ASSESSMENT OF FUTURE IMPACTS OF CLIMATE CHANGE AND ADAPTATION STRATEGIES IN SEMI-ARID REGIONS

David Pulido Velázquez
Spanish Geological Survey (IGME); Unidad de Granada; Departamento de Infraestructura Geocientífica y Servicios

Granada, June 25 2013

(1) INTRODUCTION: Legal, social & technical framework

(2) A **method** to diagnose climate change impacts, vulnerability and adaptation strategies in **CU** systems at **basin scale** (Pulido-Velazquez et al., 2011)

- Serpis River Basin (Pulido-Velazquez et al., 2011; Master Thesis Montes, 2012)
- Jucar River Basin (Escriva-Bou et al., u.r.). Generation of **FUTURE Q SCENARIOS**

(3) **Sensitivity of Groundwater recharge** to climate change

- Serral Salinas aquifer (Pulido-Velazquez et al., u.r; JL Molina et al., 2012)
- La mancha Oriental aquifer

(4) Conclusions

Water Framework Directive (WFD, 2000)

- ✓ **Main target:** Good status of surface & GW bodies (2015)

- ✓ Necessity of analysing WR management at basin scale (CU)

(20) The **quantitative status of groundwater** may have an **impact on** the ecological quality of **surface waters** & terrestrial ecosystems associated

(33)The objective of achieving good status should be pursued for each **river basin**, measures in respect of **surface water & groundwaters** belonging to the **same** ecological**,** hydrological and hydrogeological **system** are **coordinated**

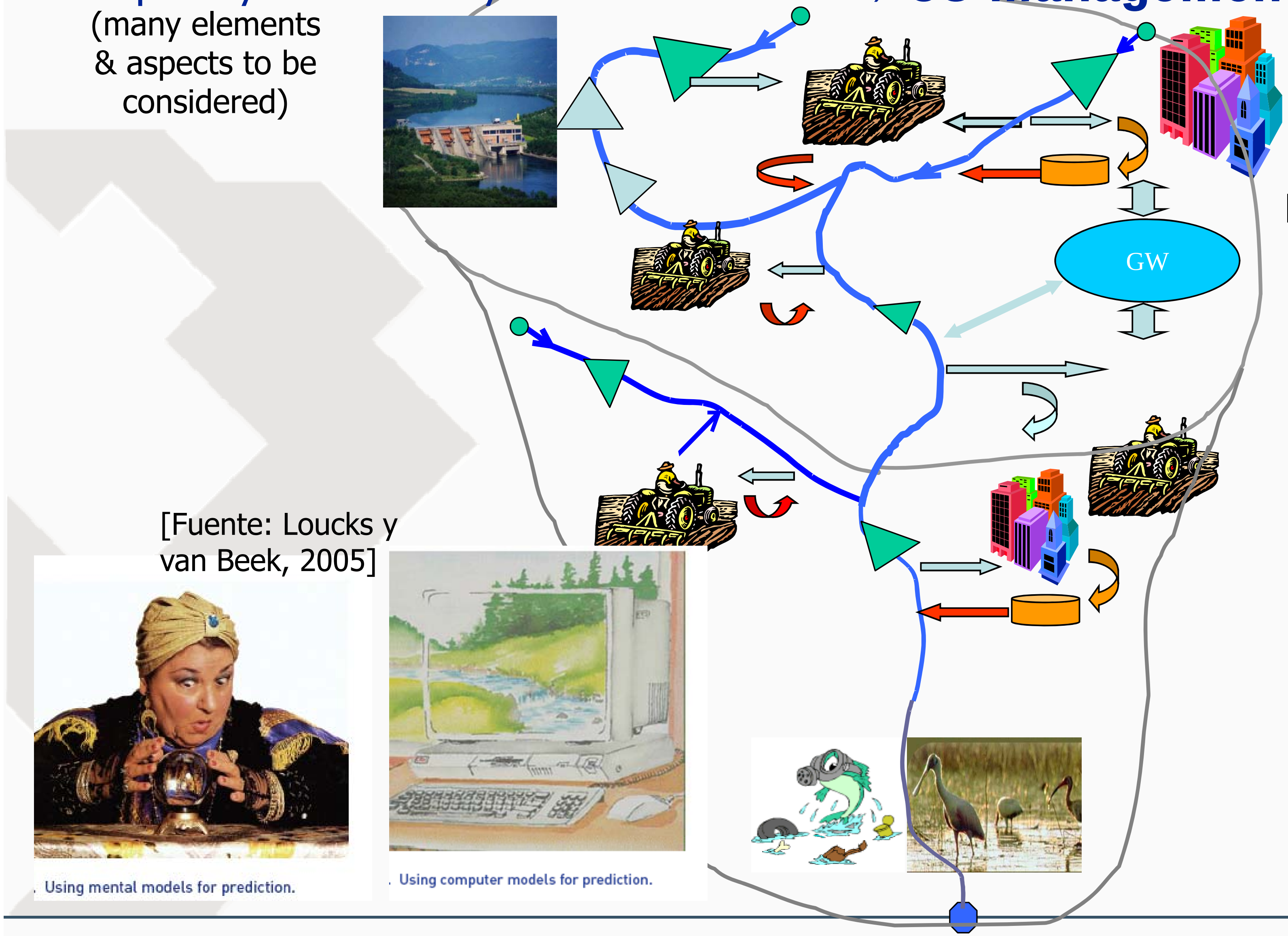
GLOBAL CHANGE & measures to achieve WFD objs

- Preoccupation & interest about GC in Europe [guide document "*River Basin Management in a Changing Climate*" (UE, 2009)]

- Great strategic importance of **knowing impact of CC on WR**, hydrological planning + its guiding role in other sectors and systems (PNACC, 2006)

Complexity of WR analysis at basin scale ⇒ **CU management models**

(many elements & aspects to be considered)



[Fuente: Cai et al.]

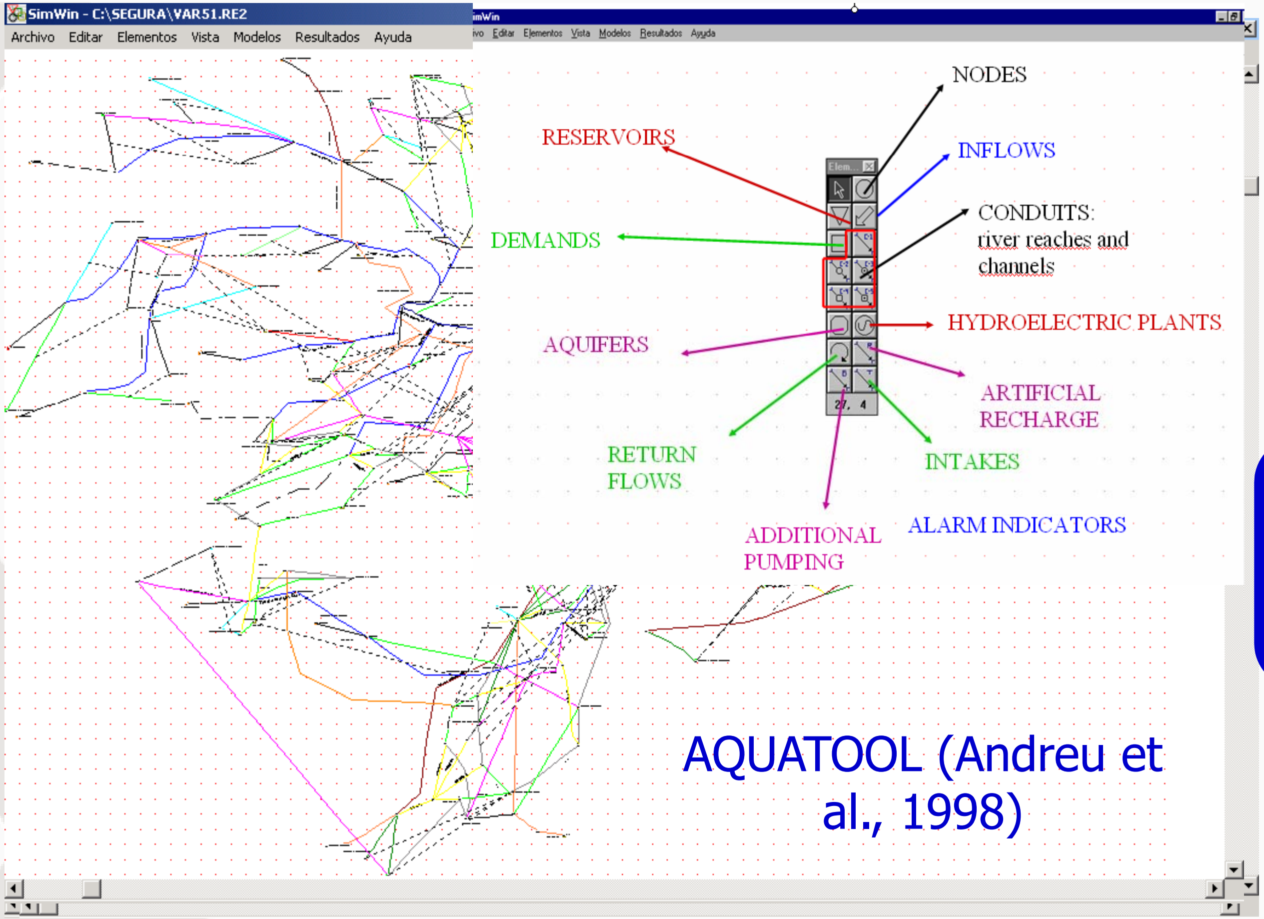
[Fuente: Loucks y van Beek, 2005]

. Using mental models for prediction.

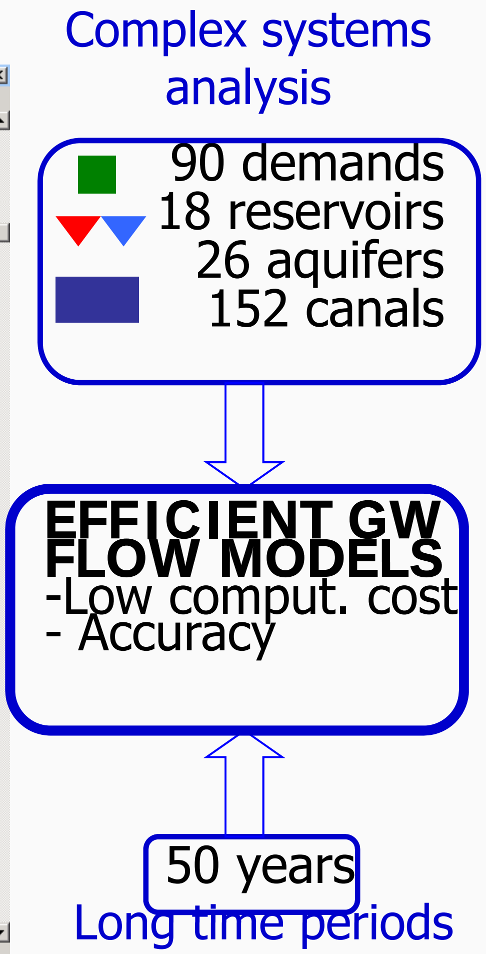
. Using computer models for prediction.

