Assessing Future Scenarios of Global Change, Impacts And Adaptation Measures in Water Resources Systems

Hydroeconomic Modelling and Impacts and Adaptation to Climate and Land Use Changes

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Proyecto "Sustainability and Adaptation of WAter REsource Systems to long-term future scenarios" (SAWARES)

PLAN NACIONAL I+D+i 2008-2011

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Granada, 25 de junio de 2013

CONTENT:

- Introduction. Adaptation of WRS to CLUC
- Hydroeconomic models: concepts, tools, potential
- Ex.1. Adaptation in ***Jucar RB*** management
- Ex. 2. Adaptation in ***California WRS***
- Ex.3. Least-cost optimization for ***Orb RB***
- Ex.4. HEM framework for ***Mancha Oriental*** (nitrates)
- Conclusions

INTRODUCTION.
ADAPTION toCLIMATE CHANGE

STATIONARITY IS DEAD !!

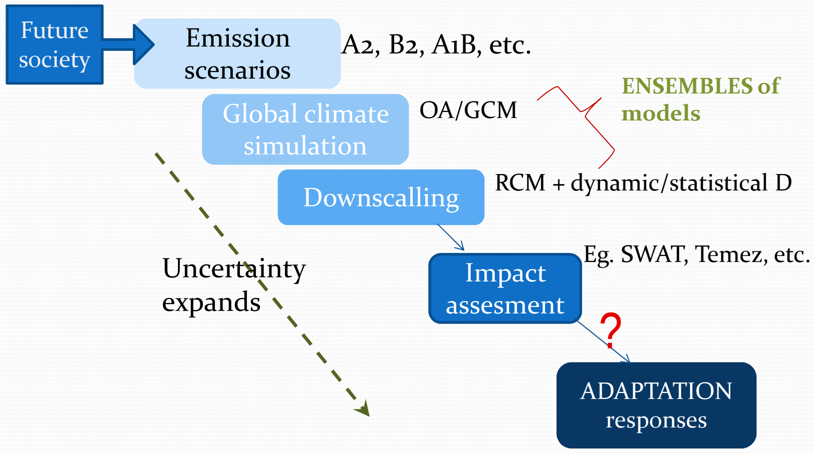
"In view of the magnitude and ubiquity of the hydro-climatic change apparently now under way, we assert that **stationarity is dead and should no longer serve as a central, default assumption** in water-resource risk assessment and planning."

(*Milly et al., 2008*)

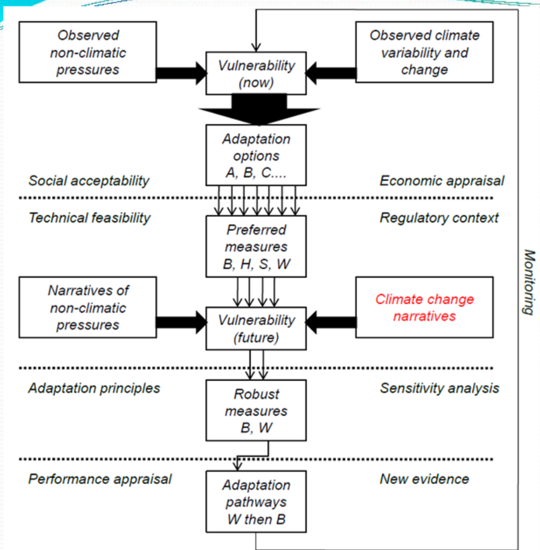
HOW BEST TO MOVE FORWARD ?

From climate change to adaptation strategy

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



BOTTOM-UP ("vulnerability-based") APPROACHES



Source: Wilby & Dessai (2010)

Local –> Global

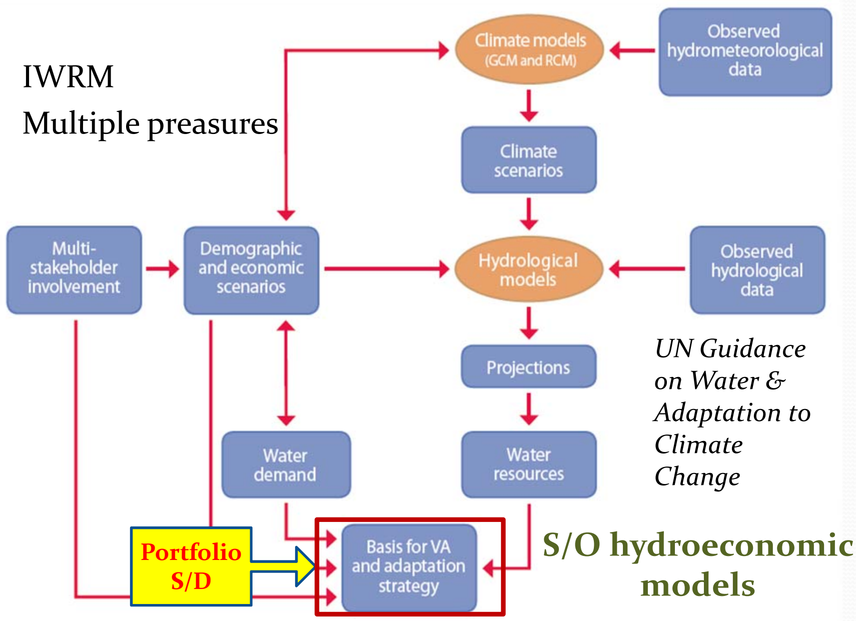
- High uncertainty & vulnerability
- Simply coping w/ present climate variability is more than a challenge

Some key MESSAGES from UN Guidance (2009):

- **No delay** (WRS vulnerable & can be strongly affected)
- **Uncertainty,** no reason for **inaction**
- Adaptation, **flexible** (uncertainties).
- **IWRM approach**
- CC, **one of many** pressures on WR (pop growth, ag. & industrial developments, Δ consumption patterns, etc.)
- **PRIORITIZATION** of measures based on: **vulnerability - CB assessments**, development **objectives**, **stakeholder** considerations, **resources** availability
- **Effective adaptation, MIX of strategies** (structural & non-structural, regulatory & ec. instruments, education & awareness)

COMBINED TOP-BOTTOM APPROACH

- IWRM
- Multiple preasures



HYDROECONOMIC MODELS.

CONCEPT, CLASSIFICATION, POTENTIAL

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EU WFD & ECONOMICS (EC, 2000)

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

- Economic principles (e.g. cost recovery, the polluter pays principle)
- Economic tools & methods (e.g. CEA, CBA)
- Economic instruments (new water pricing policy)

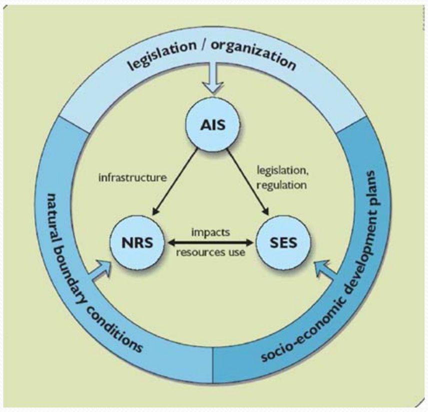
HYDRO-ECONOMIC MODELLING

WRM involves influencing and improving interactions between:

- **Natural** system
- **Socio-economic** system
- The **legal-institutional** system

HEM - models representing those interactions

Combination of ***Ec.-Engineer.-Env.*** aspects of WRS → more relevant to policy !



