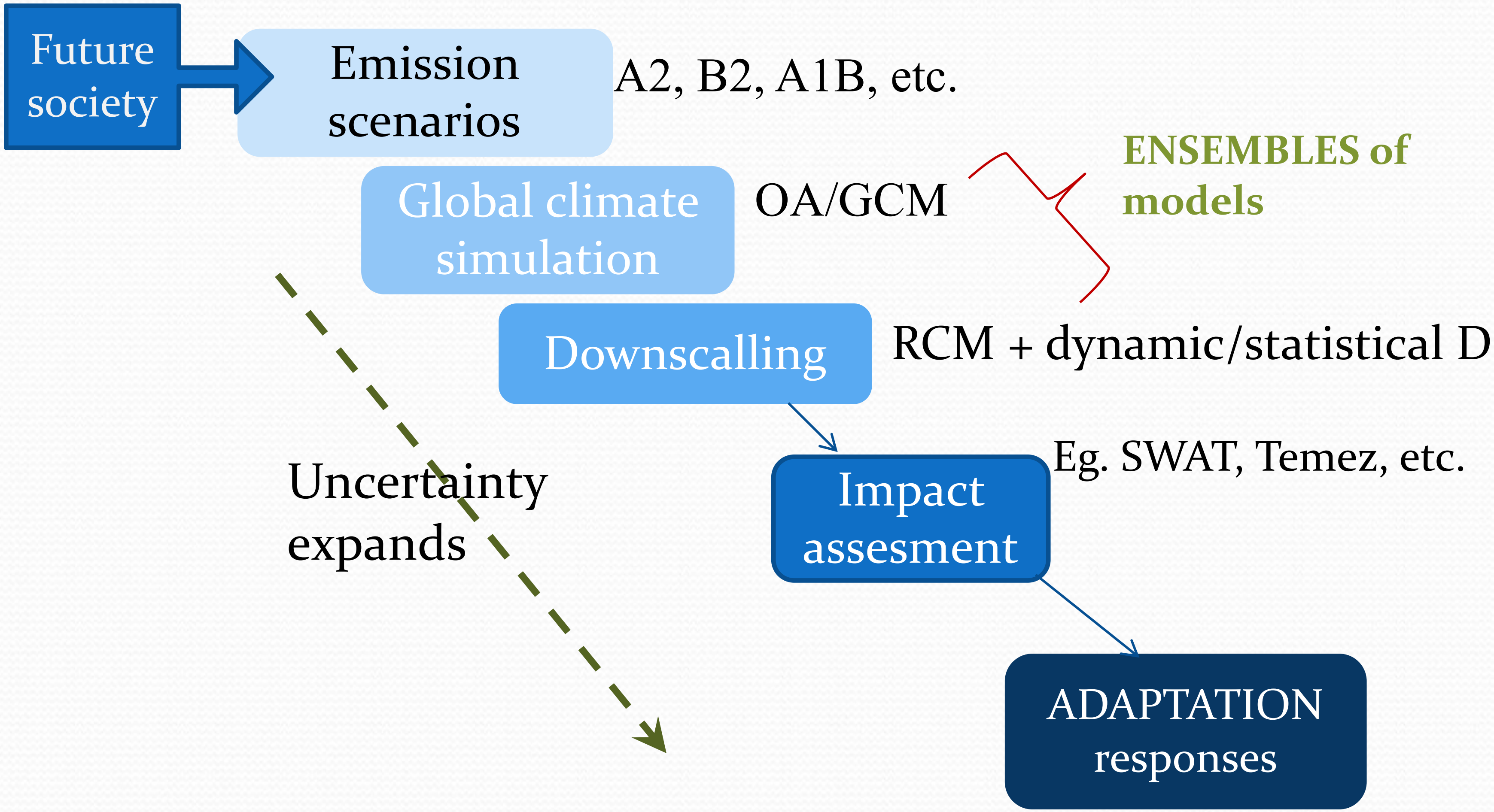
CrossMark

Corentin Girard [a,*], Jean-Daniel Rinaudo [b], Manuel Pulido-Velazquez [a], Yvan Caballero [b]

[a] *Research Institute of Water and Environmental Engineering (IIAMA), Universitat Politècnica de València, Camino de Vera s/n, Valencia 46022, Spain*
[b] *BRGM, French Geological Survey, 1039 rue de Pinville, 34000 Montpellier, France*

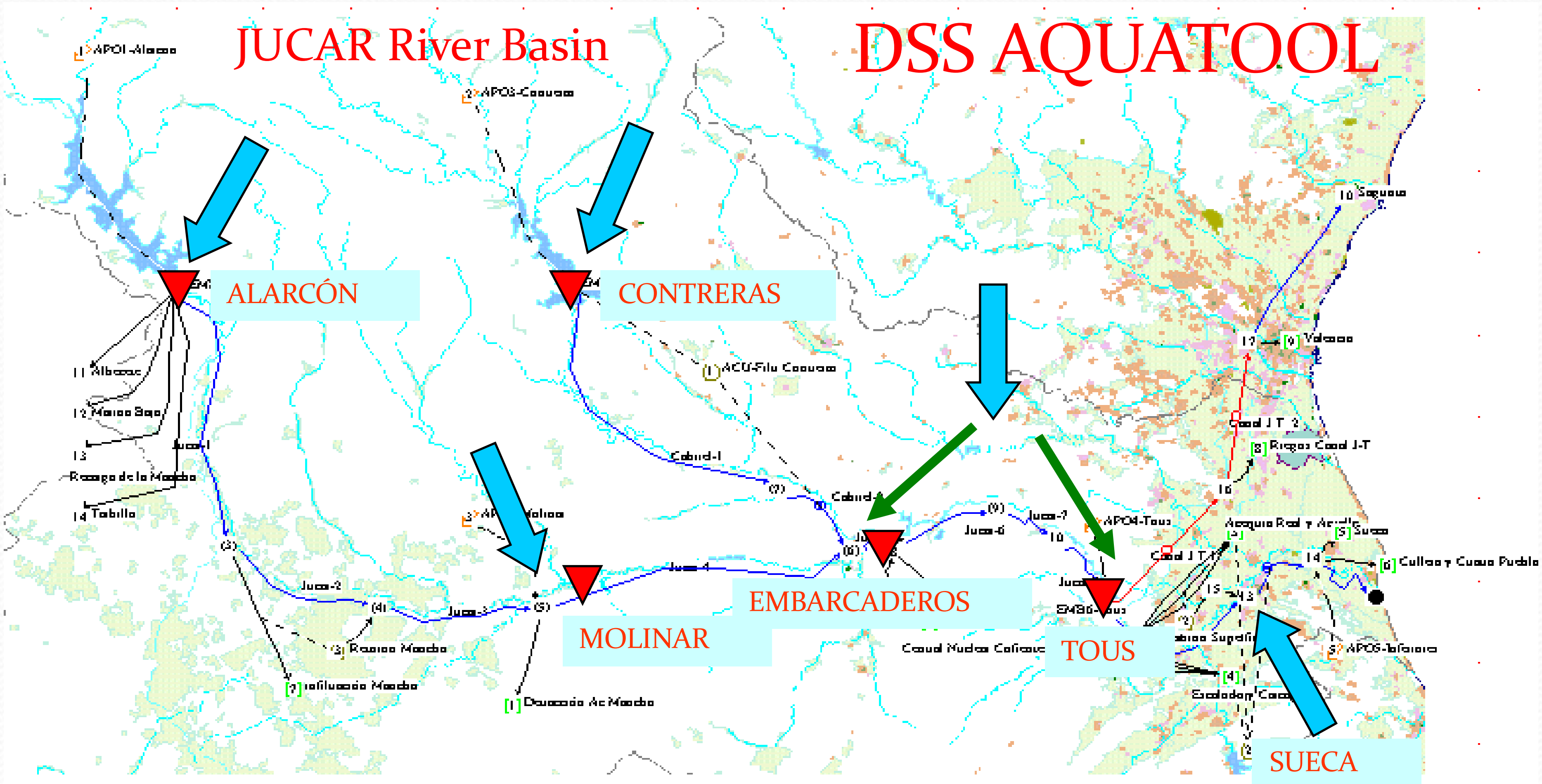
From climate change to adaptation strategy