TECHNICAL PROBLEMS in **CU MANAGEMENT simulation**:

(1) Accurate and efficient **GW FLOW simulation**



AQUATOOL (Andreu et al., 1998)


Complex systems analysis

🟩 90 demands
🔻 18 reservoirs
26 aquifers
▬ 152 canals

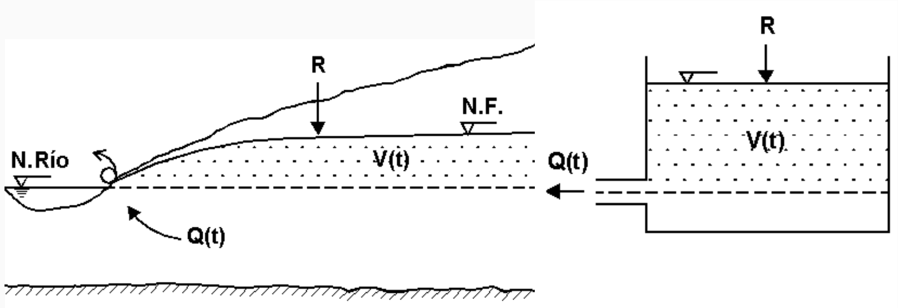
EFFICIENT GW FLOW MODELS
-Low comput. cost
- Accuracy

50 years
Long time periods

TECHNICAL PROBLEMS in **CU MANAGEMENT simulation**:

(1) Accurate and efficient **GW FLOW** simulation. **SPATIAL DETAIL**

- ☐ LUMPED MODELS:
  - Lumped variables: $V(t)$, $Q(t)$
  - Non-distributed stresses: $R(t)$
  - Equation solved = ODE



- ☐ DISTRIBUTED MODELS:
  - Distributed variables: $h(\vec{x},t)$, $Q(\vec{x},t)$
  - Distributed stresses : $W(\vec{x},t)$
  - Equation solved = PDE

TECHNICAL PROBLEMS in **CU MANAGEMENT simulation**:

(1) Accurate and efficient **GW FLOW** simulation. **DISTRIBUTED APPROACH**

- ☐ CLASSIC NUMERICAL METHODS (FD & FE): Not in COMPLEX MANAGEMENT MODELS over long time periods (Matsukawa et al., 1992; Theodossiou, 2004)

- ☐ INFLUENCE FUNTIONS (Maddock, 1972; Morel-Seytoux y Daly, 1975; Schwarz, 1976): LOWER COMPUTATIONAL COST than FDM and FEM
  - Disadvantage: to STORE previous stresses and IF; Linear GW flow problems

- ☐ Conceptual EMM (stream-aquifer interaction (Pulido-Velazquez et al., 2007; 2011) & hydraulic heads (Pulido-Velazquez et al., 2012) simulated with min computational cost
  - STATE EQ facilitates the integration in CONJUNCTIVE USE MODELS

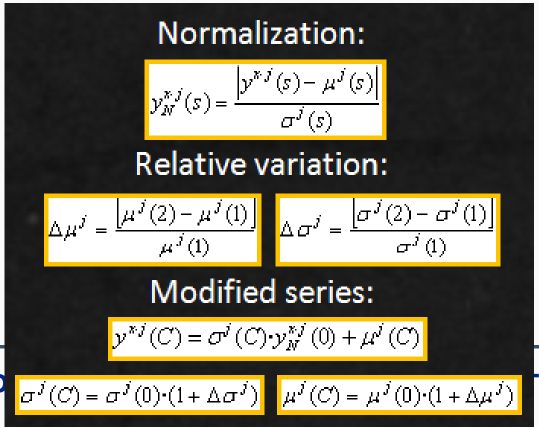
TECHNICAL PROBLEMS in **CU MANAGEMENT simulation.**

(2) Generation of **future hydrological series** (inflows, recharge)

Extensive literature about methods of **downscaling climatic series** to smaller cells, less attention has been paid to downscaling to study the impacts of CC on WR systems (Fowler et al., 2007b; Cayan et al., 2008)

❑ Hydrologic response ratios (ej. Zhu et al., 2005) **modifying** μ of historical series. Simplification usually adopted in river basin management models = modifies mean according to change deduced from climate models

❑ Incorporating not only **change** μ, but **also** σ (CC could significantly modify it) predicted by climate models (**Pulido-Velazquez et al., 2011**)



Normalization:

$$y_N^{x,j}(s) = \frac{\left|y^{x,j}(s) - \mu^j(s)\right|}{\sigma^j(s)}$$

Relative variation:

$$\Delta\mu^j = \frac{\left|\mu^j(2) - \mu^j(1)\right|}{\mu^j(1)} \qquad \Delta\sigma^j = \frac{\left|\sigma^j(2) - \sigma^j(1)\right|}{\sigma^j(1)}$$

Modified series:

$$y^{x,j}(C) = \sigma^j(C)\cdot y_N^{x,j}(0) + \mu^j(C)$$

$$\sigma^j(C) = \sigma^j(0)\cdot(1 + \Delta\sigma^j) \qquad \mu^j(C) = \mu^j(0)\cdot(1 + \Delta\mu^j)$$

ASSESSMENT OF FUTURE IMPACTS AND ADAPTATION STRATEGIES TO CLIMATE CHANGE IN SEMI-ARID REGIONS

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IMPACT & ADAPTATION STRATEGIES.
(2) Basin scale CU analysis

Method: diagnose CC impacts, vulnerability and adaptation strategies

KINDS OF PROBLEMS

Demand satisfaction index $\mathrm{I}_{\mathrm{s}} = \frac{\mathrm{S}}{\mathrm{D}}$

Demand reliability index $I_r = \frac{S_r}{D}$

ORIGIN of problems & possible ADAPTIVE strategies

Withdrawal index $I_w = \frac{Y}{D}$

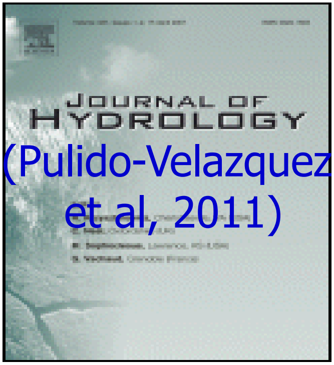
Withdrawal use index $I_u = \frac{S}{Y}$

				DEMAND RELIAVILITY (I_r)					
				High (I_r^+)		Intermediate ($I_r^=$)		Low (I_r^-)	
		WITHDRAWAL (I_w)	WITHDRAWAL USE (I_u)	Problems	Solutions	Problems	Solutions	Problems	Solutions
DEMAND SATISFACTION (I_s)	**High (I_s^+)**	High (I_w^+)	High (I_u^+)			$2^=$	A^-	2^+	A^-
			Low (I_u^-)			$2^= - 4^-$	$A^- - C^-$	$2^+ - 4^-$	$A^- - C^-$
		Low (I_w^-)	High I_u^+)			$2^= - 3^-$	$A^- - B^-$	$2^+ - 3^-$	$A^- - B^-$
	Intermediate ($I_s^=$)	High (I_w^+)	Low (I_u^-)	$1^= - 4^=$	$A^= - C^=$	$1^= - 2^= - 4^=$	$A^= - C^=$	$1^= - 2^+ - 4^=$	$A^= - C^=$
		Low (I_w^-)	High (I_u^+)	$1^= - 3^=$	$A^= - B^=$	$1^= - 2^= - 3^=$	$A^= - B^=$	$1^= - 2^+ - 3^=$	$A^= - B^=$
	Low (I_s^-)	High (I_w^+)	Low (I_u^-)	$1^+ - 4^+$	$A^+ - C^+$	$1^+ - 2^= - 4^+$	$A^+ - C^+$	$1^+ - 2^+ - 4^+$	$A^+ - C^+$
		Low (I_w^-)	High (I_u^+)	$1^+ - 3^+$	$A^+ - B^+$	$1^+ - 2^= - 3^+$	$A^+ - B^+$	$1^+ - 2^+ - 3^+$	$A^+ - B^+$
			Low (I_u^-)	$1^+ - 3^+ - 4^+$	$A^+ - B^+ - C^+$	$1^+ - 2^= - 3^+ - 4^+$	$A^+ - B^+ - C^+$	$1^+ - 2^+ - 3^+ - 4^+$	$A^+ - B^+ - C^+$

+ high = intermediate - low

Problem:
1 Vulnerable: water scarcity may produce significant damages
2 Unreliable: low intensity droughts may lead to water scarcity
3 Excess of demand with respect to withdrawal (pumping+natural inflows-depletions produced by pumping)
4 Reduced use of withdrawal

Solution:
A Demand management
B Complemetary resources are needed (adittional pumping, water transfer, water reuse, etc)
C Increase regulation of the system withdrawal (surface structural workws, artificial recharge, water reuse, etc)



(Pulido-Velazquez et al, 2011)

Instituto Geológico y Minero de España

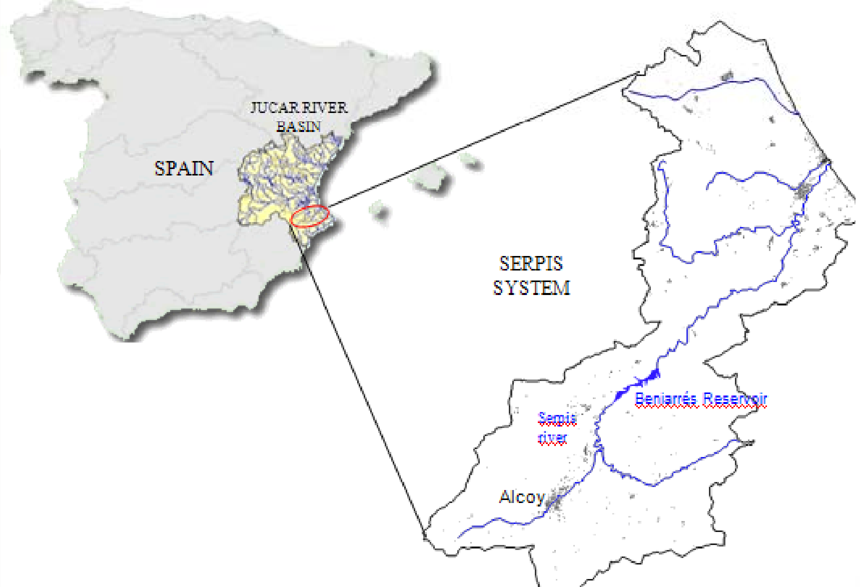
IMPACT & ADAPTATION STRATEGIES.

(2) Basin scale CU analysis

Serpis River Basin

Jucar River Basin

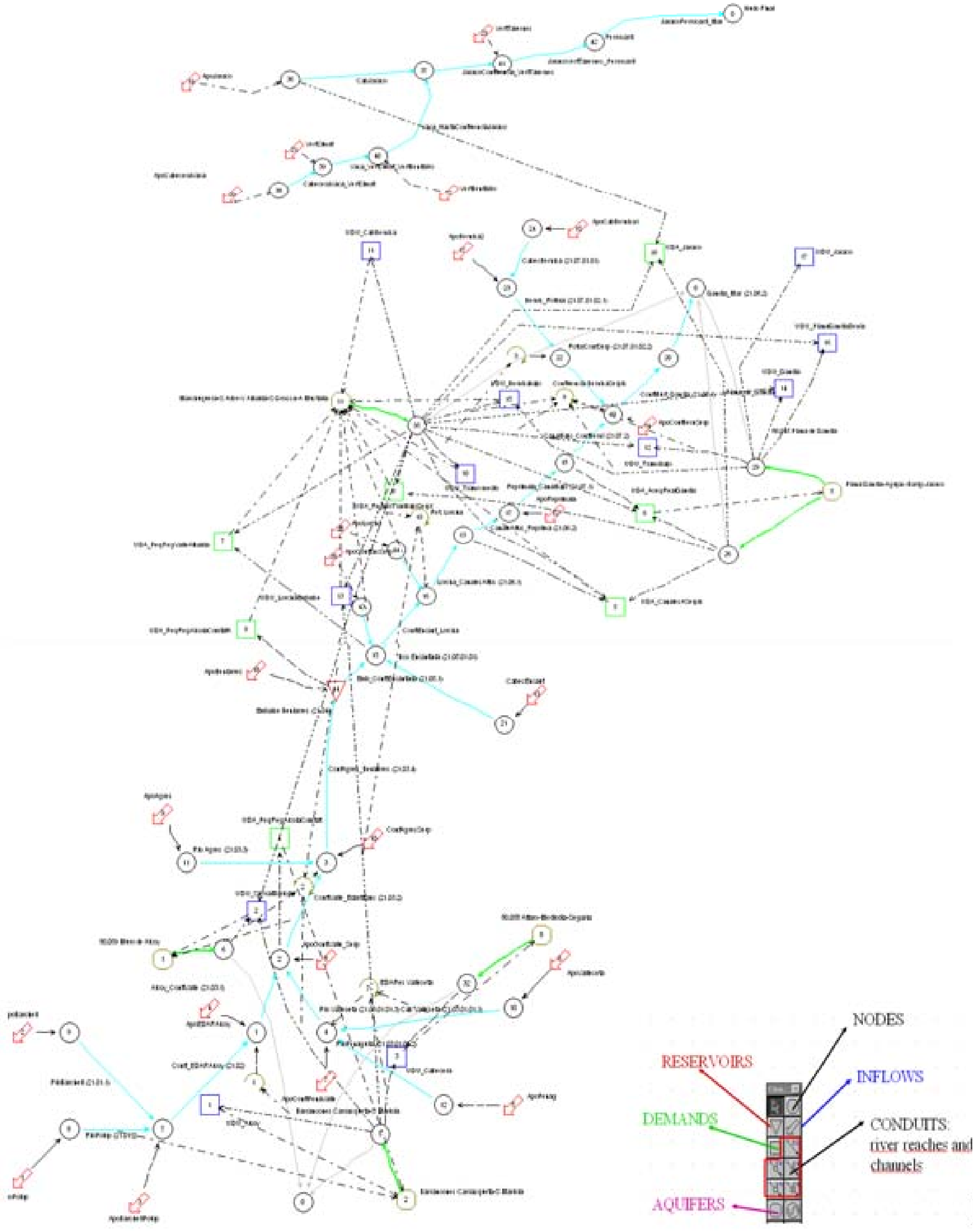
SERPIS SYSTEM



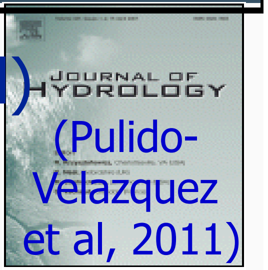
S= 990 km^2; $\mu_{rainfall}$=630 mm/y; μ_{Ta}=16.3 ^{o}C; μ_{Qnat} = 96 Mm^3/y.