HYDRO-ECONOMIC MODELS

INPUTS

- TOPOLOGY
- HYDROLOGY
- Economic characterization (DEMANDS, operating costs)
- INFRASTRUCTURE
- CONSTRAINTS Institucional Environmental

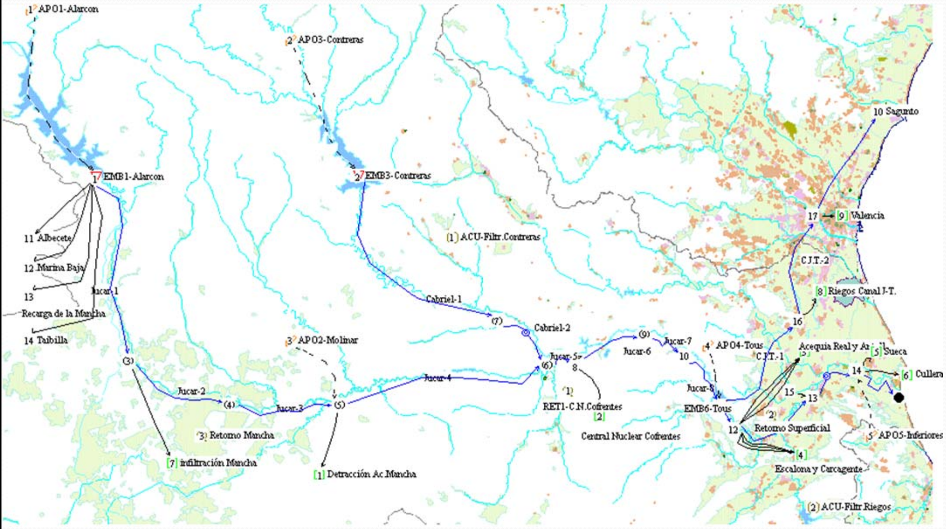
SIMULATION

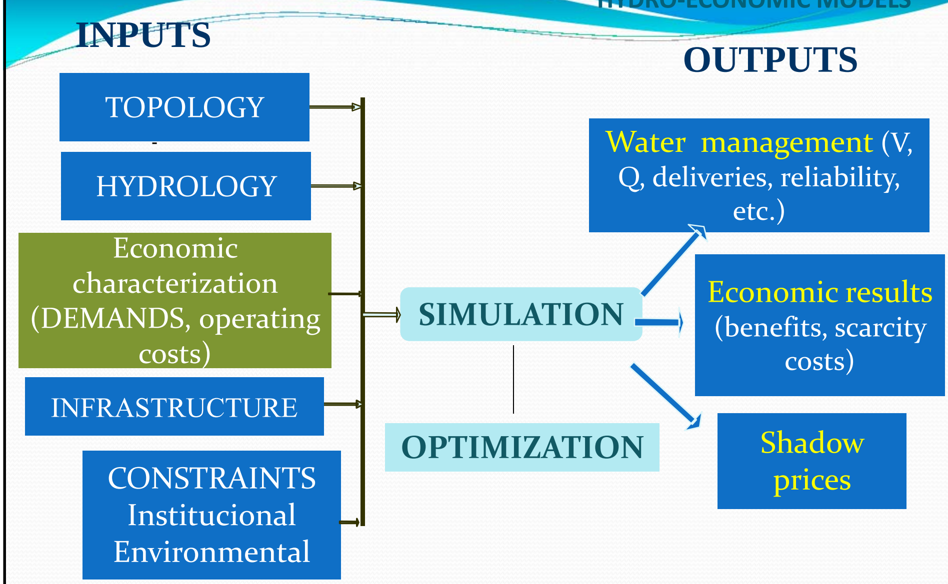
OPTIMIZATION

OUTPUTS

- Water management (V, Q, deliveries, reliability, etc.)
- Economic results (benefits, scarcity costs)
- Shadow prices

Flow Network: nodes & links

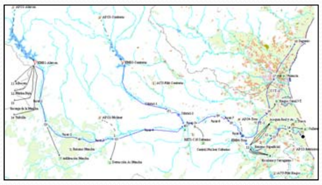




Classification of HEM:

- ***Simulation*** *(a-priori operating rules)* vs
  Ec. Optimization *(max net benefits over a period)*
- *"Ad-hoc" vs.* ***generalized DSS***

ex. **UPV tools**

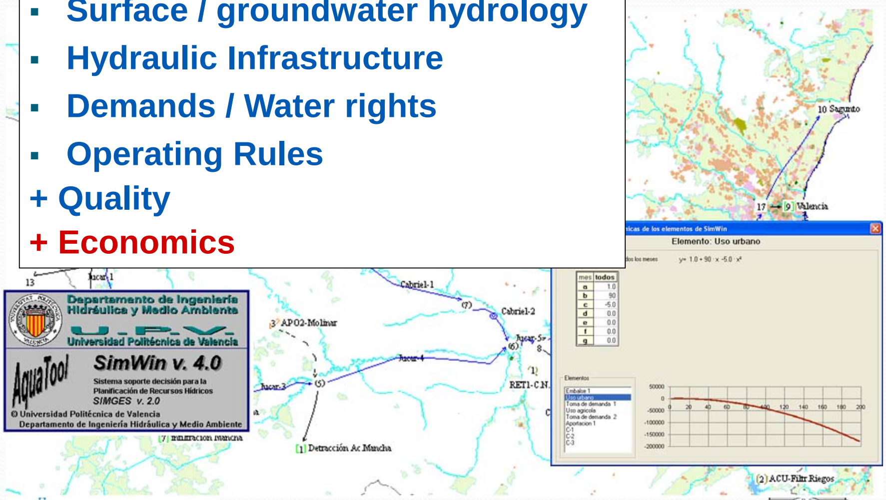


DSS AQUATOOL, INTEGRATED MODELLING

- **Surface / groundwater hydrology**
- **Hydraulic Infrastructure**
- **Demands / Water rights**
- **Operating Rules**