TOP-DOWN ("scenario-led") **APPROACH** Global -› Local



Simulation of water management for:

- Base case
- New future inflow & demands scenarios



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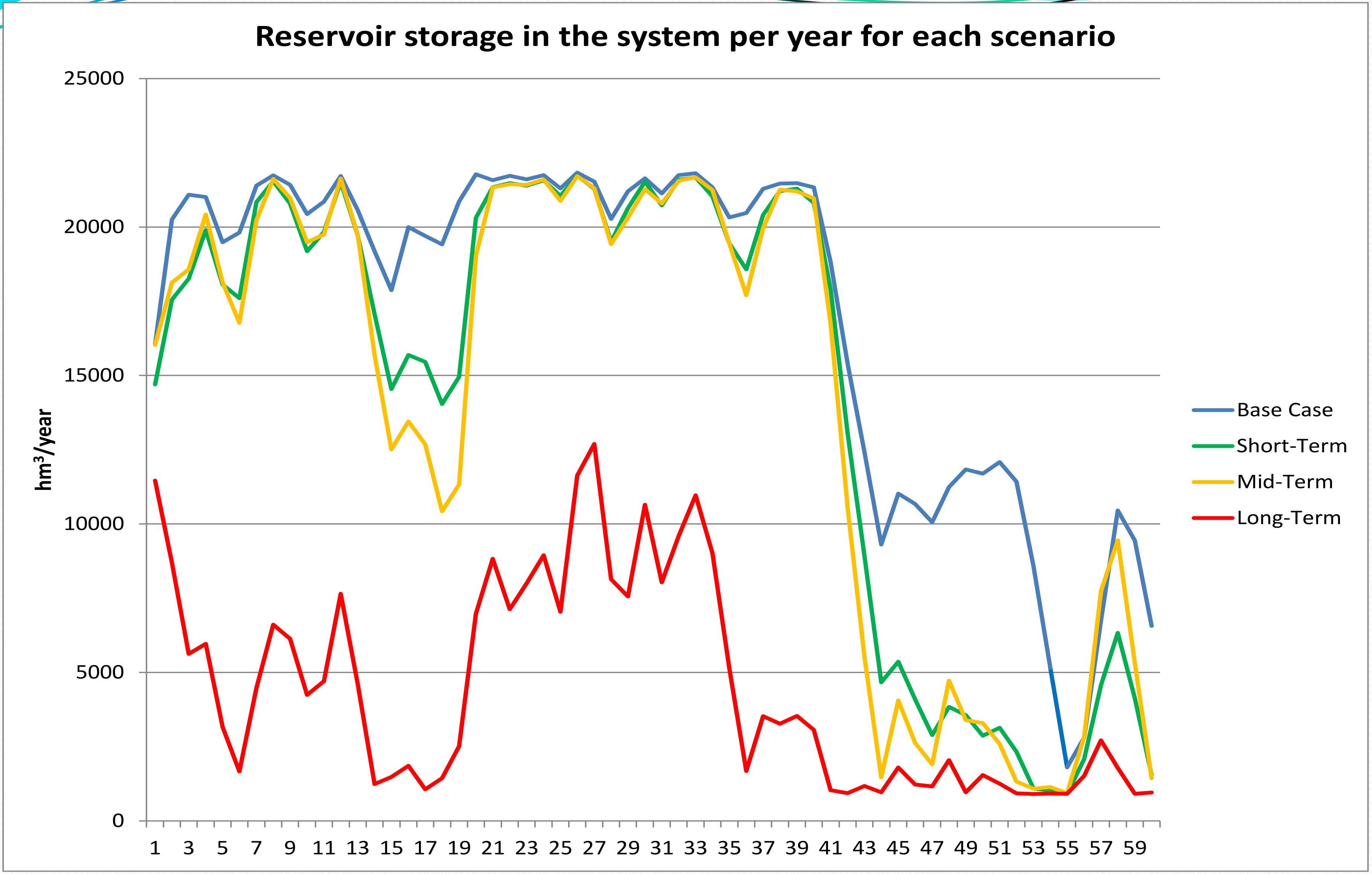
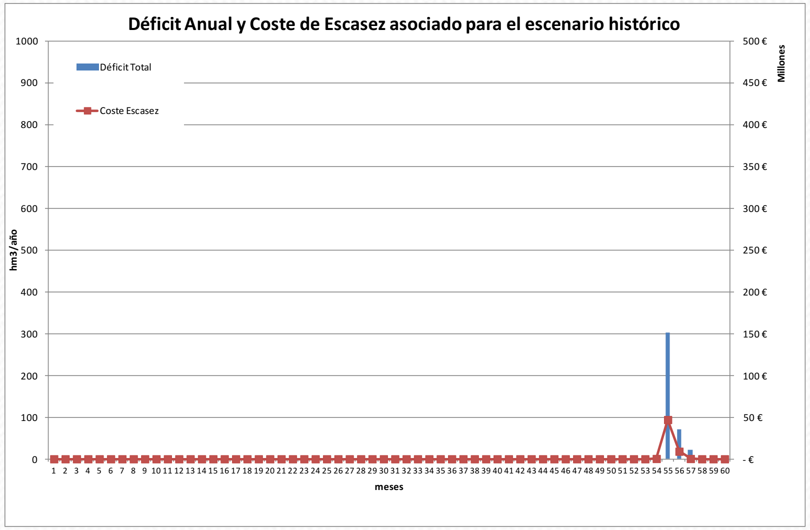
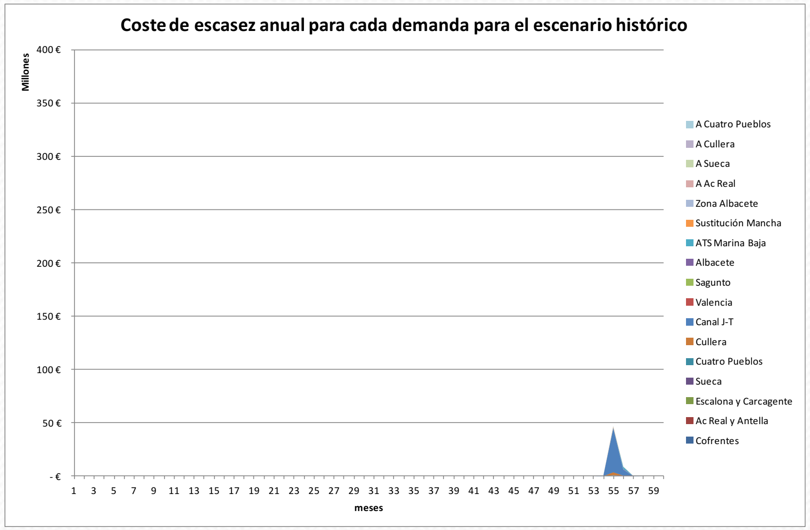
SIMULATION RESULTS