Most **urban demand** (32.5 Mm^3/year) supplied with GW; summer increases 50 %.

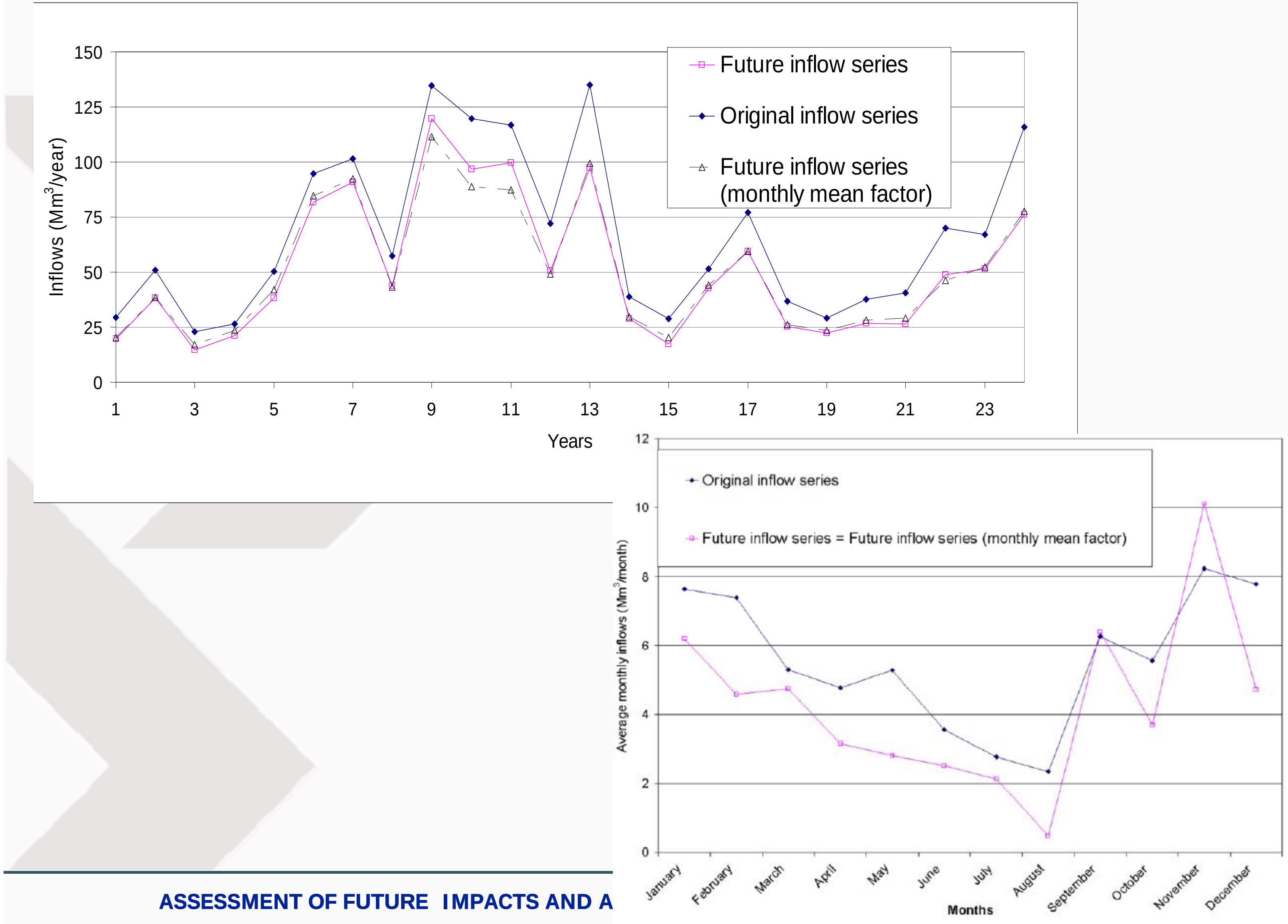
Agricultural = 103 Mm^3/year (76% of 135.5 Mm^3/year): 45% in summer.
Agricultural land covers 37,401 Hm^2,
41 % (15,169 Hm^2) is irrigated.



SERPIS SYSTEM (2071-2100; A2 scenario, GKSS model)



(Pulido-Velazquez et al, 2011)



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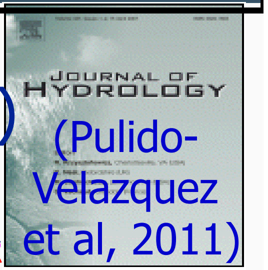
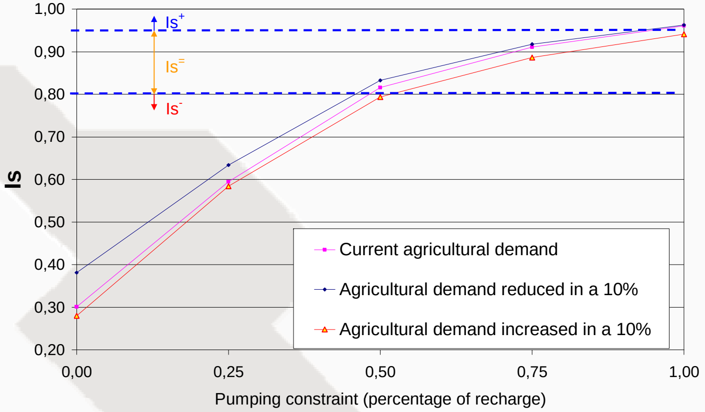
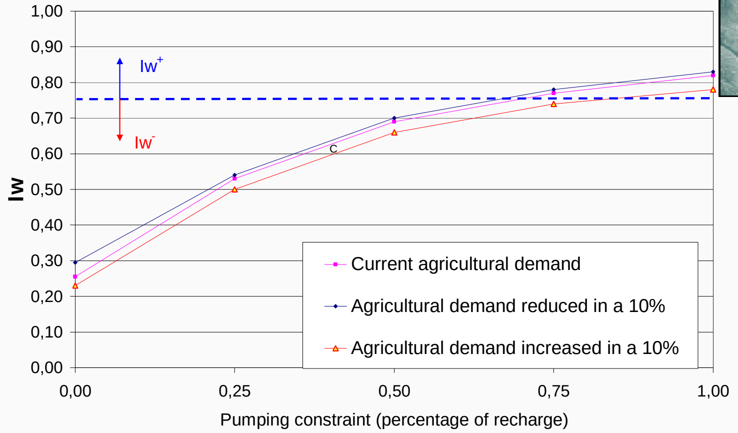
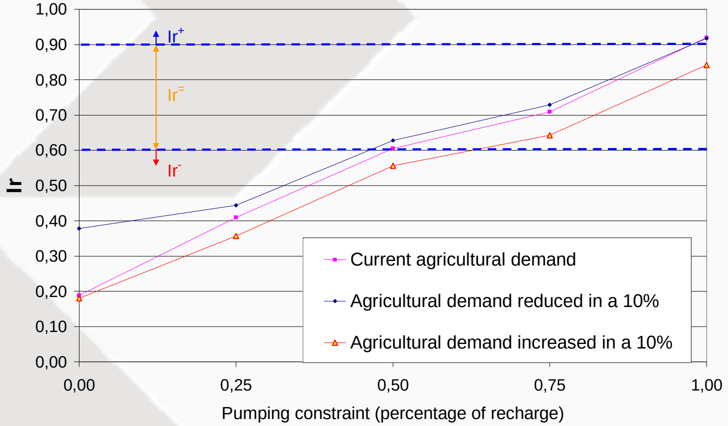
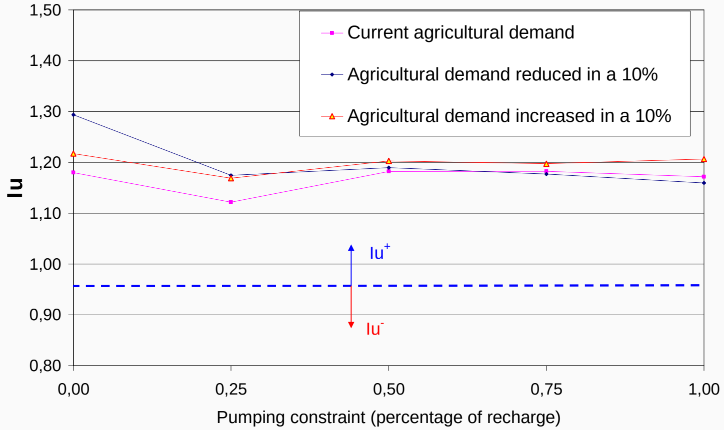


(Pulido-Velazquez et al, 2011)









If Pumpin (P)< aquifer recharge (R)

Problems: vulnerability, unreliability & demand > withdrawal, (severity ↑ when B constraint ↑).

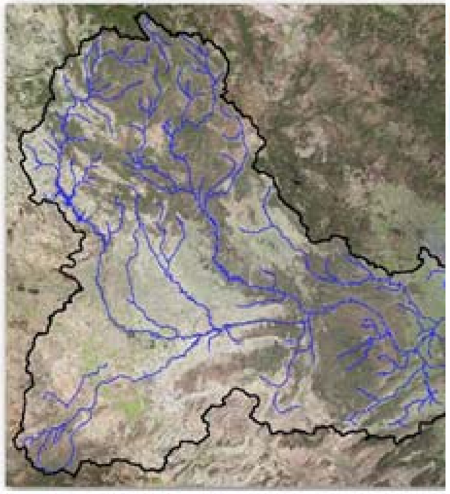
Solutions: demand management &/or complementary resources (additional B or water transfer).

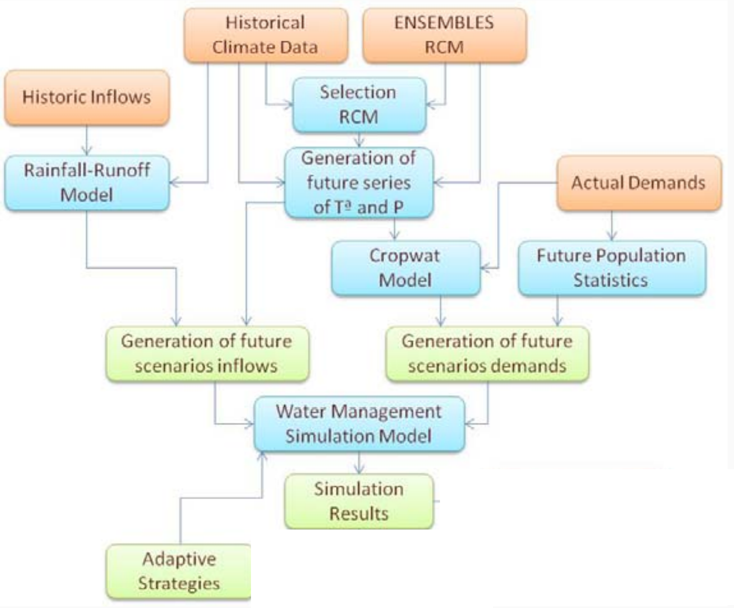
(2) Basin scale CU analysis

Serpis River Basin

→ **Jucar River Basin**

JUCAR SYSTEM





Historical Climate Data

ENSEMBLES RCM

Historic Inflows

Selection RCM

Rainfall-Runoff Model

Generation of future series of Tª and P

Actual Demands

Cropwat Model

Future Population Statistics

Generation of future scenarios inflows

Generation of future scenarios demands

Water Management Simulation Model

Simulation Results

Adaptive Strategies

Area 22.348 km^2; $\mu_{rainfall}$= 510 mm/y; μ_{Ta}= 13.6ºC;

Water **resources** available are 2384 Mm^3; 75% regulated with reservoirs (1793 hm^3)

Global **demand** = 1611 Mm^3 (87.8% agriculture, 8.7% urban, 3.5% industrial)