+ Quality

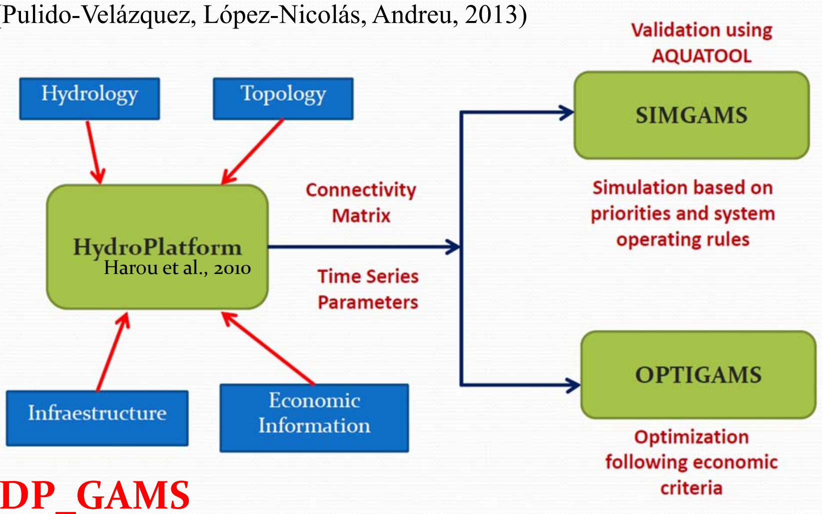
+ Economics



SIMGAMS _ OPTIGAMS

HYDRO-ECONOMIC MODELS

(Pulido-Velázquez, López-Nicolás, Andreu, 2013)



SDP_GAMS

(Héctor Macián y Pulido-Velázquez, 2013)

STOCHASTIC DYNAMIC PROGRAMMING. AVOID PERFECT FORSIGHT EFFECT OF DETERMINISTIC OPTIMIZATION

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Some HEM applications:

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]

[a] Environment Institute and Department of Civil, Environmental and Geomatic Engineering, University College London, Pearson Building, Gouwer Street, London, UK
[b] Departamento de Ingeniería Hidráulica y Medio Ambiente, Universidad Politécnica de Valencia, Camí 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

- Intersectorial water allocation (markets, banks, priorities, etc.).
- Impact and management of DROUGHTS
- DEMAND adaptation
- SUPPLY options (eg. nonconventional sources), new infrastructure
- Economic instruments for WM
- Conflict resolution in transboundary basins
- Land use managements/eg,. floods, water quality, etc.
- **Economic impact of cc and adaptation**

EXAMPLES of HEM & CC adaptation:

- Ex.1. Adaptation in ***Jucar RB*** management
- Ex. 2. Adaptation in ***California WRS***
- Ex. 3. Least-cost optimization for ***Orb RB***
- Ex. 4. HEM framework for ***Mancha Oriental*** (nitrates)

Ex.1. CC adaptation in **Jucar RB**

(tesis Á. Escribá)

A. Escribá, M. Pulido-Velazquez, D. Pulido-Velazquez

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http://www.iiama.upv.es/igme/sawares/sobre.html

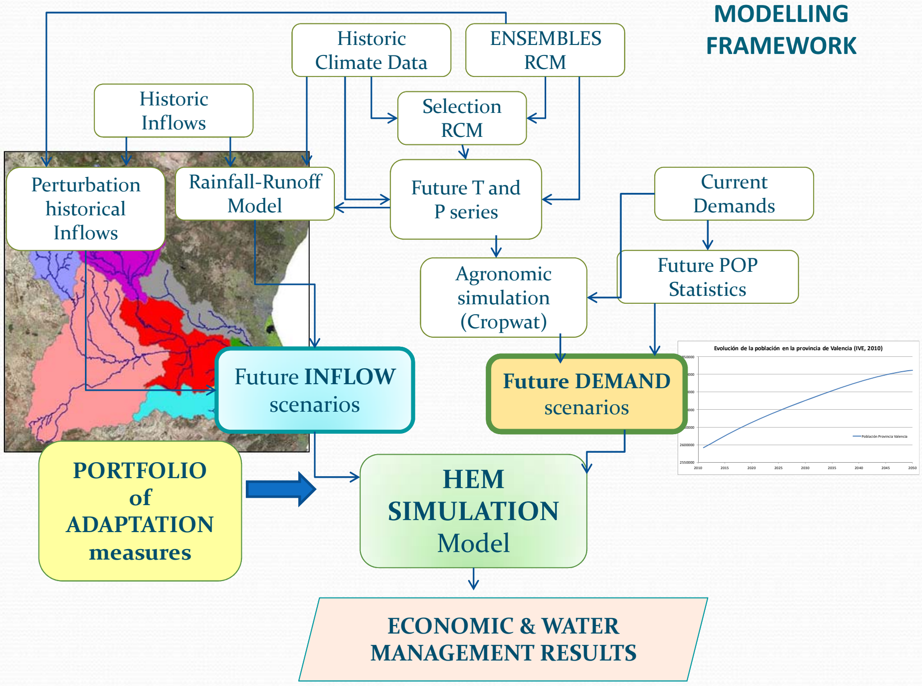
MOTIVATION

- Few studies have assessed economically adaptive strategies to climate change
- Update previsions of impacts with the latest climatic studies (ENSEMBLES, 2009)

OBJECTIVE

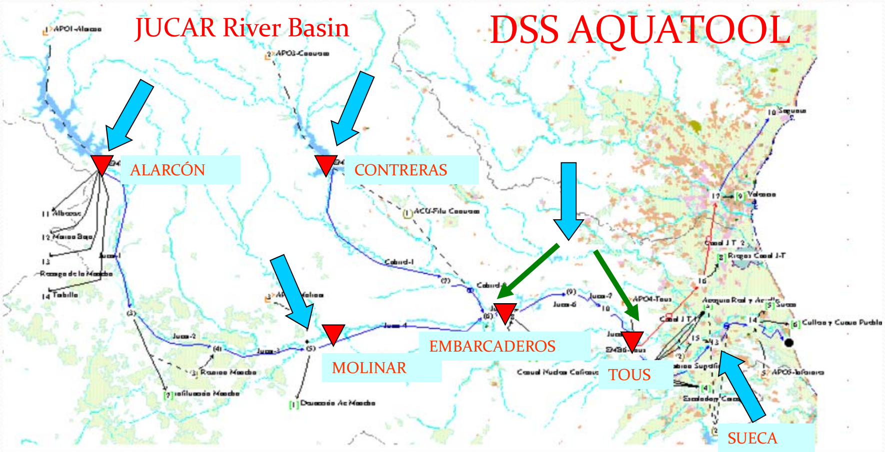
- Develop a methodology to define and assess *adaptive strategies* to climate change in water resource systems
- Short- (2011-2040), Mid- (2041-2070) and LT Scenarios (2071-2100) were compared with the Base Case (1961-1990).