Deficits & scarcity cost



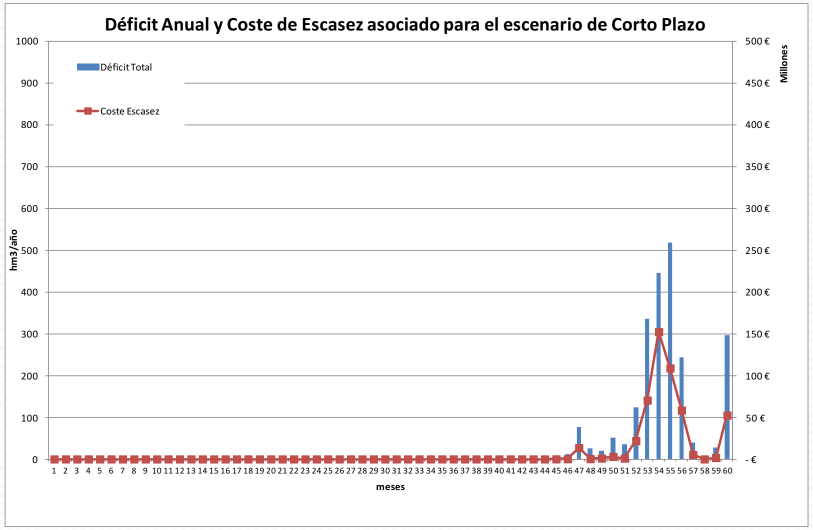


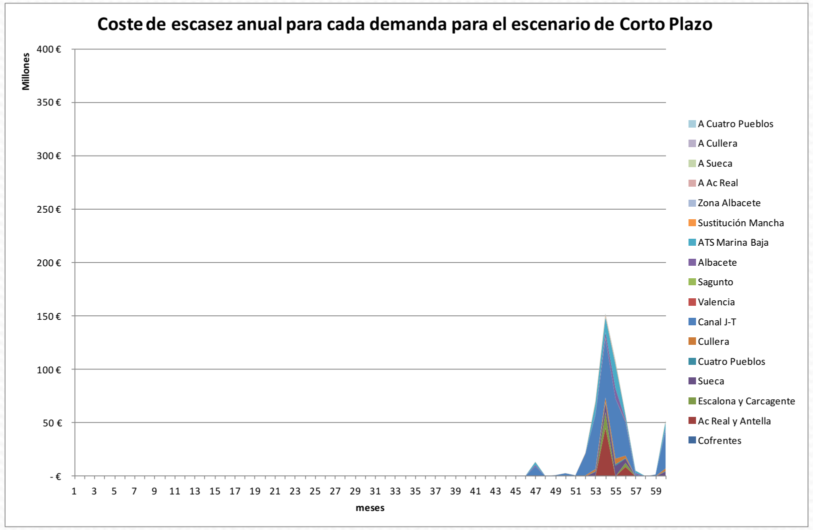
Historical scenario

Lumped deficit and scarcity cost

Per demand

Deficits & scarcity cost





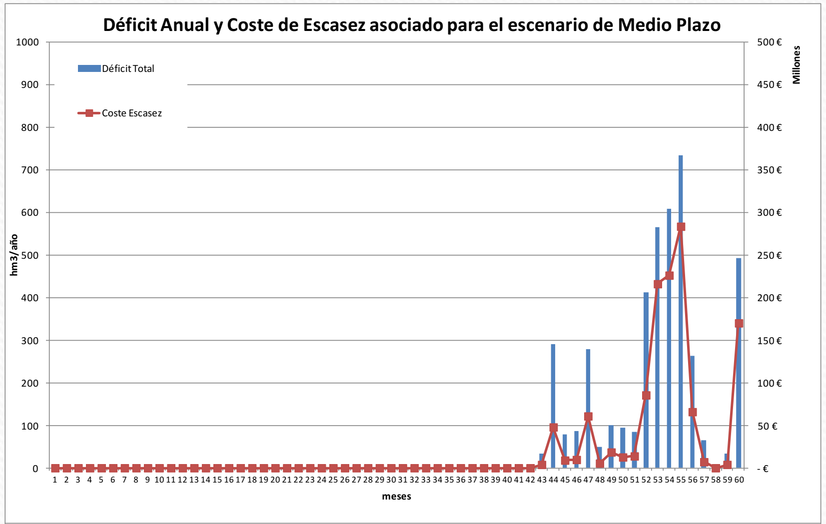
Short-term

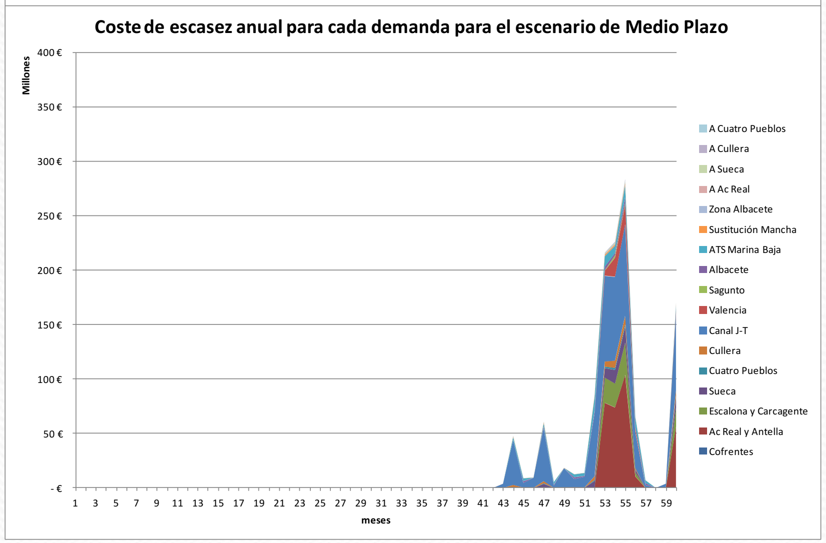
(2011 – 2040)

Lumped deficit and scarcity cost

Per demand

Deficits & scarcity cost





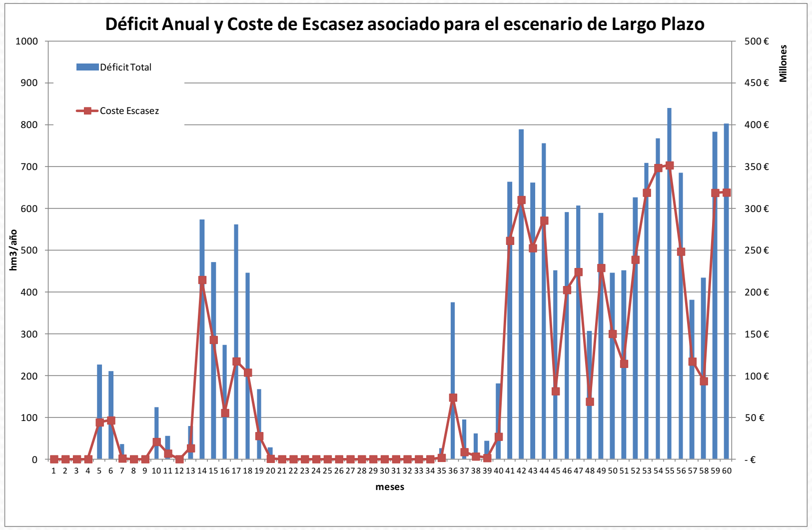
Medium-term

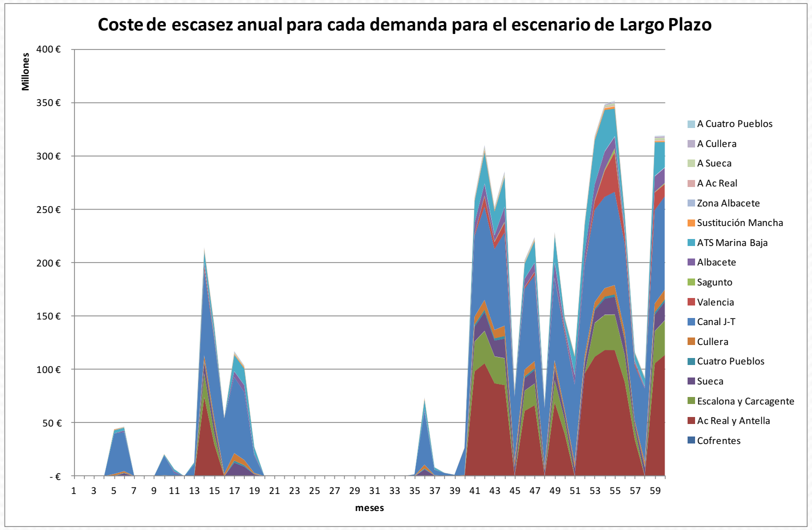
(2041 – 2070)

Lumped deficit and scarcity cost

Per demand

Deficits & scarcity cost





Long-term

(2041 – 2070)