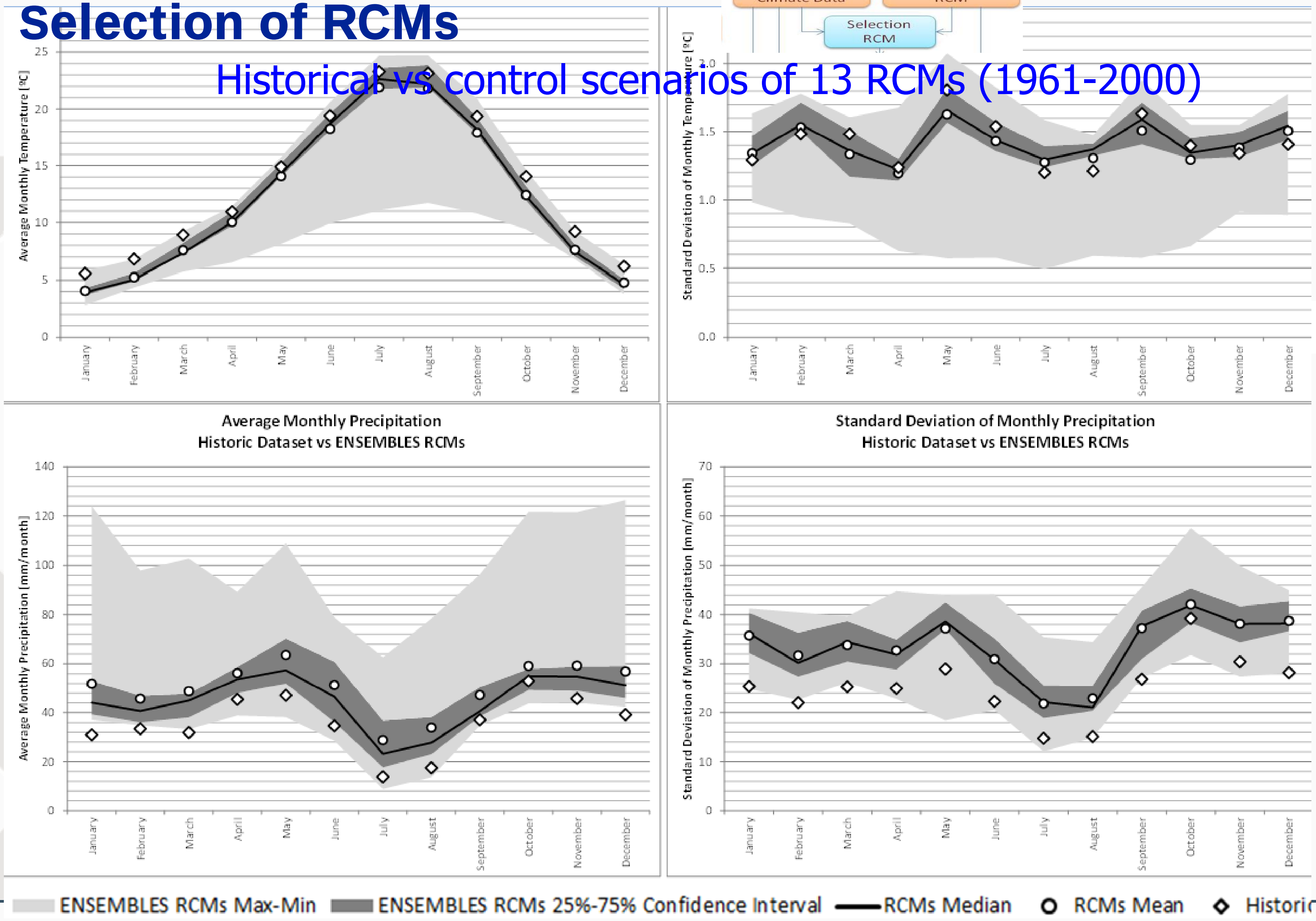
Historical Climate Data

ENSEMBLES RCM

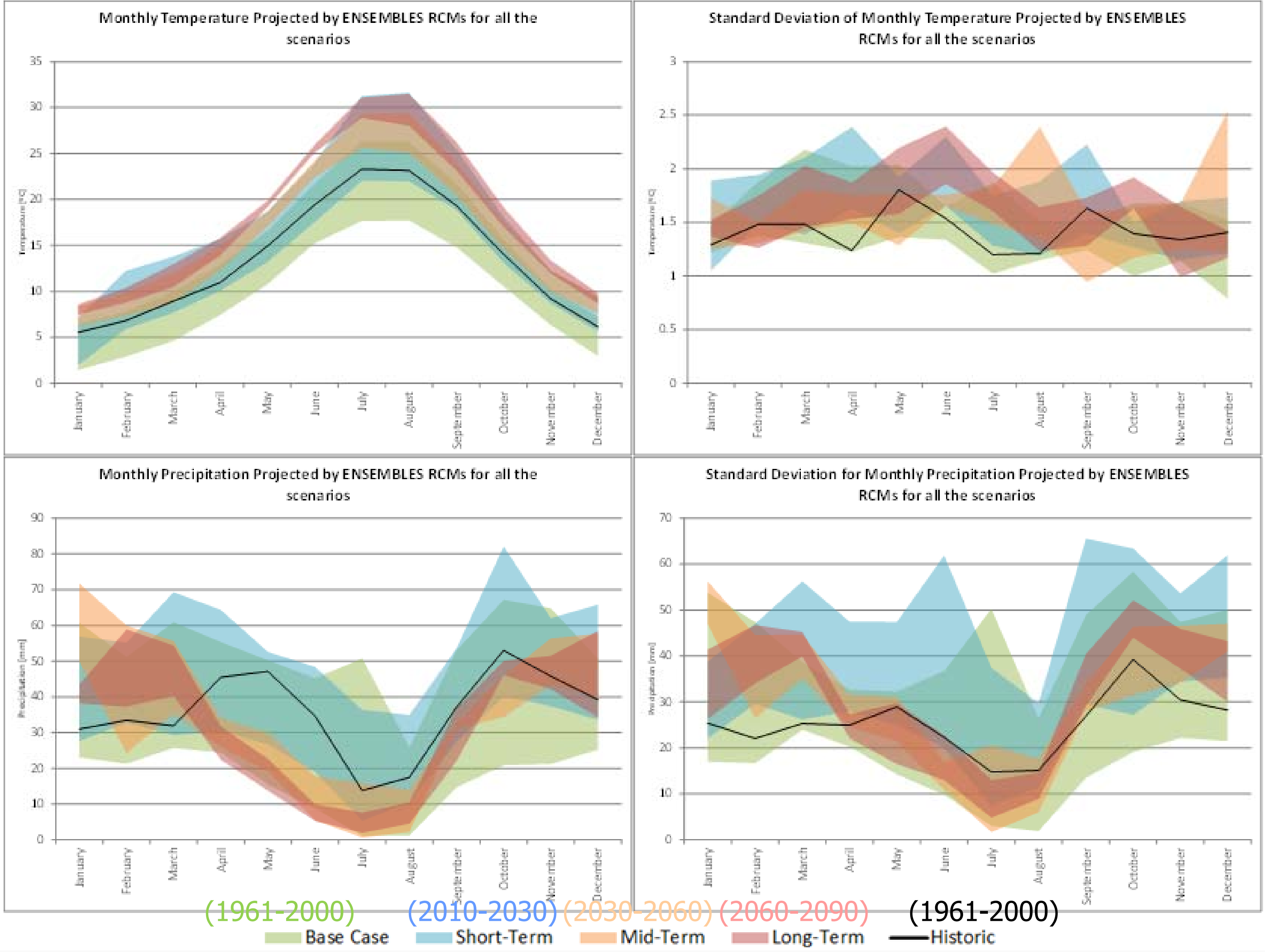
Selection RCM

Selection of RCMs

Historical vs control scenarios of 13 RCMs (1961-2000)



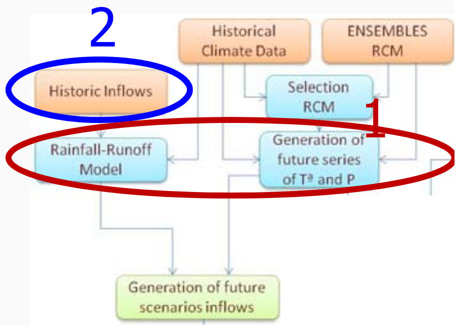
Selection of RCMs ⇒ Rg of **RCMs** values (A1B scenario)



(1961-2000) (2010-2030) (2030-2060) (2060-2090) (1961-2000)

Generation of **Future Q escenarios**

Long (2071-2100); mid (2041-70); short (2010-41) **horizons**



1. PERTURBATION (monthly μ & σ) of **historical P** & **Tª** + calibrated **Rainfall-runoff** model

2. **PERTURBATION** (monthly μ & σ) of natural **historical Q**

(3*) STOCHASTIC generation (Master Thesis Montes, 2012; SERPIS system):

3.1 Stochastic model of future **P** & **Tª** + **Rainfall-runoff** model

3.2 Stochastic model of future **Q**

IMPACT & ADAPTATION STRATEGIES.

(2) Basin scale CU analysis

Serpis River Basin

⇨ **Jucar River Basin**

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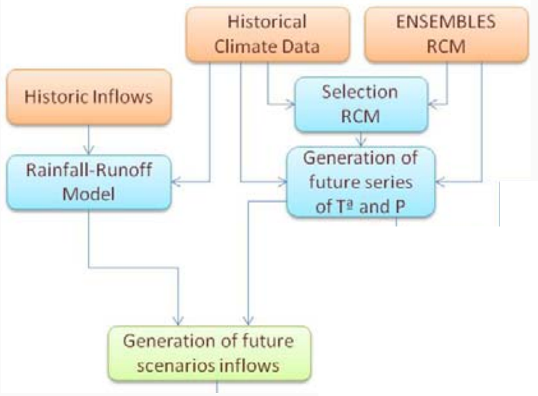
Long (2071-2100); mid (2041-70); short (2010-41) **horizons**


Historical Climate Data

ENSEMBLES RCM

Historic Inflows

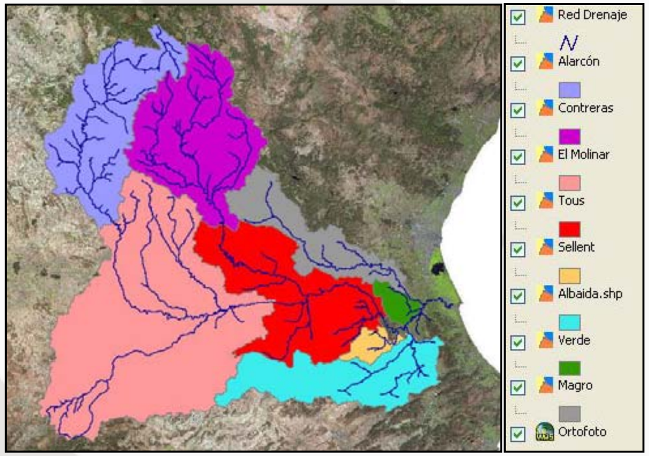
Selection RCM

Rainfall-Runoff Model

Generation of future series of Tª and P

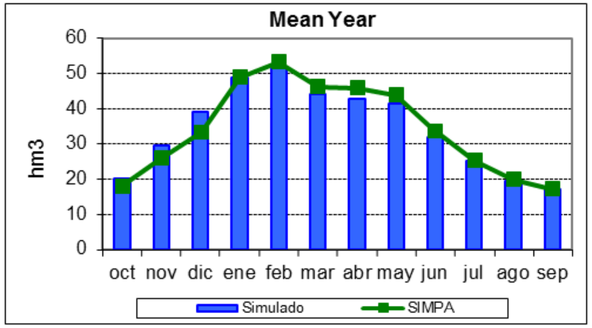
Generation of future scenarios inflows

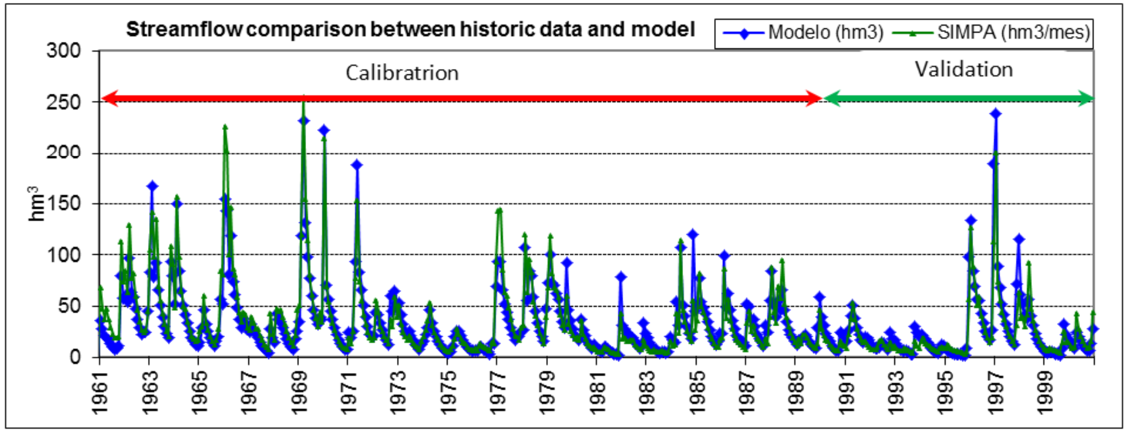
1. PERTURBATION (monthly μ & σ) of Historical P & Tª + **Rainfall-runoff models**