MODELLING FRAMEWORK

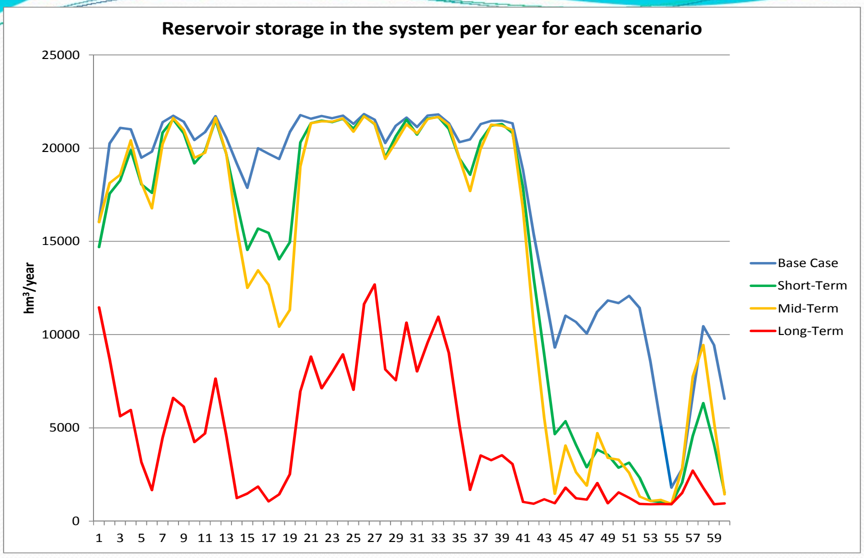


(1) Simulation of water management for:

- Base case
- New future inflow & demands scenarios



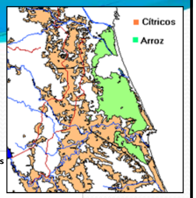
SIMULATION RESULTS

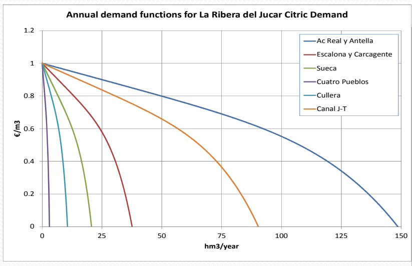


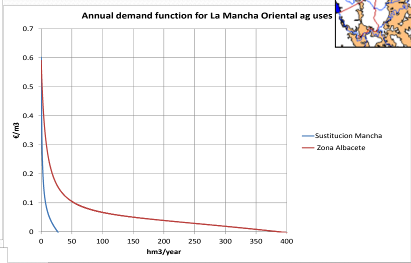
(2) Economic appraisal of BAU scenarios

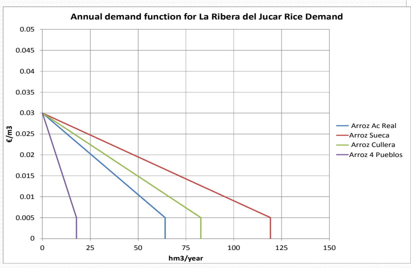
Economic demand curves

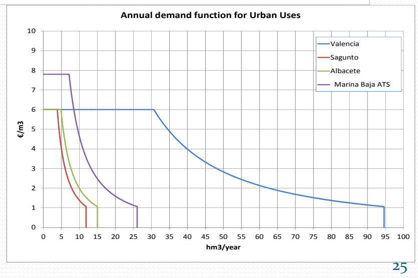
PMP, MultiAttibute method
Point-expansion method











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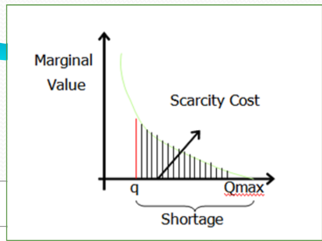
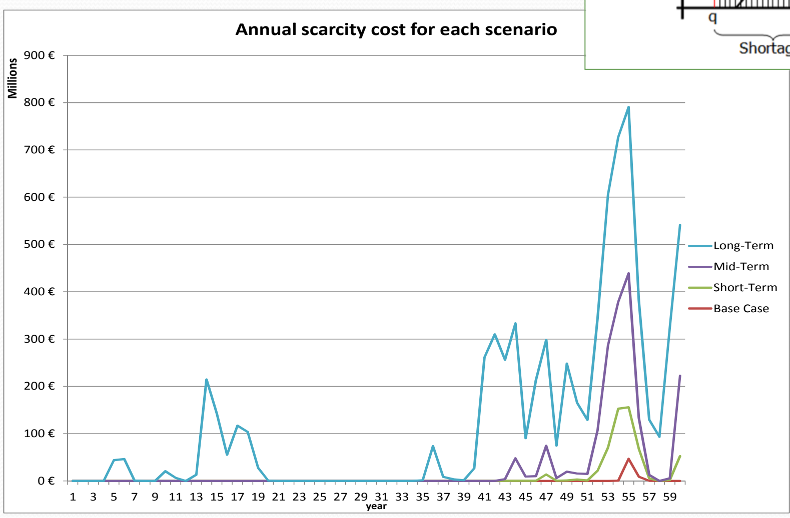
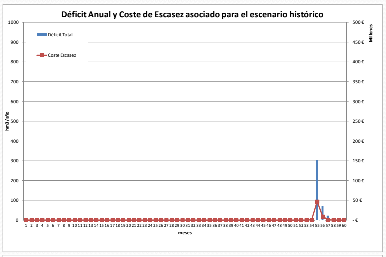
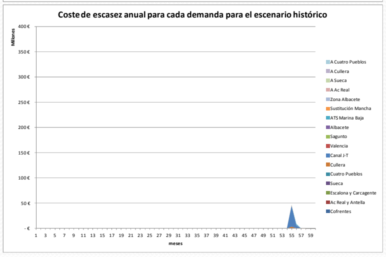
Scarcity cost





Deficits & scarcity cost



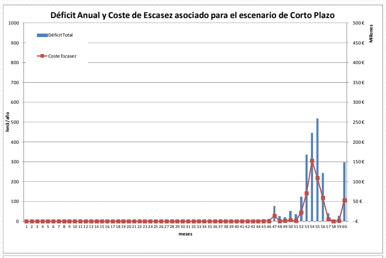


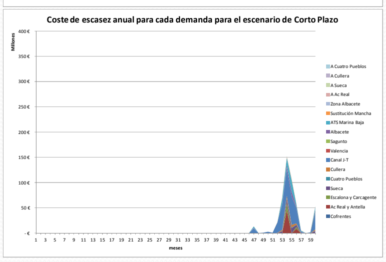
Historical scenario

Lumped deficit and scarcity cost

Per demand

Deficits & scarcity cost



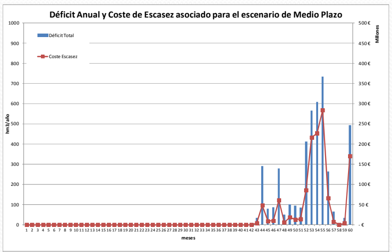


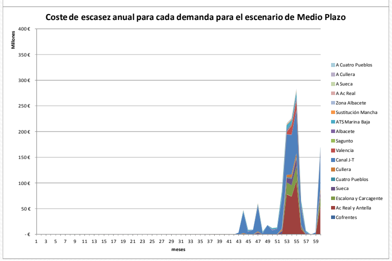
Short-term
(2011 – 2040)