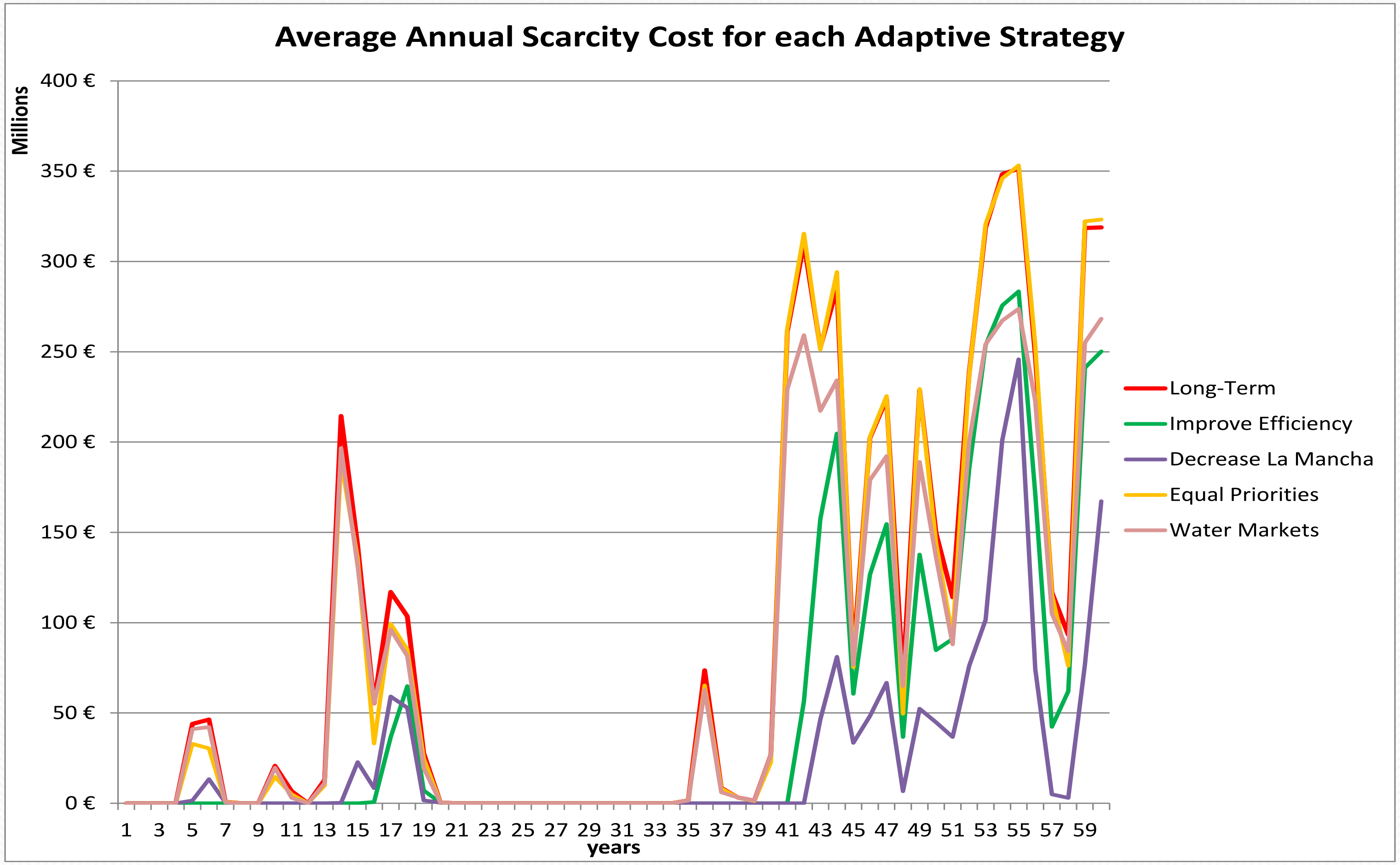
Lumped deficit and scarcity cost

Per demand

Analysis of ADAPTATION STRATEGIES

- **DEMAND management options**:
  - **Efficiency** improvements in ***Ribera del Júcar*** irrigation D
  - Reduction of Mancha Oriental demand through **water pricing**: [0,06 €/m3 -> 75% reduction]

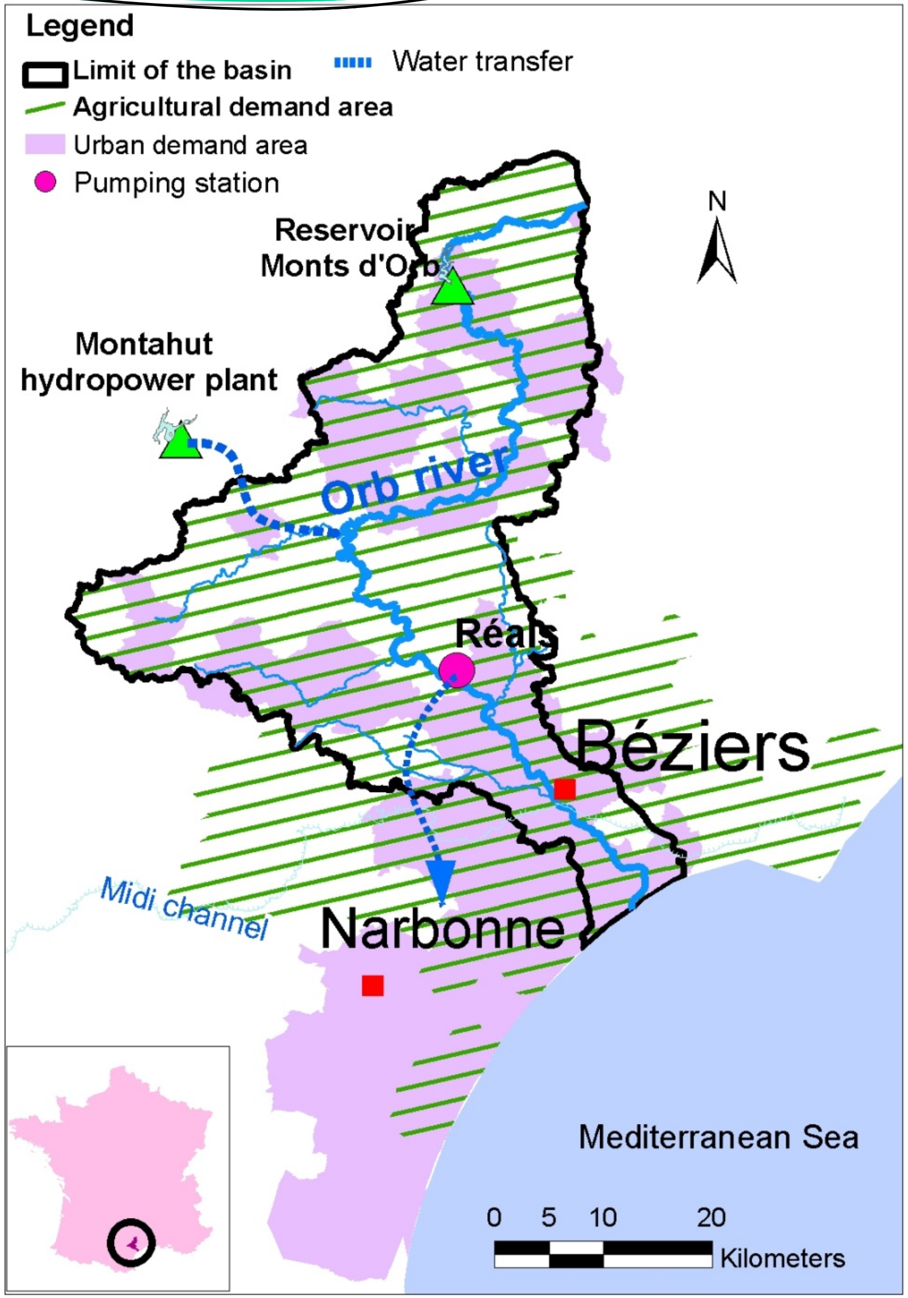
- **System mngmt. options:**
  - Change in **priorities**
  - Water **markets**



Climate change adaptation in Orb river basin
(southeast France)