8 subbasins

RESULTS	
Simulated	410.7
Measured	410.7
Annual Mean Error	84.42
Squared Error	31.05
Coef Correl - R	0.94
Nash-Sutcliffe Coeff.	0.88

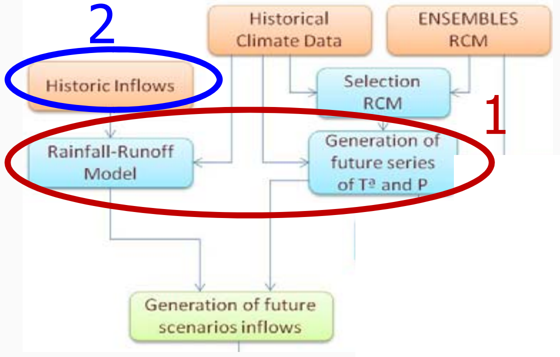




IMPACT & ADAPTATION STRATEGIES.
(2) Basin scale CU analysis

Serpis River Basin

➡ **Jucar River Basin**



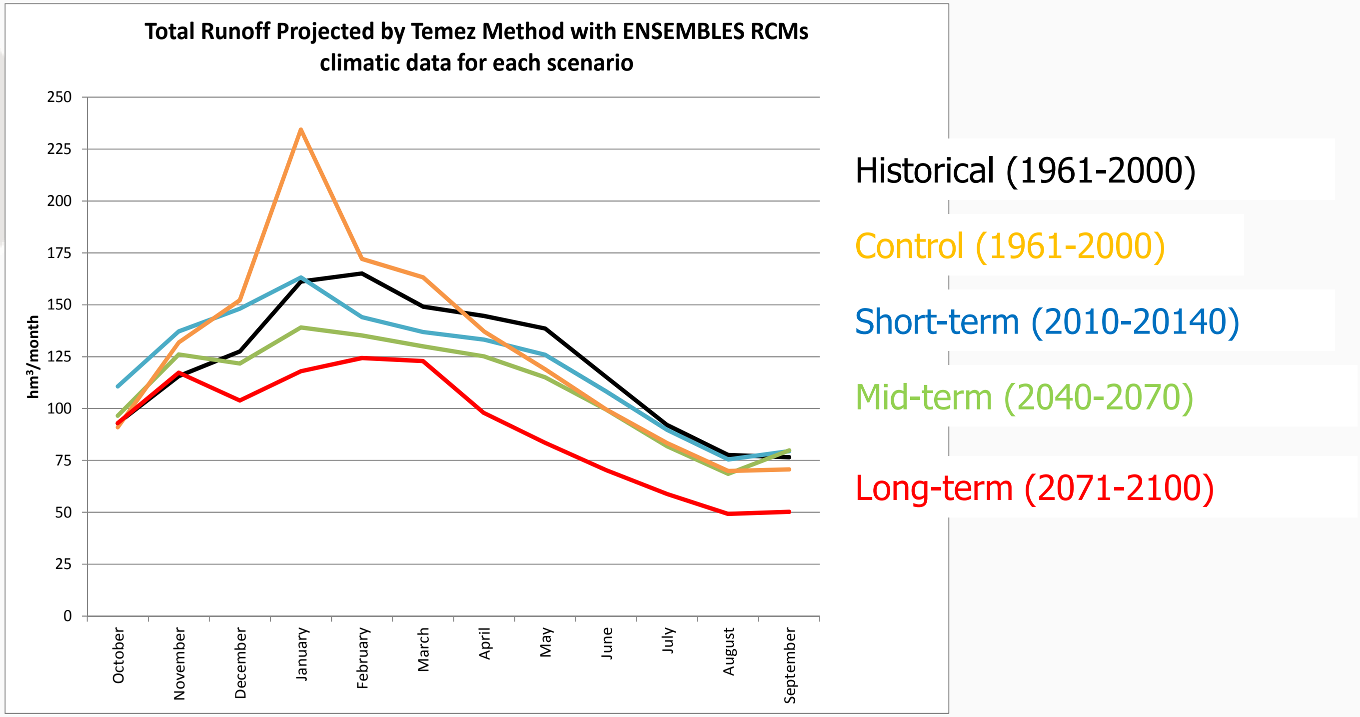
Generation of **Future Q escenarios**

Long (2071-2100); mid (2041-70); short (2010-41) **horizons**

TOTAL RUN-OFF

1. $Q_{future}=[(T^a+P)_{Historical} + \Delta_{futureRCMs}]$

Rainfall-runoff models



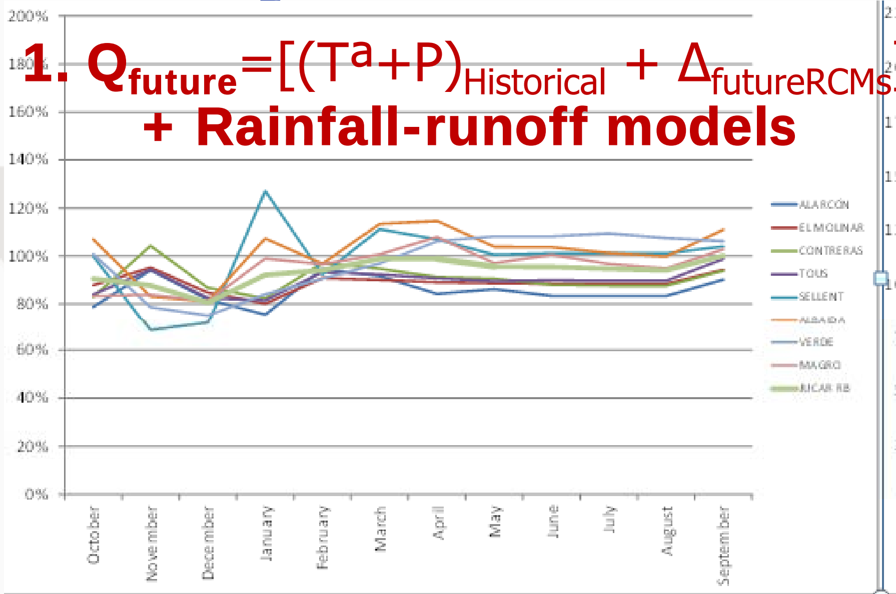
IMPACT & ADAPTATION STRATEGIES.

(2) Basin scale CU analysis

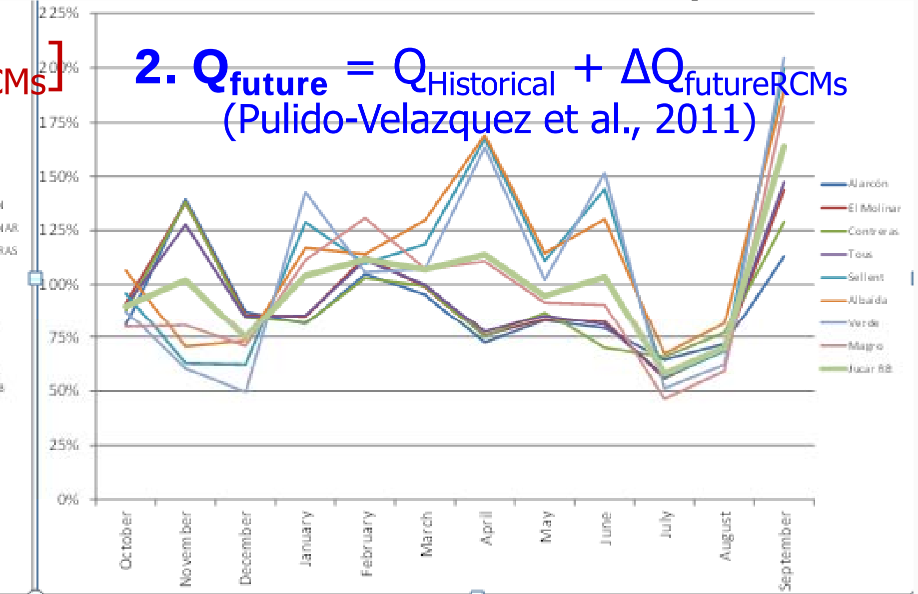
Serpis River Basin

Jucar River Basin

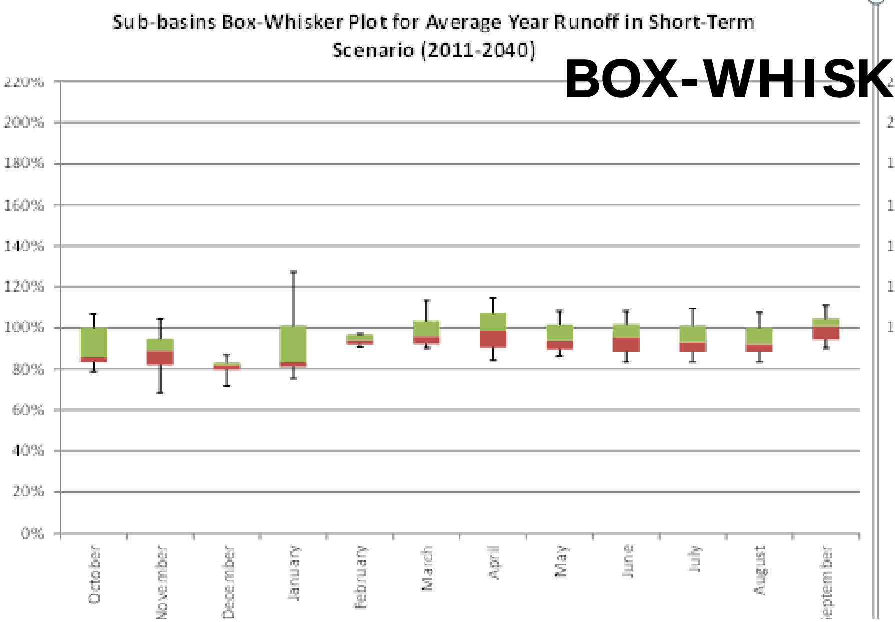
Future Q escenarios. **8 Sub-basin;** Short-term **horizons** (2010-2041)



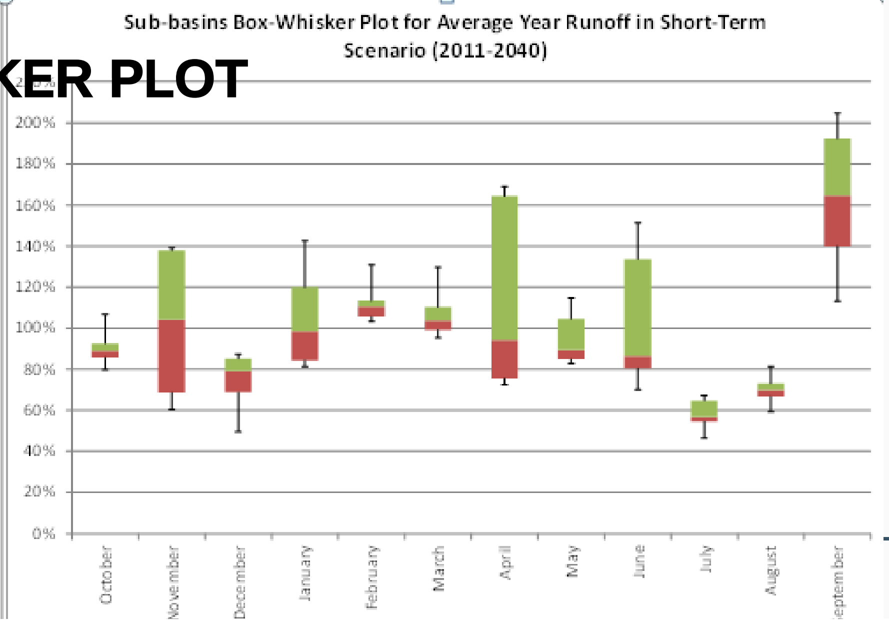
1. $\mathbf{Q_{future}}=[(T^{a}+P)_{Historical} + \Delta_{futureRCMs}]$
+ Rainfall-runoff models



2. $\mathbf{Q_{future}} = Q_{Historical} + \Delta Q_{futureRCMs}$
(Pulido-Velazquez et al., 2011)


Sub-basins Box-Whisker Plot for Average Year Runoff in Short-Term Scenario (2011-2040)