Lumped deficit and scarcity cost

Per demand

Deficits & scarcity cost



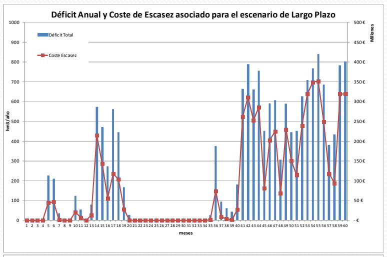


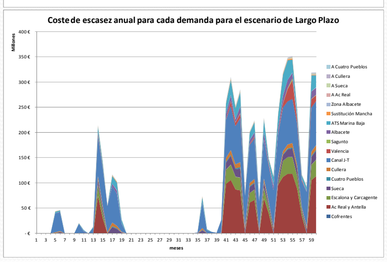
Long-term
(2071 – 2100)

Lumped deficit and scarcity cost

Per demand

Deficits & scarcity cost





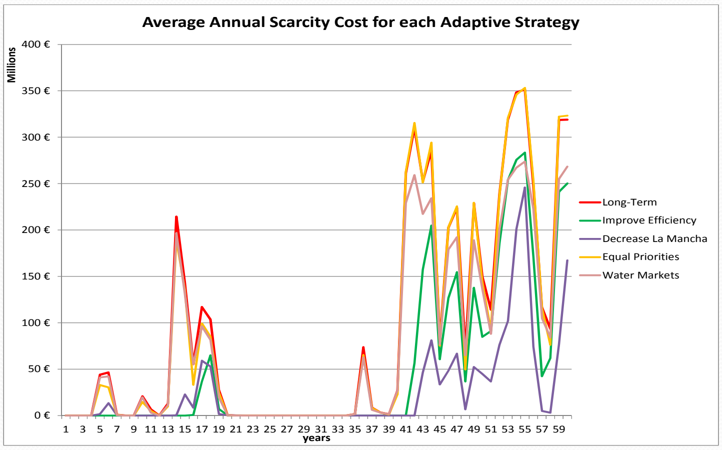
Long-term
(2041 – 2070)

Lumped deficit and scarcity cost

Per demand

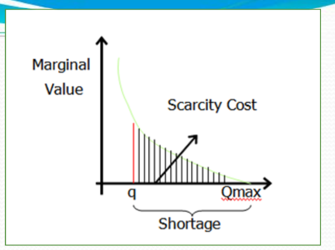
(3) Analysis of ADAPTATION STRATEGIES (HEM)

- **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**



Economic Loss Index

$$I_p = \frac{C_e}{B}$$



- Per demand -> equity issues
- Lumped -> economic impact of different management scenarios

	Histórico	Corto Plazo	Medio Plazo	Largo Plazo
Is (satisfacción)	0.9943	0.9691	0.9515	0.8213
Ir (garantía)	0.9893	0.9470	0.9228	0.7517
Iw (recursos)	1.4101	1.2685	1.1773	0.8613
Iu (aprovechamiento)	0.7051	0.7640	0.8082	0.9536
Ip (perjuicio)	0.12%	1.01%	2.26%	9.79%

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Ex.. 2. Adaptation in California WRS

CLIMATE WARMING AND WATER MANAGEMENT ADAPTATION FOR CALIFORNIA

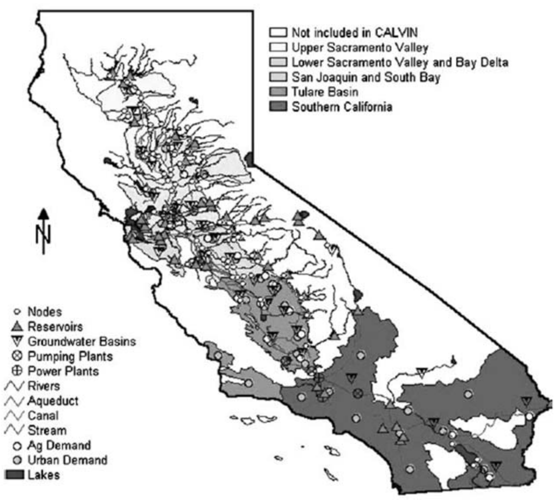
STACY K. TANAKA, TINGJU ZHU, JAY R. LUND, RICHARD E. HOWITT, MARION W. JENKINS, MANUEL A. PULIDO, MÉLANIE TAUBER, RANDALL S. RITZEMA and INÊS C. FERREIRA

Department of Civil and Environmental Engineering, Department of Agricultural and Resource Economics, University of California, Davis 95616