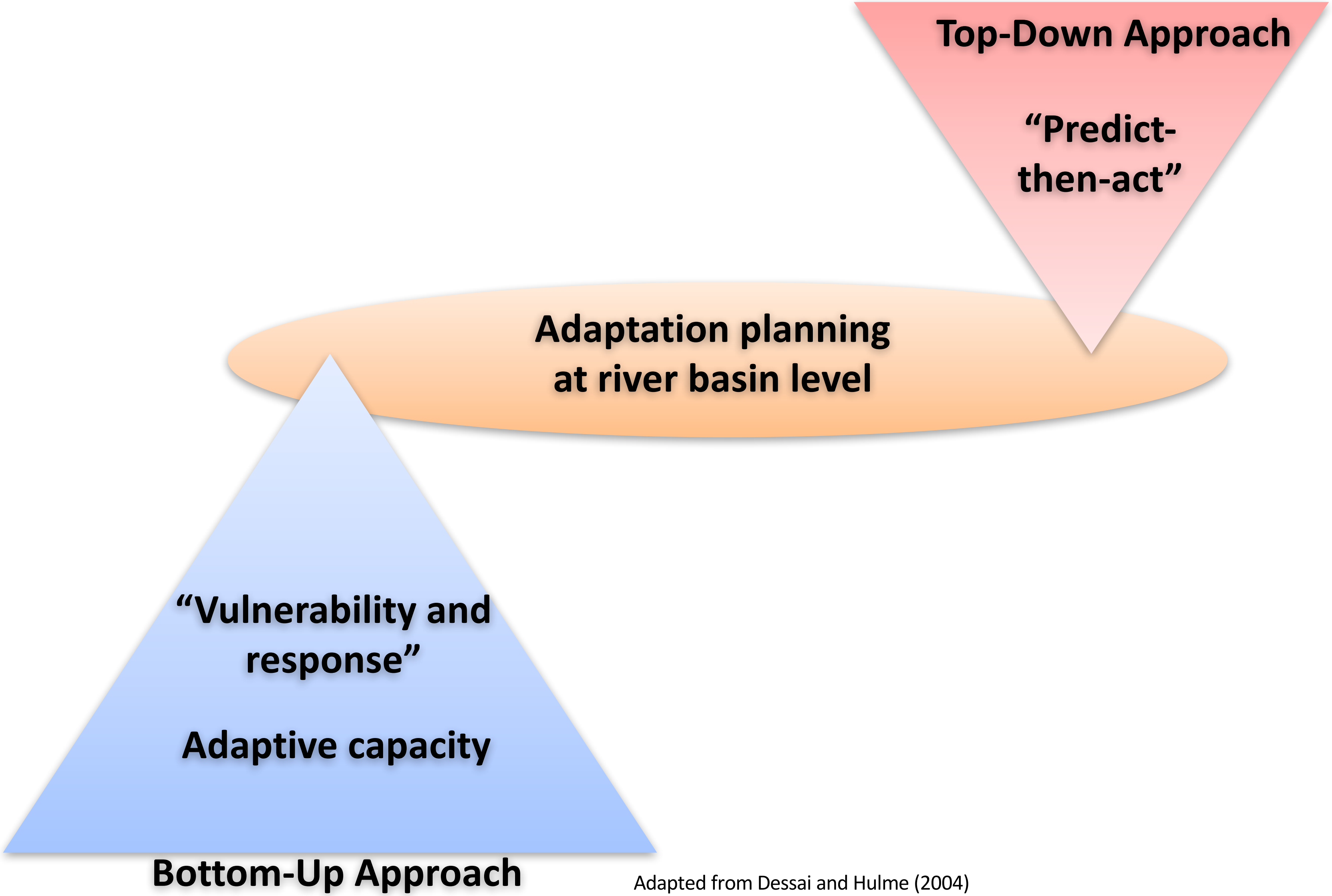
- Mediterranean basin (1580 km^2)
- High pop growth (+1.4%)
- Development of irrigated vineyard
- Monts d'Orb reservoir (30.6 Mm^3)
- 2 inter-basin transfers