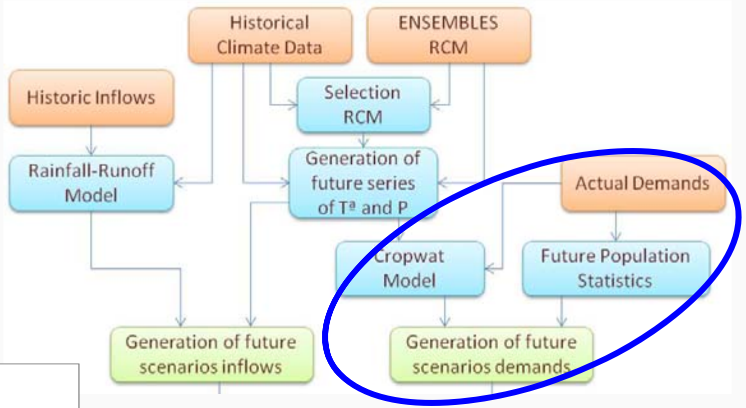
BOX-WHISKER PLOT

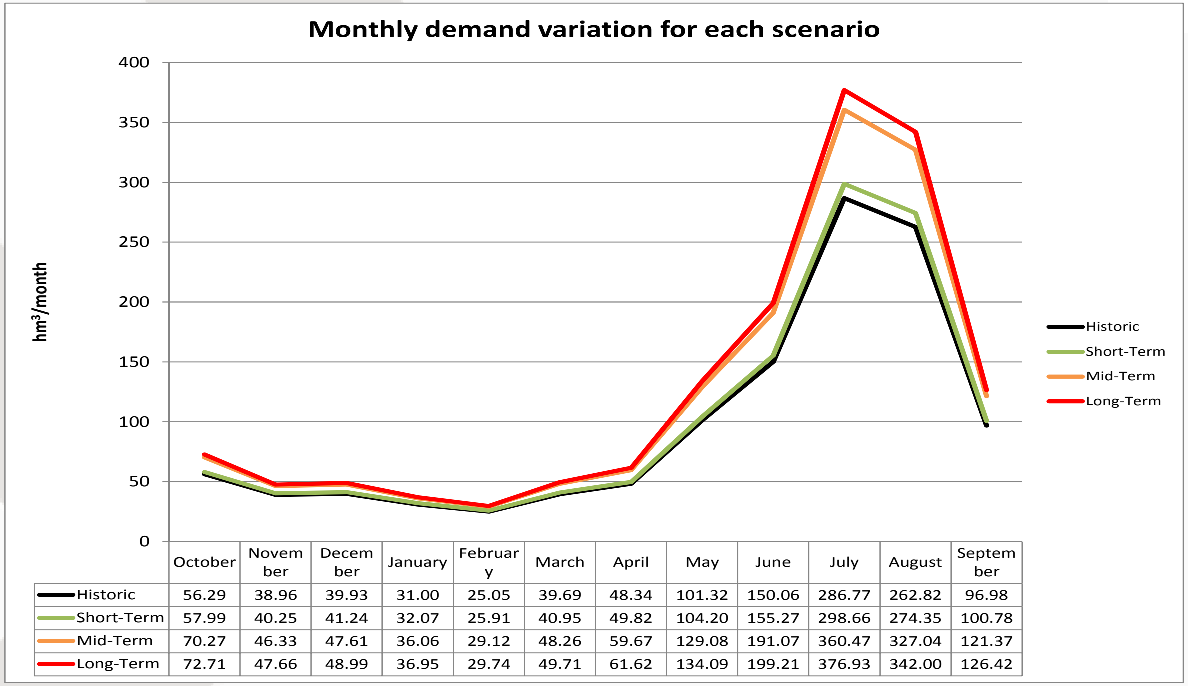

Sub-basins Box-Whisker Plot for Average Year Runoff in Short-Term Scenario (2011-2040)

Future demand scenarios

- **Urban** = Projection of population (IVE, 2012) ;
= per capita consumption

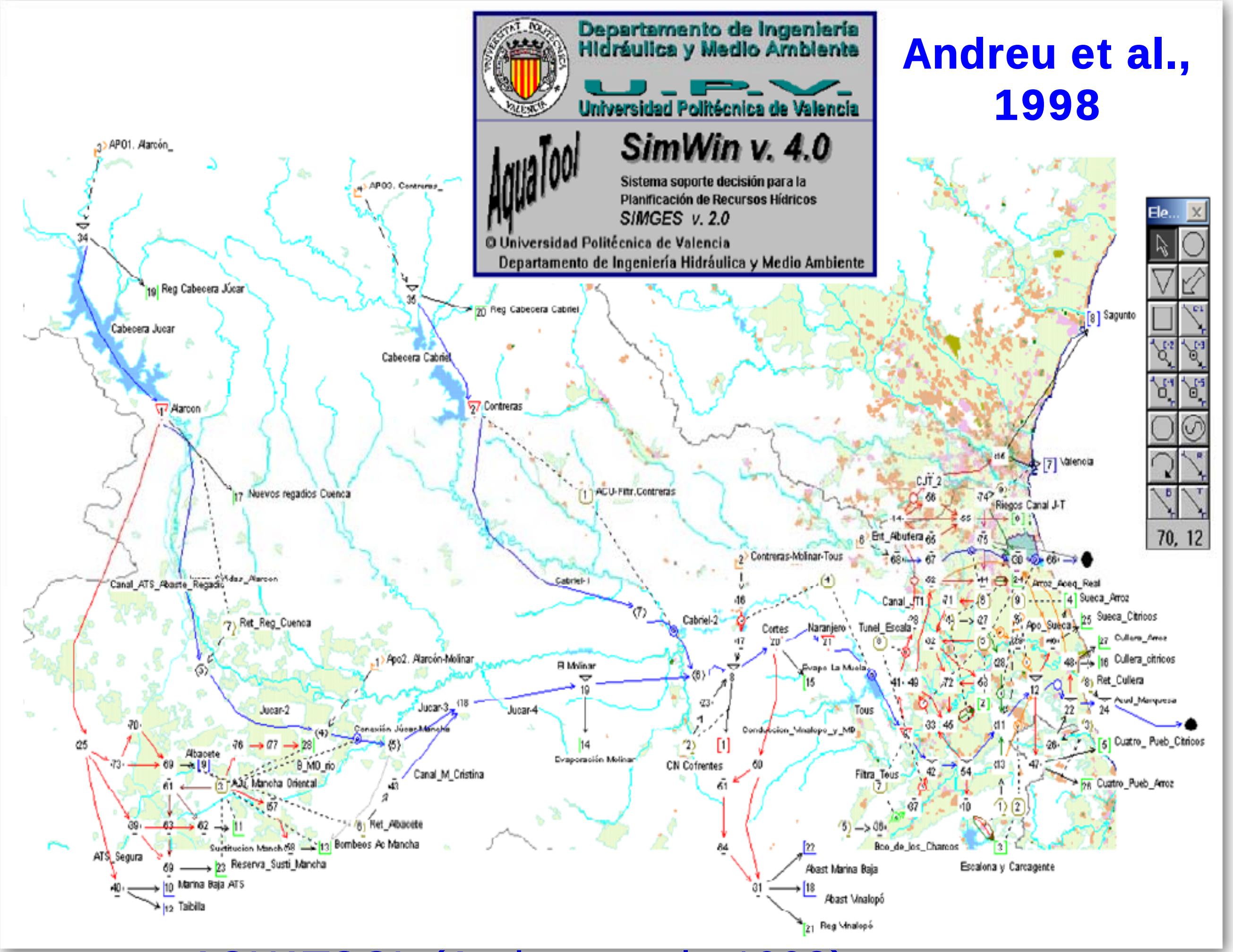
- **Agricultural** = **Future T° + P +** Cropwat model





	October	November	December	January	February	March	April	May	June	July	August	September
Historic	56.29	38.96	39.93	31.00	25.05	39.69	48.34	101.32	150.06	286.77	262.82	96.98
Short-Term	57.99	40.25	41.24	32.07	25.91	40.95	49.82	104.20	155.27	298.66	274.35	100.78
Mid-Term	70.27	46.33	47.61	36.06	29.12	48.26	59.67	129.08	191.07	360.47	327.04	121.37
Long-Term	72.71	47.66	48.99	36.95	29.74	49.71	61.62	134.09	199.21	376.93	342.00	126.42

Water management models


Departamento de Ingeniería Hidráulica y Medio Ambiente
U.P.V.
Universidad Politécnica de Valencia
AquaTool
SimWin v. 4.0
Sistema soporte decisión para la Planificación de Recursos Hídricos
SIMGES v. 2.0
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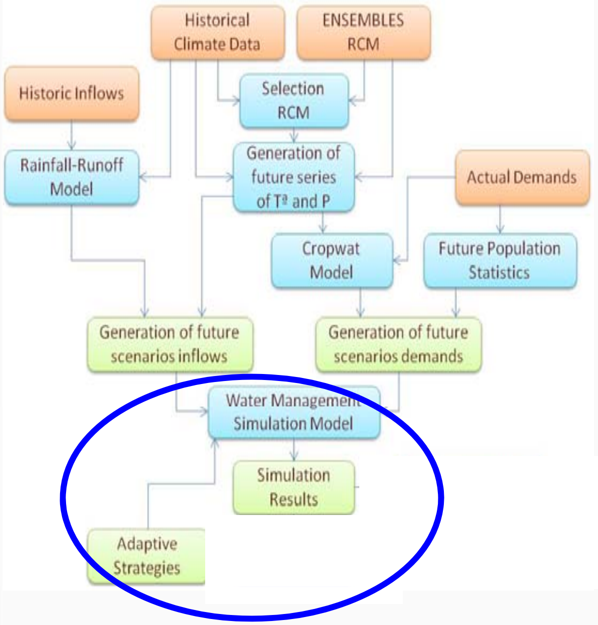
Andreu et al., 1998

AQUATOOL (Andreu et al., 1998)


Historical Climate Data
ENSEMBLES RCM
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Rainfall-Runoff Model
Generation of future series of Tª and P
Actual Demands
Cropwat Model
Future Population Statistics
Generation of future scenarios inflows
Generation of future scenarios demands
Water Management Simulation Model
Simulation Results
Adaptive Strategies

8 inflows (our sub-basins),
7 reservoirs, 46 conduits,
17 consumptive demands,
3 hydro-power plants and
5 aquifers.

Instituto Geológico y Minero de España

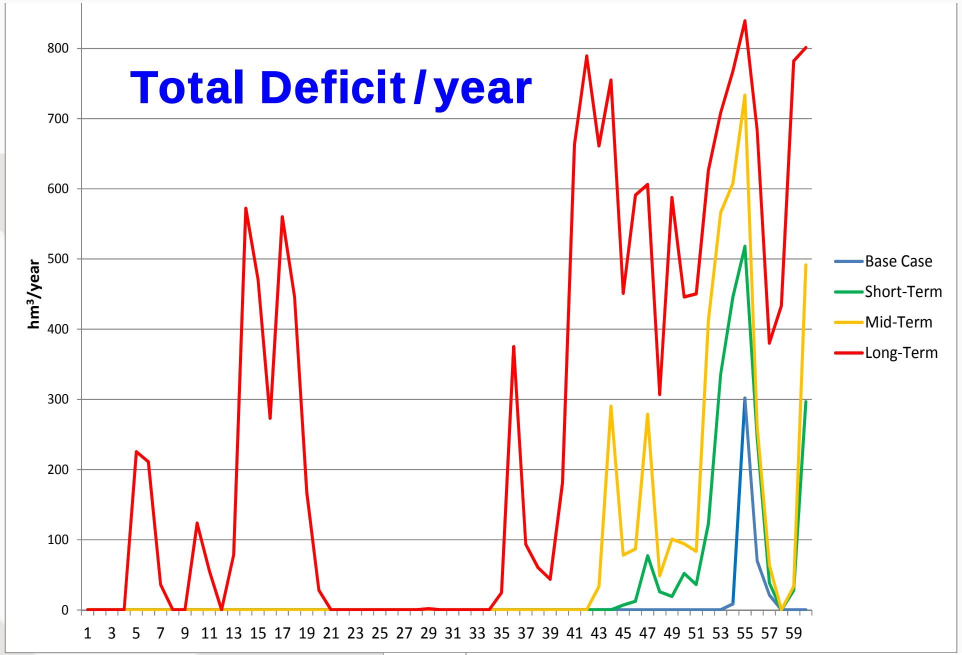
IMPACT & ADAPTATION STRATEGIES.