Climatic Change (2006)
DOI: 10.1007/s10584-006-9079-5

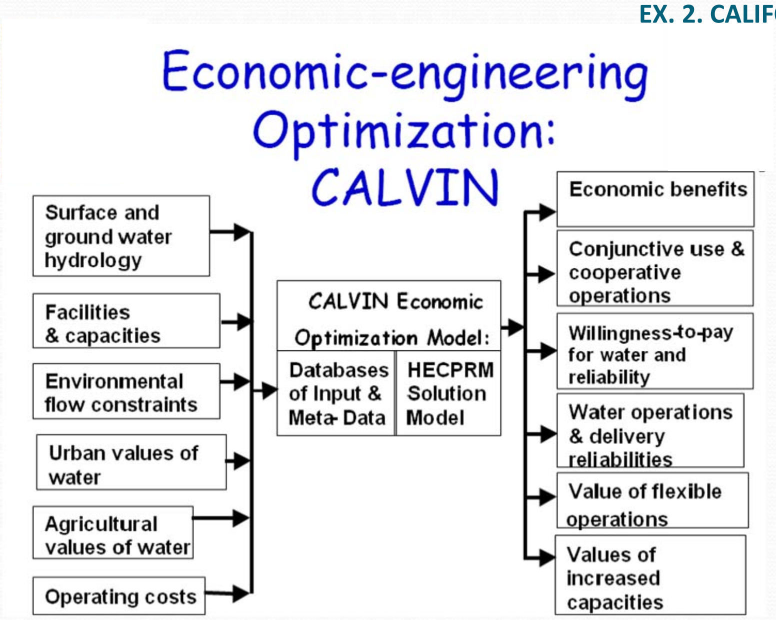
EX. 2. CALIFORNIA

CLIMATE WARMING AND WATER MANAGEMENT ADAPTATION FOR CALIFORNIA

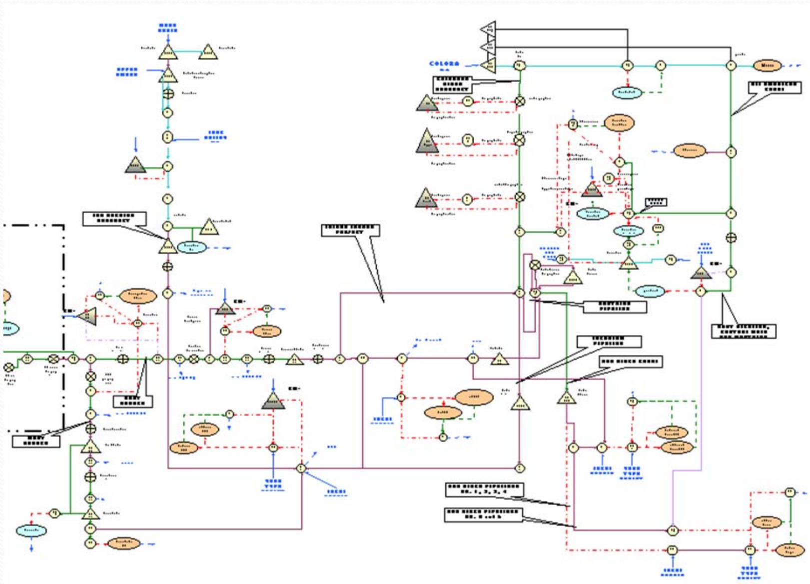


- **Adaptation capacity of California's WRS to LT (2100) climatic and demographic changes**
- **Statewide HE optimization model of water supply management**

EX. 2. CALIFORNIA



HEM of Southern California (Pulido-Velazquez et al., WRR, 2004)

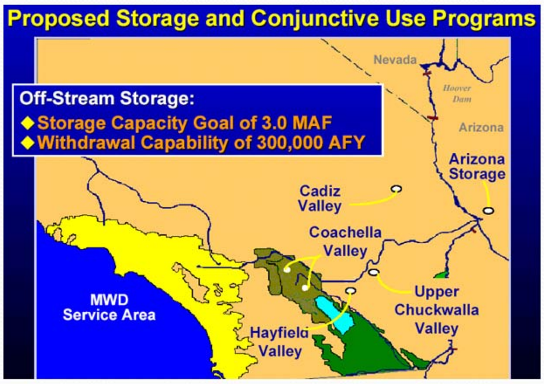


EX. 2. CALIFORNIA

Physically capable of adapting to significant changes

- Changes in the operation of California's large GW storage capacity (**CU**)
- Significant transfers among water users (**water markets**)

althoug at a significant cost …



Ex.3. Cost of cc adaptation, **Orb RB** (France)

GIRARD, C. , Pulido-Velazquez, M. (UPV, Spain), Rinaudo, J.D. (BRGM, France), Caballero, Y. (BRGM, France)

Géosciences pour une Terre durable
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EX. 3. ORB RB

OBJECTIVES:

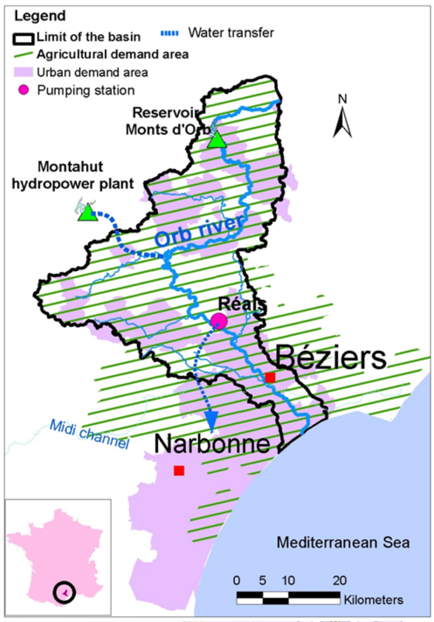
- Assess the impact of cc on Orb river basin
- Apply a **Least-Cost River Basin Optimization** model to select optimal portfolio of adaptation measures
- Analyze **uncertainty** associated to GCMs in the selection of measures

EX. 3. ORB RB

The Orb river basin

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

Threaten by the impact of climate change on water resources within "Mediterranean Hot spot" (Giorgi and Lionello, 2008)



General map of the Orb River basin

Modeling chain: from cc scenarios to adaptation

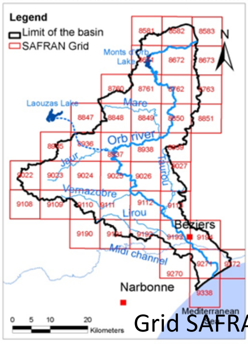
Emission scenarios → A1B

Global climate simulation → Arpège, CCMA, CNRM, GFDL, IPSL, MPI ECHAM, MRI, NCAR

Downscalling → « Wheater type » downscaling CERFACS (Boé et al., 2009)

Impact assesment → GR2M hydrological model

Adaptatiton strategy → Least-Cost River Basin Optimization

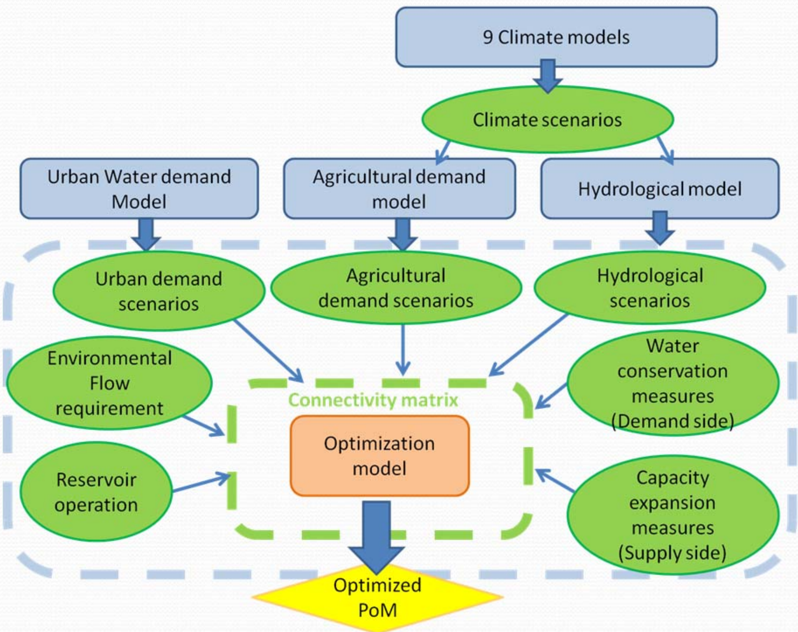


Grid SAFRAN of 8 km² (French MetOffice)

Historical (1971 to 2000) & future MT period (2046 to 2065)

Multi-model average trends: PET: + 13 %, P: - 6 % per year

APPROACH / least-Cost RB optimization model



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PORTFOLIO water management measures