Threaten by impact of CC on WRs

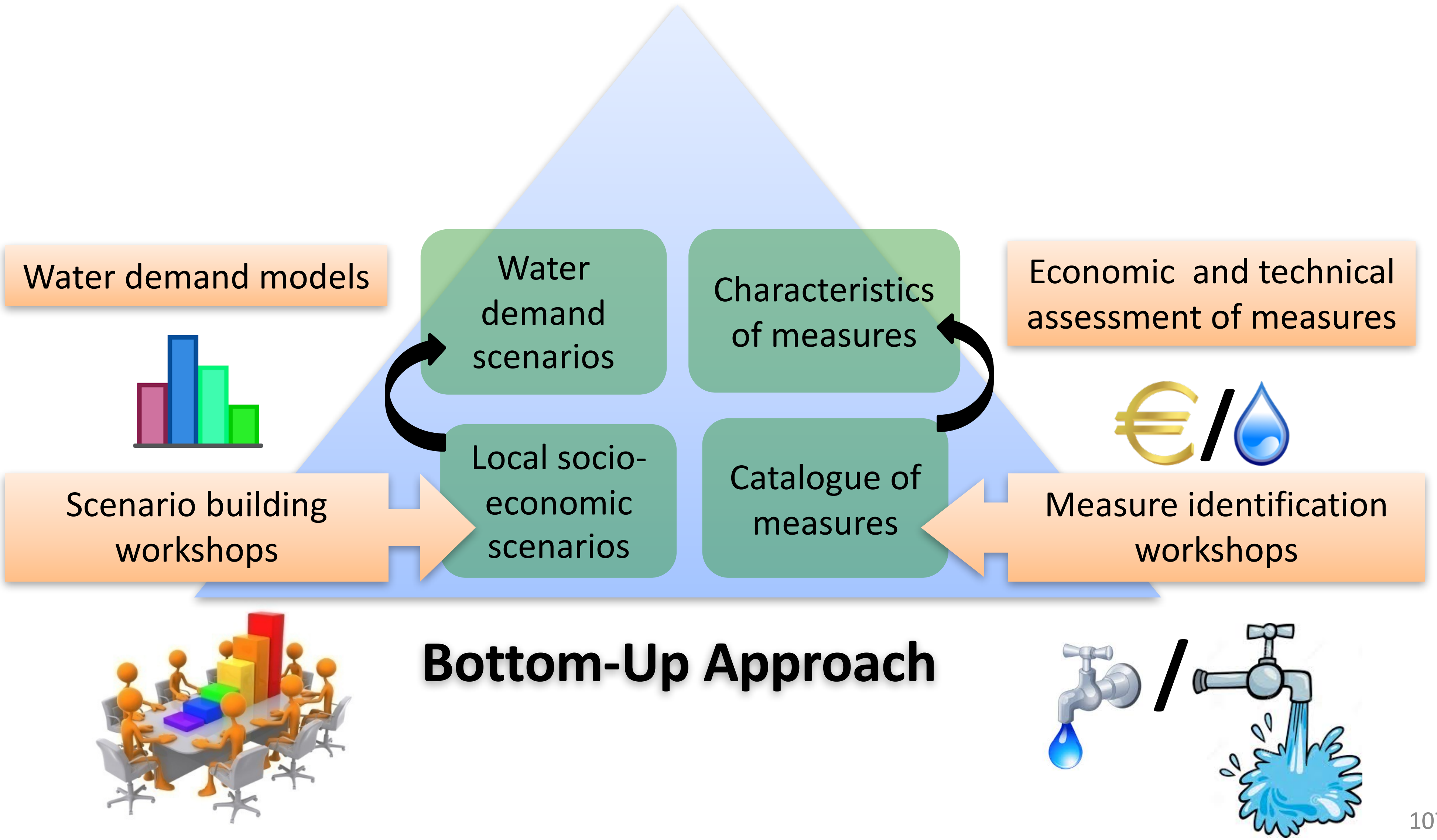


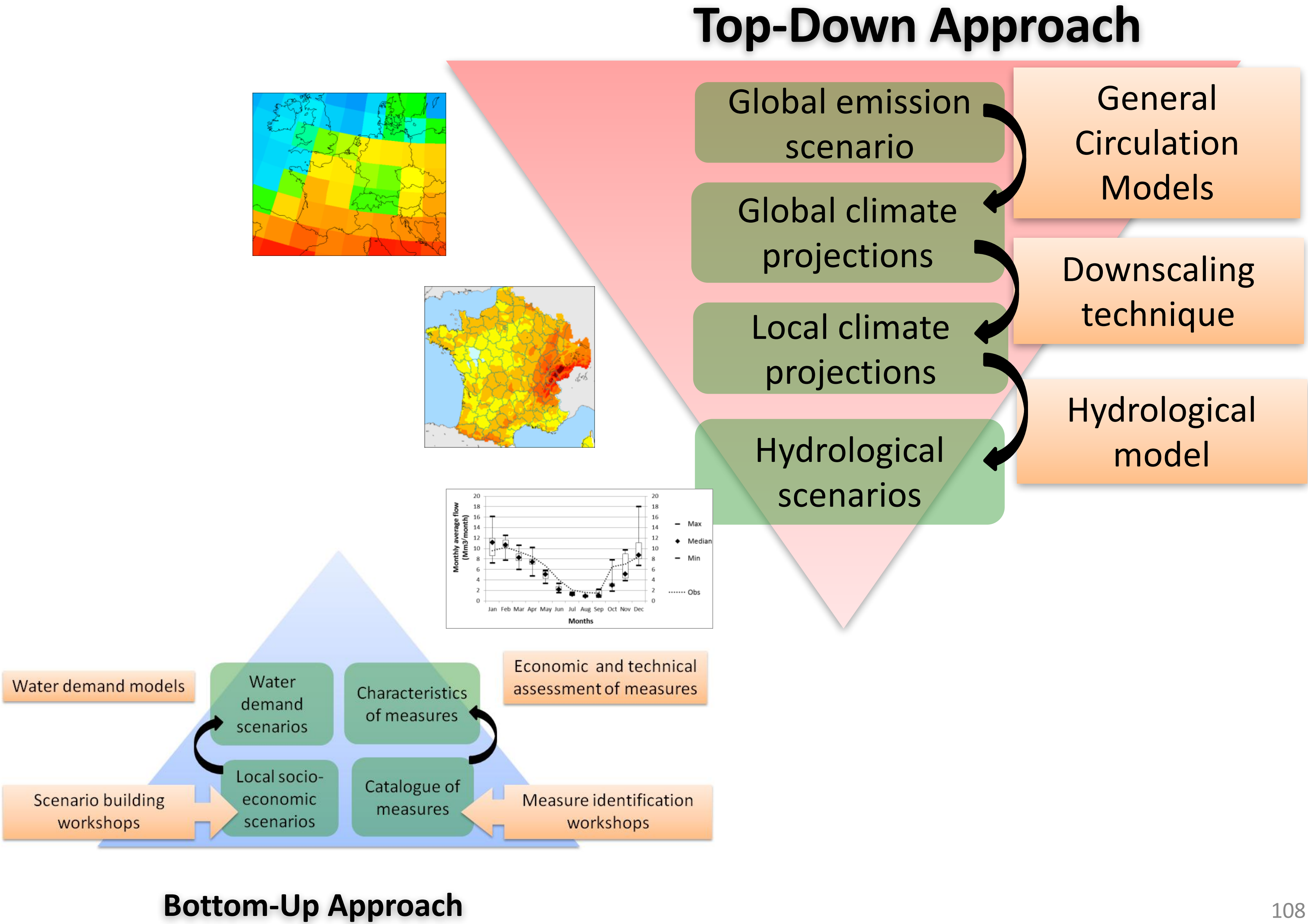
River basin adaptation plan ??

Top-down and bottom-up approaches



Adapted from Dessai and Hulme (2004)


Water demand models
Water demand scenarios
Characteristics of measures
Economic and technical assessment of measures
Local socio-economic scenarios
Catalogue of measures
Scenario building workshops
Measure identification workshops
€/
/
Bottom-Up Approach


Top-Down Approach
Global emission scenario
Global climate projections
Local climate projections
Hydrological scenarios
General Circulation Models
Downscaling technique
Hydrological model
Monthly average flow (Mm3/month)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Months
Max
Median
Min
Obs
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Local socio-economic scenarios
Catalogue of measures
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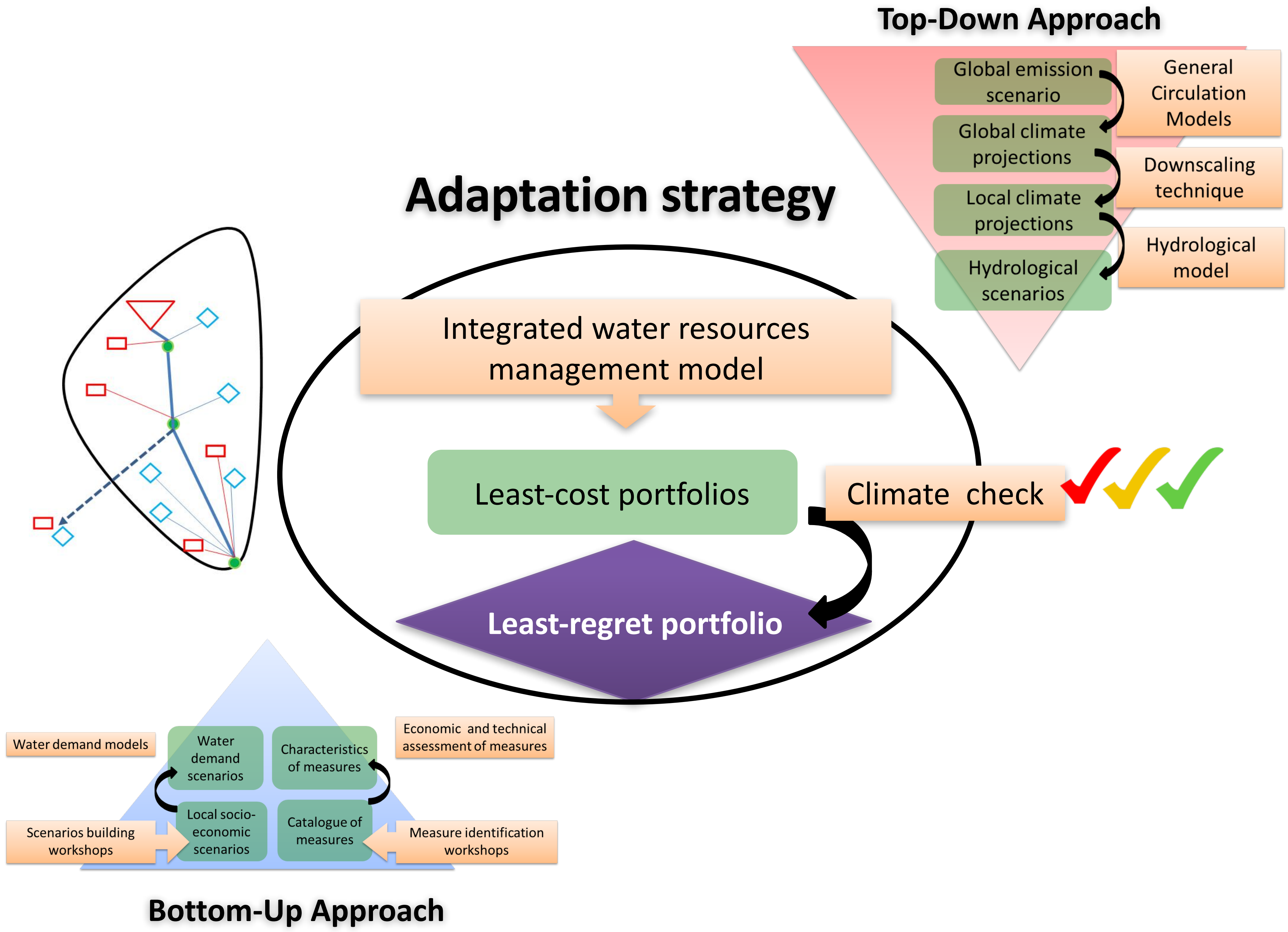
Bottom-Up Approach