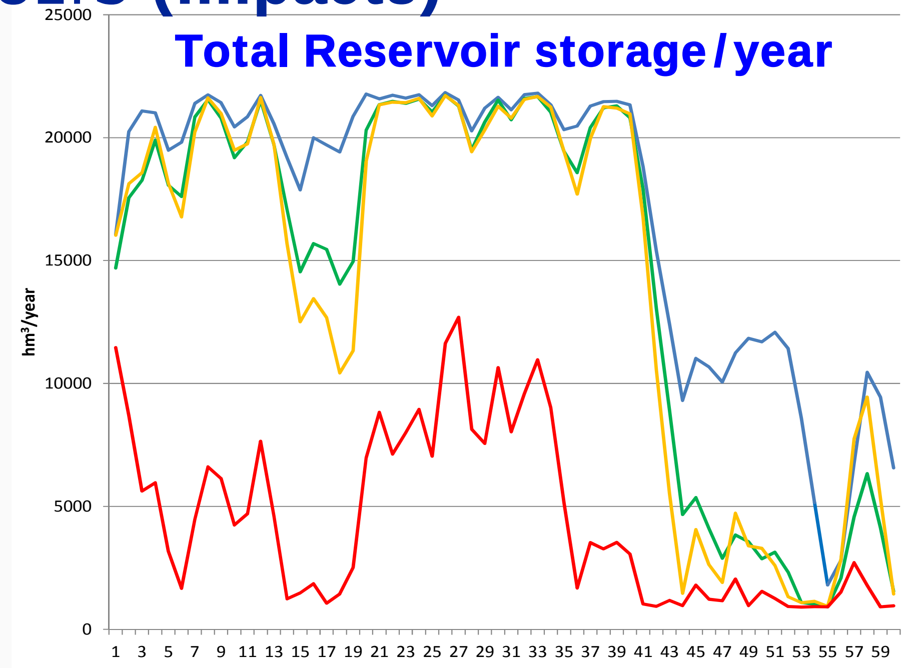
(2) Basin scale CU analysis ⇨

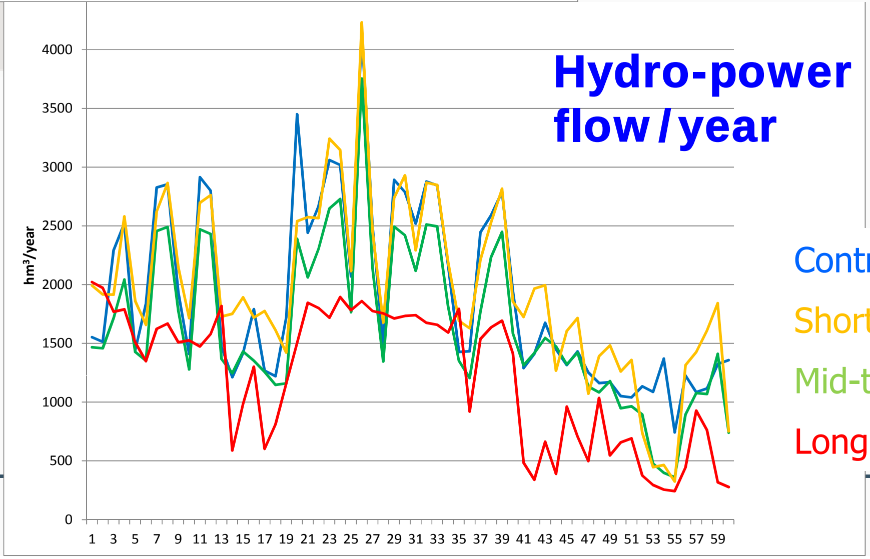
Serpis River Basin

Jucar River Basin

Water management models. RESULTS **(impacts)**







Control (1961-2000)

Short-term (2010-20140)

Mid-term (2040-2070)

Long-term (2071-2100)

Water management models. RESULTS **(impacts)**

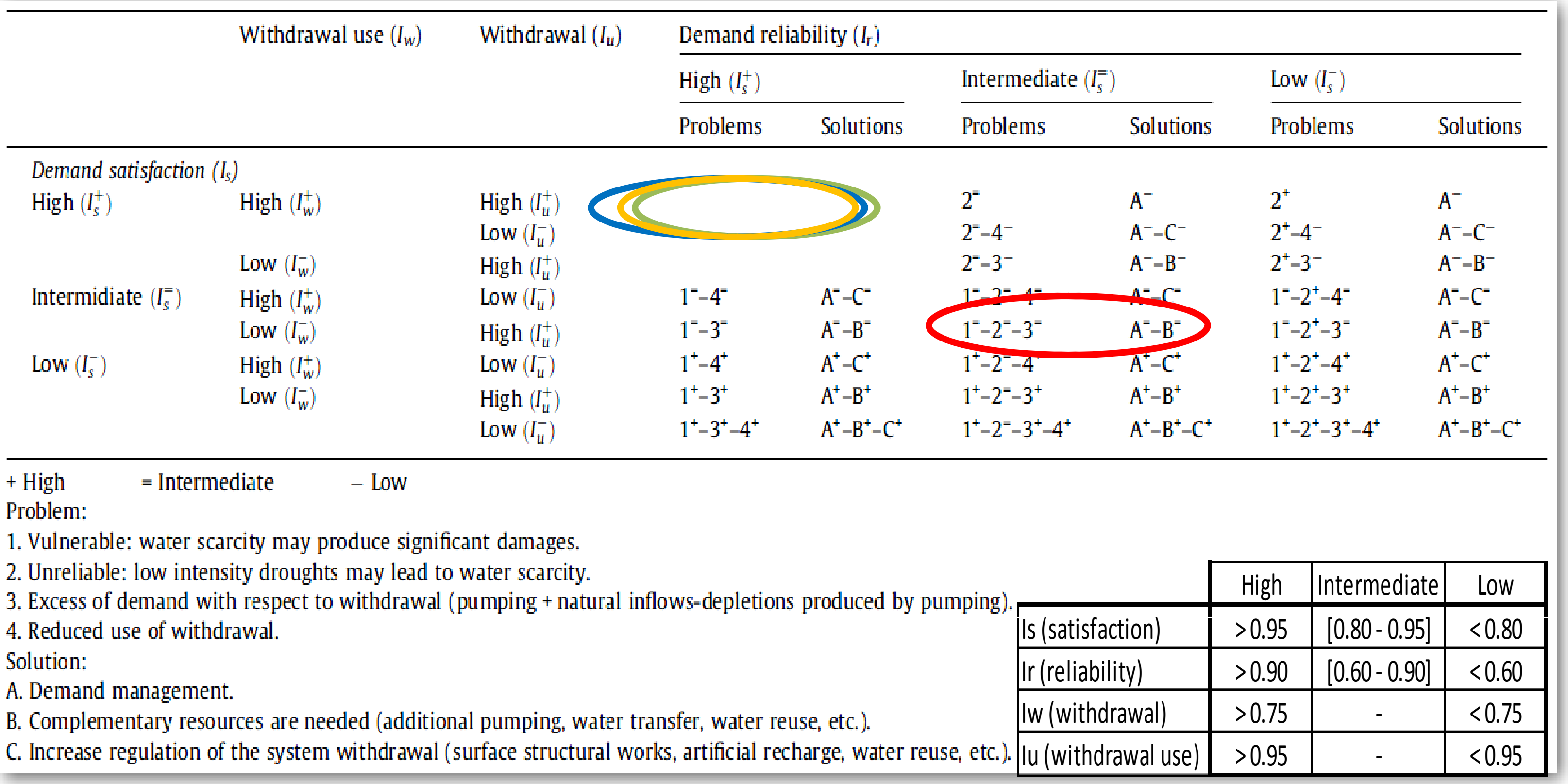
	Base Case			Short-Term (2011-2040)			Mid-Term (2041-2070)			Long-Term (2071-2100)		
Demand	Monthly Guarantee	Annual Guarantee	Volumetric Guarantee	Garantía Mensual	Garantia Anual	Garantía Volumétrica	Garantía Mensual	Garantia Anual	Garantía Volumétrica	Garantía Mensual	Garantia Anual	Garantía Volumétrica
Valencia	100.00%	100.00%	100.00%	99.70%	100.00%	100.00%	98.10%	95.00%	99.40%	92.90%	83.30%	98.00%
Sagunto	100.00%	100.00%	100.00%	99.70%	100.00%	100.00%	98.30%	95.00%	99.50%	94.30%	86.70%	98.70%
Albacete	99.90%	98.30%	99.90%	97.90%	88.30%	98.20%	97.50%	80.00%	97.90%	85.80%	53.30%	87.00%
Marina Baja ATS	99.70%	98.30%	99.90%	96.90%	88.30%	97.30%	96.40%	78.30%	96.70%	81.00%	46.70%	83.00%
CN Cofrentes	100.00%	100.00%	100.00%	99.60%	96.70%	99.70%	96.90%	85.00%	97.60%	89.90%	63.30%	91.10%
Ac. Real y de Antella	83.30%	98.30%	99.30%	82.10%	88.30%	95.80%	66.80%	80.00%	93.40%	68.30%	46.70%	73.50%
Escalona y Carcagente	96.70%	96.70%	99.00%	70.80%	86.70%	94.40%	75.40%	78.30%	91.90%	39.90%	45.00%	69.70%
Sueca	96.70%	96.70%	98.80%	84.00%	90.00%	94.00%	81.70%	78.30%	91.70%	47.50%	45.00%	68.10%
Cuatro Pueblos	96.70%	96.70%	98.80%	84.00%	90.00%	93.90%	81.70%	78.30%	91.60%	47.50%	45.00%	67.80%
Cullera	96.70%	96.70%	98.80%	84.00%	90.00%	93.90%	81.70%	78.30%	91.60%	47.50%	43.30%	67.50%
Canal Júcar Turia	97.50%	96.70%	98.10%	88.60%	83.30%	90.70%	86.40%	71.70%	86.30%	61.20%	41.70%	55.80%
Sustitución Mancha	73.30%	96.70%	98.50%	89.30%	86.70%	91.50%	87.60%	73.30%	88.10%	62.20%	43.30%	61.60%
Zona Albacete	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Arroz Ac Real	82.90%	98.30%	99.20%	81.90%	88.30%	95.40%	71.80%	80.00%	92.90%	64.40%	46.70%	72.60%
Arroz Sueca	96.70%	96.70%	99.00%	84.00%	90.00%	94.70%	81.70%	78.30%	92.70%	47.50%	43.30%	72.90%
Arroz Cullera	96.70%	96.70%	99.00%	84.00%	90.00%	94.70%	81.70%	78.30%	92.70%	47.50%	43.30%	72.80%
Arroz Cuatro Pueblos	96.70%	96.70%	99.00%	84.00%	90.00%	94.70%	81.70%	78.30%	92.70%	47.50%	43.30%	72.90%

IMPACT & ADAPTATION STRATEGIES.
(3) Basin scale CU analysis

Serpis River Basin

⇨ **Jucar River Basin**

Water management models. RESULTS **(adaptive strategies)**



	Withdrawal use (I_w)	Withdrawal (I_u)	Demand reliability (I_r)					
			High (I_s^+)		Intermediate ($I_s^=$)		Low (I_s^-)	
			Problems	Solutions	Problems	Solutions	Problems	Solutions
Demand satisfaction (I_s)								
High (I_s^+)	High (I_w^+)	High (I_u^+)			$2^=$	A^-	2^+	A^-
		Low (I_u^-)			$2^=-4^-$	A^--C^-	2^+-4^-	A^--C^-
	Low (I_w^-)	High (I_u^+)			$2^=-3^-$	A^--B^-	2^+-3^-	A^--B^-
Intermidiate ($I_s^=$)	High (I_w^+)	Low (I_u^-)	$1^=-4^=$	$A^=-C^=$	$1^=-2^=-4^=$	$A^=-C^=$	$1^=-2^+-4^=$	$A^=-C^=$
	Low (I_w^-)	High (I_u^+)	$1^=-3^=$	$A^=-B^=$	$1^=-2^=-3^=$	$A^=-B^=$	$1^=-2^+-3^=$	$A^=-B^=$
Low (I_s^-)	High (I_w^+)	Low (I_u^-)	1^+-4^+	A^+-C^+	$1^+-2^=-4^+$	A^+-C^+	$1^+-2^+-4^+$	A^+-C^+
	Low (I_w^-)	High (I_u^+)	1^+-3^+	A^+-B^+	$1^+-2^=-3^+$	A^+-B^+	$1^+-2^+-3^+$	A^+-B^+
		Low (I_u^-)	$1^+-3^+-4^+$	$A^+-B^+-C^+$	$1^+-2^=-3^+-4^+$	$A^+-B^+-C^+$	$1^+-2^+-3^+-4^+$	$A^+-B^+-C^+$

+ High = Intermediate – Low

Problem:

1. Vulnerable: water scarcity may produce significant damages.
2. Unreliable: low intensity droughts may lead to water scarcity.
3. Excess of demand with respect to withdrawal (pumping + natural inflows-depletions produced by pumping).
4. Reduced use of withdrawal.

Solution:

A. Demand management.
B. Complementary resources are needed (additional pumping, water transfer, water reuse, etc.).
C. Increase regulation of the system withdrawal (surface structural works, artificial recharge, water reuse, etc.).