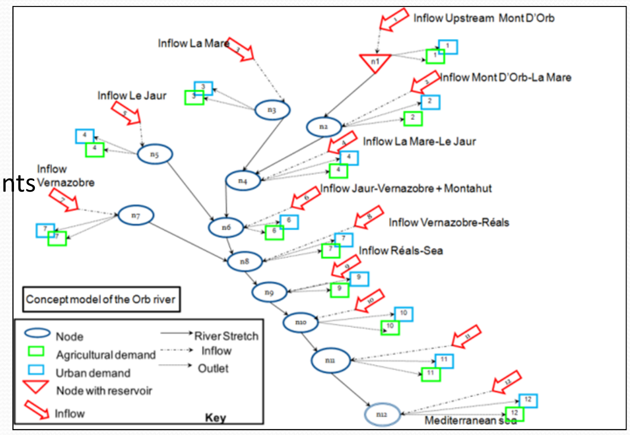
Assessmnet of measures' Effectiveness / Cost

Annalized direct cost

= f(discount rate of 4 %, lifespan, Investment, O&M)

Least-Cost RB optimization model

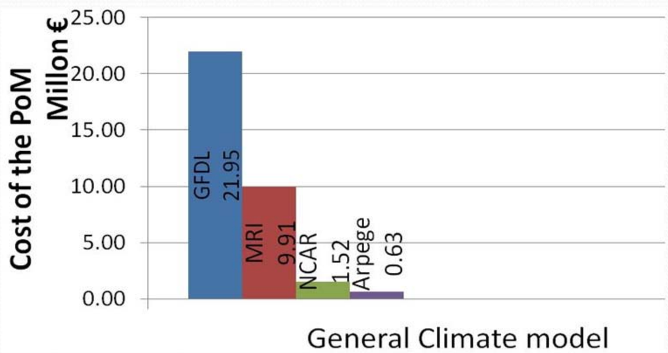
- Modeling software:
  - **GAMS** General Algebraic Modeling System (Rosenthal, 2008)
  - **Linear and Mixed Integer Programming** (Cplex solver)
- Features:
  - Monthly time scale
  - 20 year time period
  - Return flows
  - Ecological flow constraints
  - 64 UDUs, 19 ADUs
  - 11 Nodes/subbassins
  - 1 reservoir



EX. 3. ORB RB

COST of *adaptation* to climate change

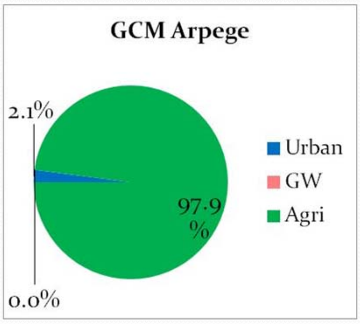
Comparison across CC scenarios

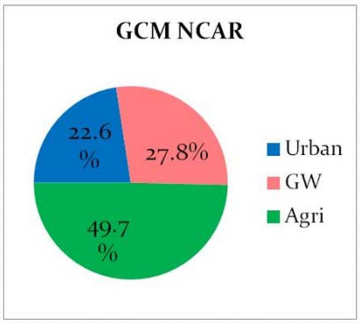


→ High sensitivity to GCMs

EX. 3. ORB RB

Distribution of COST of the **ADAPTATION MEASURES**





How to deal with this uncertainty ??

Analyze robustness of the proposed strategies acrosss scenarios / low-impact, low-regret, "soft" solutions

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EX. 4. GW IMPACT ASSESSMENT AND ADAPTATION TO CLIMATE CHANGE

CS: MANCHA ORIENTAL GW SYSTEM

Manuel Pulido-Velazquez, Salvador Peña (ETH), Lenin Henriquez, Alberto García Prats, Carlos Llopis, David Pulido, Antonio López-Nicolás

Groundwater and Dependent Ecosystems: New Scientific and Technological Basis for Assessing Climate Change and Land-use Impacts on Groundwater (**GENESIS**)

*www.the**genesisproject**.eu/*

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GENESIS
groundwater and dependent ecosystems

- **OBJECTIVE:**

Methodology & modelling framework to assess **impact of future LU** & **CC** on **GW systems** (⊂ ec. impacts) & **adaptation**

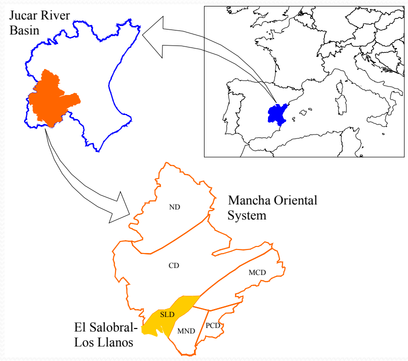
- **APPROACH:**

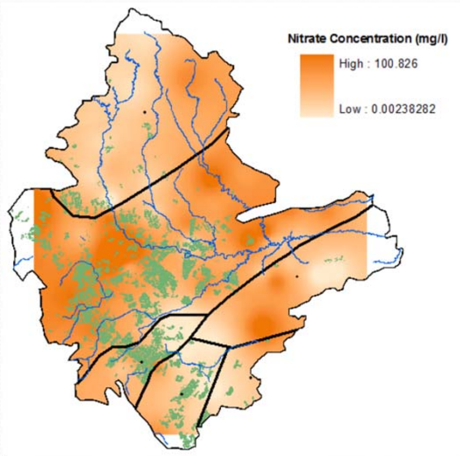
Holistic *HEM*, based on **integration of** different **models, GIS & remote sensing information** (crop areas)

- **APPLICATION:**

Impact of different scenarios on GW quality (nitrates) & **quantity** in **Mancha Oriental**

Ex. 4. MANCHA ORIENTAL

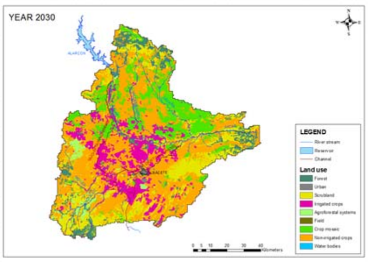


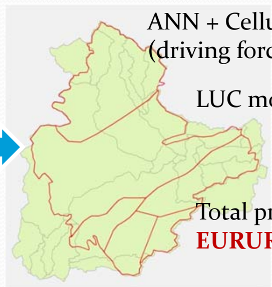


Policy mechanisms for non-point pollution control:

- Direct regulations → **Fertilizer standards**
- Economic instruments → **Taxes** and subsidies

✓ **Land use change projections**: Henriquez-Dole's MSc thesis (2011)





ANN + Cellular automata (driving forces & allocating factors)

LUC module (IDRISI)

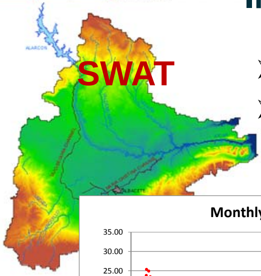
Total projection from **EURURALIS project**