Top-Down Approach
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Adaptation strategy
Integrated water resources management model
Least-cost portfolios
Climate check
Least-regret portfolio
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Catalogue of measures
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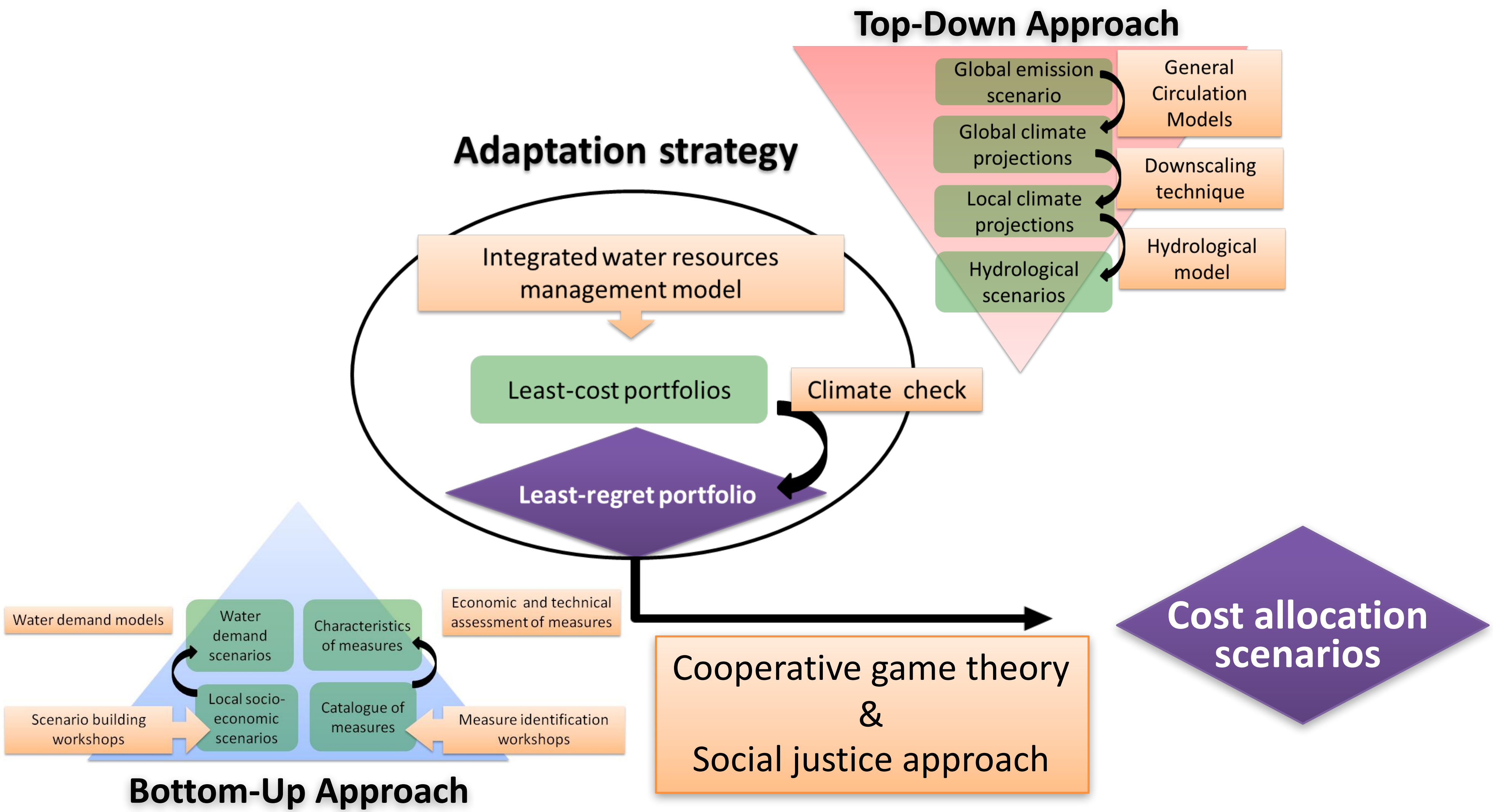
Measure identification workshops
Bottom-Up Approach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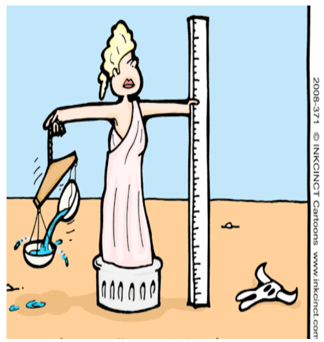
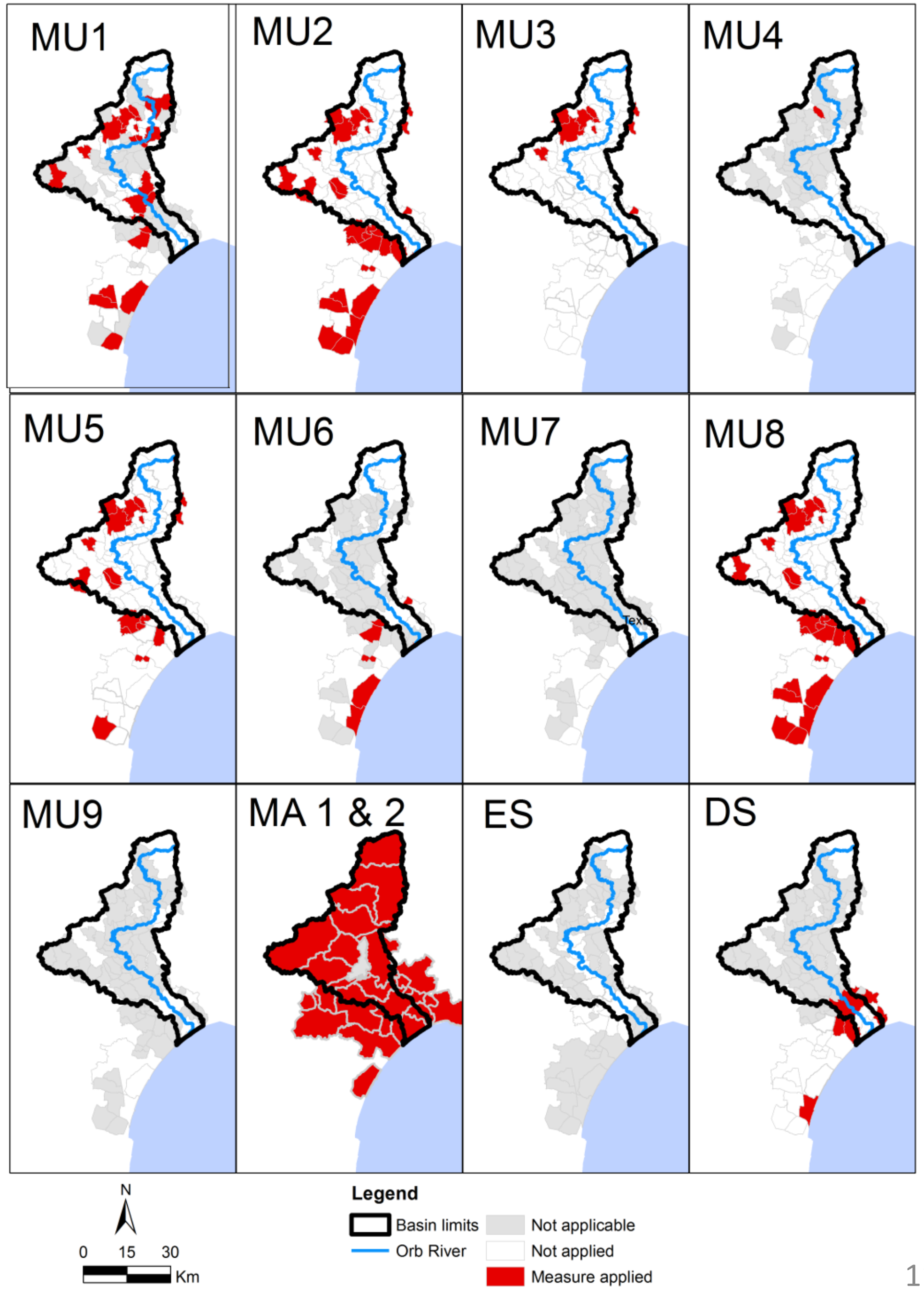
Bottom-Up Approach
Cooperative game theory
&
Social justice approach
Cost allocation scenarios



Least-cost portfolio

Id.	Measures
MU1	Water network efficiency improvement
MU2	Water saving kits (individual housing)
MU3	Audit collective housing
MU4	Water saving kits (collective housing)
MU5	Peak pricing
MU6	Water saving kits (Hotels)
MU7	Campsite audits
MU8	Mediterranean vegetation
MU9	Artificial turf
MA1	Gravity to sprinkler irrigation
MA2	Drip irrigation
GW	Groundwater projects
DS	Desalination projects



Climate check

(Girard, et al. 2015c GEC)