✓ **CC data**

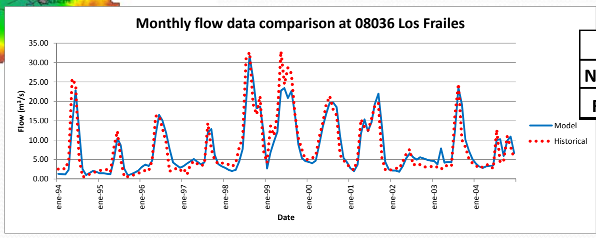
SCENARIO CODE	TYPE	EMISSION SCENARIO	GCM DRIVER	REGIONAL MODEL	SPATIAL MESH	DATA TIME PERIOD
200713	Climate change	SRES A1B	ECHAM5-r3	SMHIRCA 3.0	50 Km	1961-2100
200924	Climate change	SRES A1B	CNRM	SMHIRCA 3.0	50 Km	1961-2100
201011	Climate change	SRES A1B	HADCM3-Q0	SMHIRCA 3.0	50 Km	1961-2099

IMPACT ASSESSMENT

GENESIS – groundwater and dependent ecosystems



- Changes in HYDROLOGIC balancce
- Time series of GW recharge



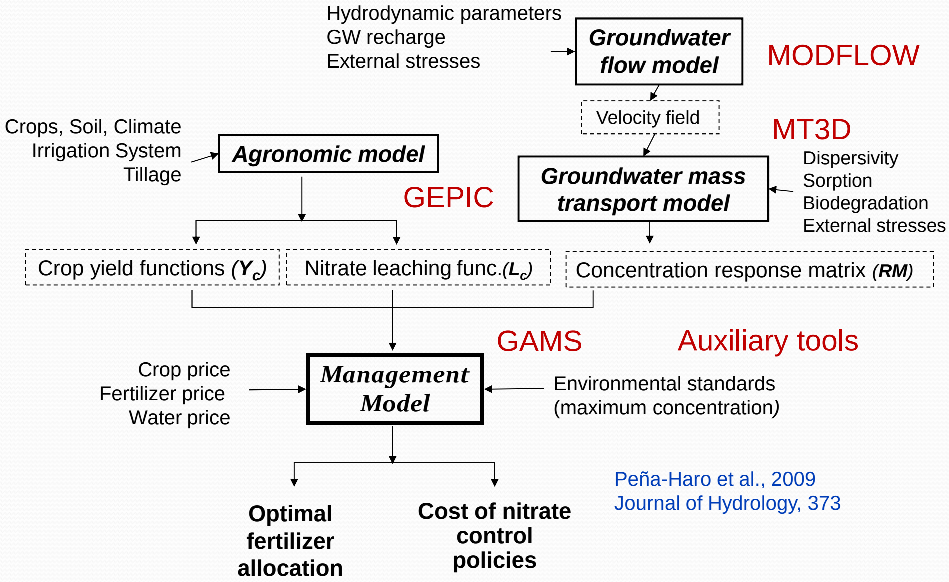
R	0.92
Nash-Sutcliffe	0.84
RMSE (m^3/s)	3.05

MODFLOW & MT3D

- GW flow / stream-aquifer interaction
- GW nitrate concentrations

MODELLING FRAMEWORK …

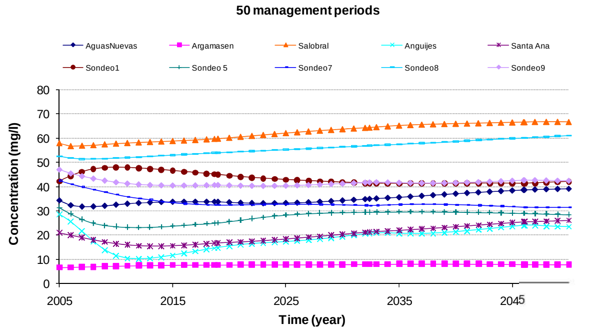
Ex. 4. MANCHA ORIENTAL



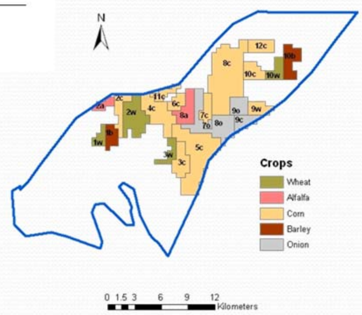
Peña-Haro et al., 2009
Journal of Hydrology, 373

Ex. 4. MANCHA ORIENTAL

Evolution of nitrates concentration over time



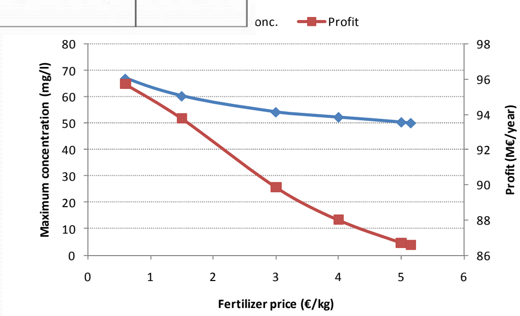
Optimal fertilizer applications



	Aplicación media fertilizante (kg/hec.)	Max concentración de nitratos (mg/l)	Benef. netos (M€/año)
Escenario 1. **Business As Usual**	240	72	96.6
Escenario 2. **Max Beneficios**	219	67	96.7
Escenario 3. **Valores de referencia**	158	57	80.9
Escenario 4. **Fertilizante óptimo. Tiempo recuper.: 2015**	201	50 (tras 2015)	95.4
Escenario 5. **Fertilizante óptimo. Tiempo recuper.: 2021**	204	50 (tras 2021)	96.0

Fertilizer applications, NO3 concentrations, benefits

FERTILIZER PRICES



ASSESSMENT OF CC & LUC IMPACTS (preliminary)

CONCLUSIONS

CONCLUSIONS

- **New tools** are emerging to support adaptation options design and appraisal
- **Combined** scenario-led (top-down) **approach** with bottom-up approach (portfolio of measures)
- **HEMs** assist adaptation decision-making by:
  - evaluating adaptation portfolios using SIMULATION (Jucar)
  - getting insight into the adaptation capacity of the system by OPTIMIZATION (California, Orb river basin)
  - need to be combined with chain of models for a proper impact assessment (ex. complexity in GW cases – Mancha Oriental)
- Main challenge: **uncertainty** !!!. Trend: flexible adaptive management, robust decisions, low-regret options

Assessing Future Scenarios of Global Change, Impacts And Adaptation Measures in Water Resources Systems

Hydroeconomic modelling and impacts and adaptation to climate and land use changes

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Proyecto "Sustainability and Adaptation of WAter REsource Systems to long-term future scenarios" (SAWARES)

PLAN NACIONAL I+D+i 2008-2011

http://www.iiama.upv.es/igme/sawares/sobre.html

Granada, 25 de junio de 2013