- Indicator of robustness in the selection of measures

Id.	Measures
MU1	Water network efficiency improvement
MU2	Water saving kits (individual housing)
MU3	Audit collective housing
MU4	Water saving kits (collective housing)
MU5	Peak pricing
MU6	Water saving kits (Hotels)
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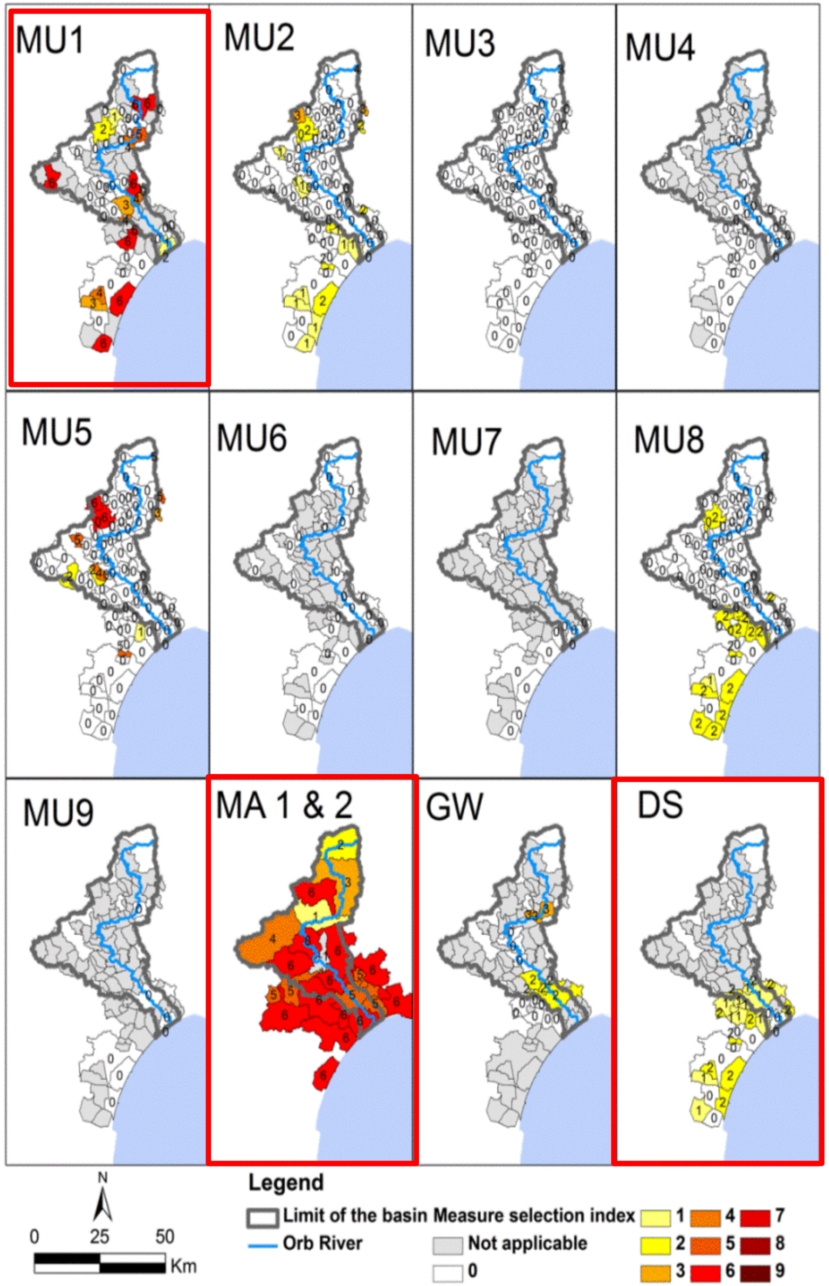
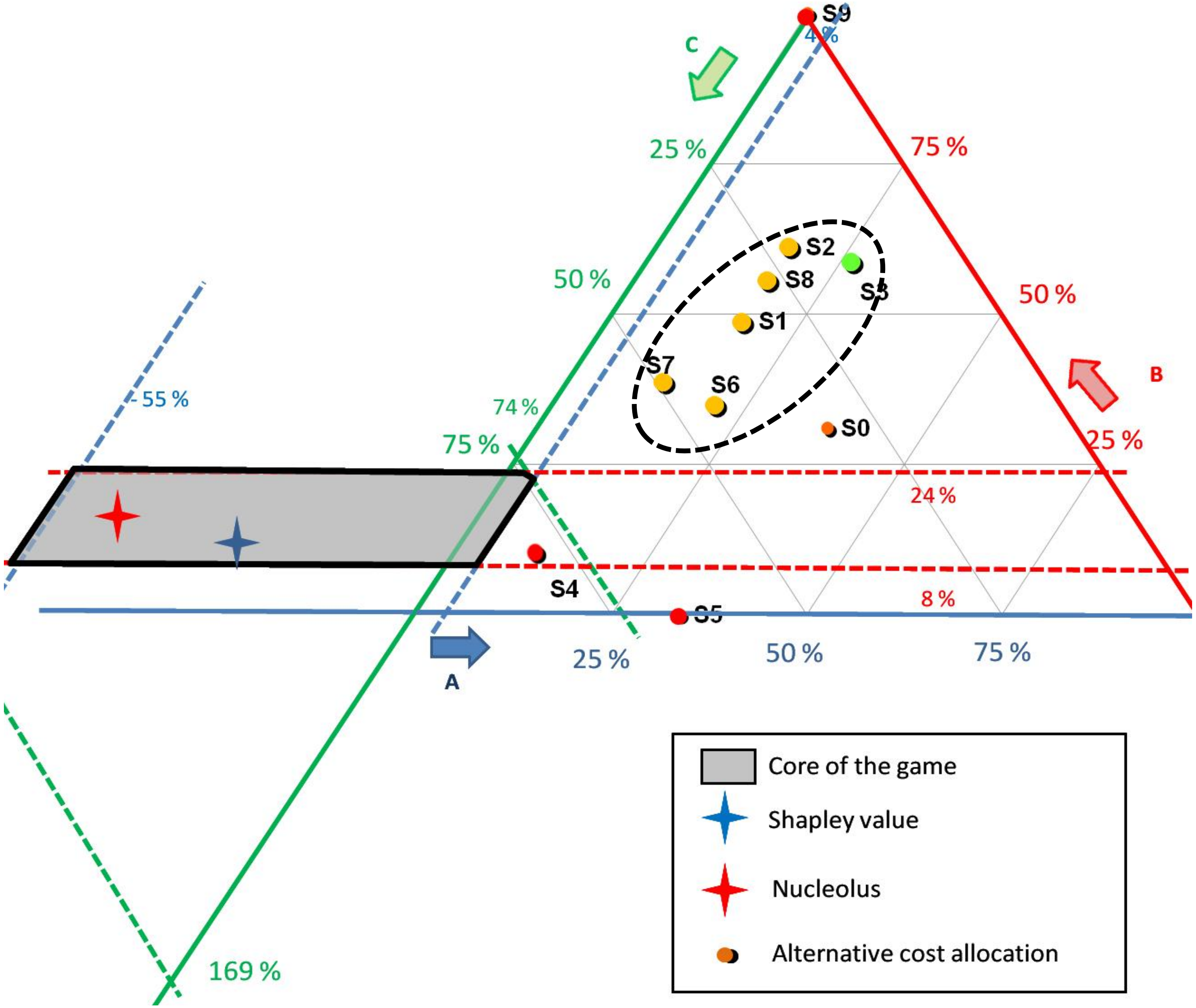


Distribution of the measures applied in the Orb River basin under 9 different climate projections.

Cost allocation

- Comparing CGT and SJ approaches



HEM's

LIMITATIONS, CHALLENGES, CONCLUSIONS

HEM's LIMITATIONS, CHALLENGES, CONCLUSIONS:

- Many … ***HEM,*** much more than just ec optimization of water allocation (profit-maximizing behavior). ***Simulation*** & ***Optimization***. ***Many applications.***
- Even simple HEM, despite their limitations, can contribute to integrated understanding & significant policy ***insights***.
- To be based on a ***sound hydrologic and economic modelling*** to yield realistic results
- New ***trends***: combination with **agent-based modelling** (non-economic drivers-individual behaviors) / **multicriteria approaches** (non-economic measures of system performance – visualization of tradeoffs)

Integrated modelling of dem
and supply. The role of
hydroeconomic mod

THANK YOU FOR YOUR ATTENTION !!!

Manuel Pulid uzquez

Smart S s for Water Management

22-2 2016, Monte Verità, Switzerland

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