	High	Intermediate	Low
Is (satisfaction)	> 0.95	[0.80 - 0.95]	< 0.80
Ir (reliability)	> 0.90	[0.60 - 0.90]	< 0.60
Iw (withdrawal)	> 0.75	-	< 0.75
Iu (withdrawal use)	> 0.95	-	< 0.95

	Base Case	Short-Term	Mid-Term	Long-Term
Is (satisfaction)	0.9943	0.9691	0.9515	0.8213
Ir (reliability)	0.9893	0.9470	0.9228	0.7517
Iw (withdrawal)	1.4101	1.2685	1.1773	0.8613
Iu (withdrawal use)	0.7051	0.7640	0.8082	0.9536

- ❑Short & Mid term indices: Acceptable situation
- ❑ Long-Term scenario indices ⇒ vulnerable, unreliable, excess of demand respect to withdrawal SOLUTIONS: Demand management + complementary resources

(1) INTRODUCTION: Legal, social & technical framework

(2) A **method** to diagnose climate change impacts, vulnerability and adaptation strategies in **CU** systems at **basin scale** (Pulido-Velazquez et al., 2011)

- Serpis River Basin (Pulido-Velazquez et al., 2011; Master Thesis Montes, 2012)
- Jucar River Basin (Escriva-Bou et al., u.r.). Generation of **FUTURE Q SCENARIOS**

(3) **Sensitivity of Groundwater recharge** to climate change

- Serral Salinas aquifer (Pulido-Velazquez et al., u.r; JL Molina et al., 2012)
- La mancha Oriental aquifer

(4) Conclusions

IMPACT & ADAPTATION STRATEGIES.

(3) Sensitivity of GW recharge. METHODOLOGY

SELECTION & ENSEMBLE OF RCMs FOR THE SYSTEM

Information required

CRU cells on the system

Meteorological series for CONTROL Scenario (1961-90) **for each RCM**

Meteorological HISTORICAL series (1961-1990)

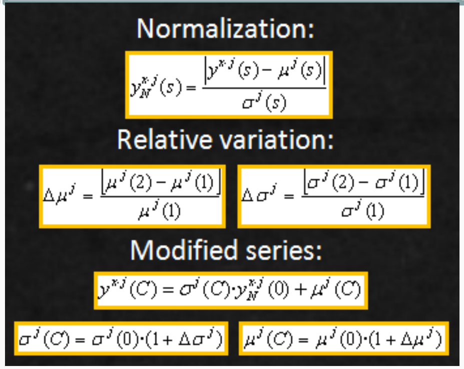
Selection of RCMs

To obtain **lumped series for the system**

To asses calibration by using the index **Id(RCM$_i$)** = f(|**differences** in μ & σ between control series and historical series|)

↓ Id(RCM$_i$) = Best fit

Multiobjetive analysis: comparison and selection of models



Normalization:

$$y_N^{x,j}(s) = \frac{\left| y^{x,j}(s) - \mu^j(s) \right|}{\sigma^j(s)}$$

Relative variation:

$$\Delta\mu^j = \frac{\left| \mu^j(2) - \mu^j(1) \right|}{\mu^j(1)} \qquad \Delta\sigma^j = \frac{\left| \sigma^j(2) - \sigma^j(1) \right|}{\sigma^j(1)}$$

Modified series:

$$y^{x,j}(C) = \sigma^j(C) \cdot y_N^{x,j}(0) + \mu^j(C)$$

$$\sigma^j(C) = \sigma^j(0) \cdot (1 + \Delta\sigma^j) \qquad \mu^j(C) = \mu^j(0) \cdot (1 + \Delta\mu^j)$$

Ensemble of RCMs

Defining **weiting indexes** I$_b$ tq Ib$_i$∝1/(Id(RCM$_i$)
(∑ Ib$_i$ reescalada a 1)

Generation of ensembled series by linear combination of RCMs series

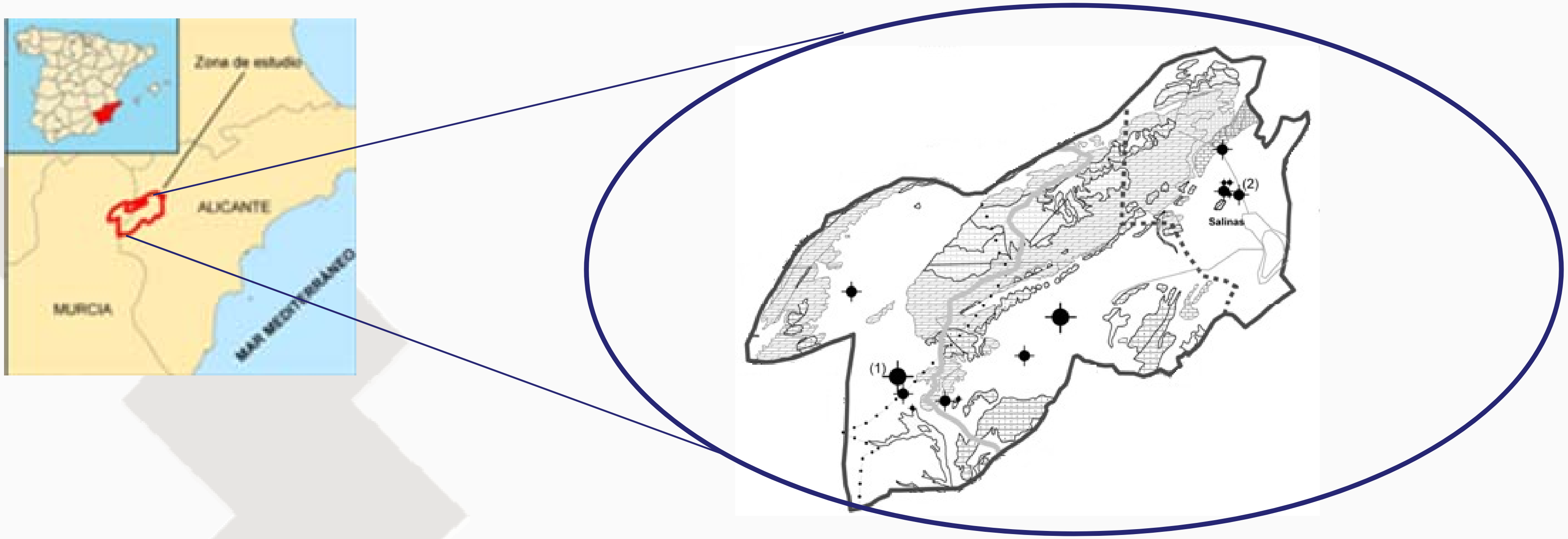
GENERATION OF FUTURE CLIMATE CHANGE SERIES (P, Tª) FOR THE SYSTEM

(Pulido-Velazquez et al. 2011)

ANALYSIS OF CLIMATE CHANGE IMPACTS ON GROUNDWATER RECHARGE IN THE AQUIFER SYSTEM

- **Simulation** of the generated **future climate series (P, Tª) within a calibrated recharge model (lumped or distributed)** for the aquifer system

IMPACT & ADAPTATION STRATEGIES.
(3) Sensitivity of GW recharge



- ❑ $S \approx 200$ km^2 (53 km^2 permeable outcrops)
- ❑Mean historical rainfall (1960-1990) = 278.3 mm/year
- ❑ Composed mainly by dolomites and limestones

IMPACT & ADAPTATION STRATEGIES.
(3) Sensitivity of GW recharge

Serral Salinas
Mancha Oriental

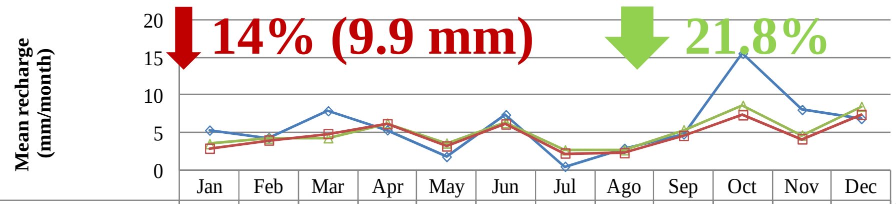
LUMPED analysis of GW RECHARGE. (Visual Balan; Samper et al., 1999)

W ENSEMBLE
Future series: Perturbation of historical series to satisfy Δmean & Δσ (RCM future-control)
Factor series: Perturbation of historical series to satisfy Δmean (RCM future-control)

Rainfall A2 scenario ⬇ 20.4 mm

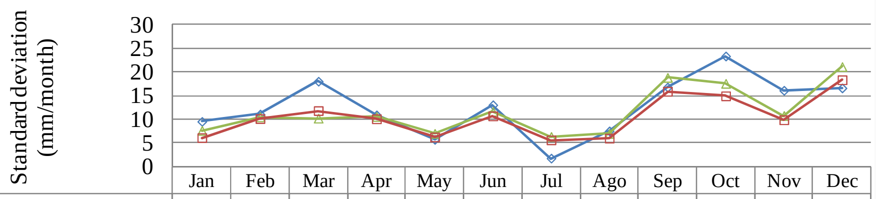
RECHARGE (mm): A2 scenario (**2071-2100**)

Monthly mean of the future recharge series for A2 scenario
(Ensembles of PRUDENCE models)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
Historical series	5.3	4.3	7.9	5.3	1.8	7.3	0.5	2.9	4.8	15.5	8.0	6.8
Future series (Ensembles of PRUDENCE models)	3.5	4.2	4.3	6.2	3.6	6.3	2.7	2.7	5.3	8.6	4.6	8.4
Factor series (Ensembles of PRUDENCE models)	2.9	4.0	4.8	6.1	3.2	6.1	2.2	2.3	4.6	7.3	4.1	7.4

Monthly standard deviation of the future recharge series for A2 scenario
(Ensembles of PRUDENCE models)

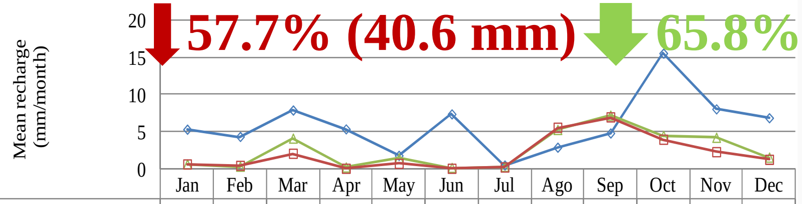


	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
Historical series	9.5	11.0	18.0	10.8	5.7	13.0	1.7	7.5	16.7	23.3	16.1	16.6
Future series (Ensembles of PRUDENCE models)	7.6	10.4	10.2	10.5	6.9	11.6	6.3	6.9	18.8	17.5	10.7	21.1
Factor series (Ensembles of PRUDENCE models)	6.1	10.1	11.8	10.0	6.2	10.6	5.6	5.9	15.9	14.9	9.8	18.3

Rainfall A1B scenario ⬇ 114.44 mm

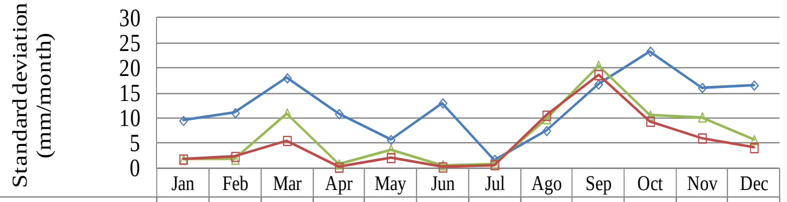
RECHARGE (mm): A1B scenario (**2071-2100**

Monthly mean of the future recharge series for A1B scenario
(Ensembles of ENSEMBLES models)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
Historical series	5.3	4.3	7.9	5.3	1.8	7.3	0.5	2.9	4.8	15.5	8.0	6.8
Future series (Ensembles of ENSEMBLES models)	0.6	0.3	4.1	0.2	1.4	0.2	0.3	5.2	7.2	4.5	4.2	1.5
Factor series (Ensembles of ENSEMBLES models)	0.6	0.4	2.1	0.0	0.7	0.0	0.2	5.6	6.9	3.9	2.3	1.2

Monthly standard deviation of the future recharge series for A1B scenario
(Ensembles of ENSEMBLES models)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
Historical series	9.5	11.0	18.0	10.8	5.7	13.0	1.7	7.5	16.7	23.3	16.1	16.6
Future series (Ensembles of ENSEMBLES models)	1.7	1.7	11.0	0.8	3.8	0.6	0.8	9.8	20.5	10.6	10.2	5.6
Factor series (Ensembles of ENSEMBLES models)	1.8	2.3	5.5	0.2	2.1	0.2	0.7	10.5	18.6	9.3	6.0	4.1

SELECTION & ENSAMBLE of RCMs for the system

Information required → **SELECTION OF RCMS** → Ensemble of RCMs

1) To obtain **lumped series** for the system → **2) TO ASSES CALIBRATION** by using the INDEXES **$Id(RCM_I)$** → **3) MULTIOBJETIVE ANALYSIS**: comparison and selection of models

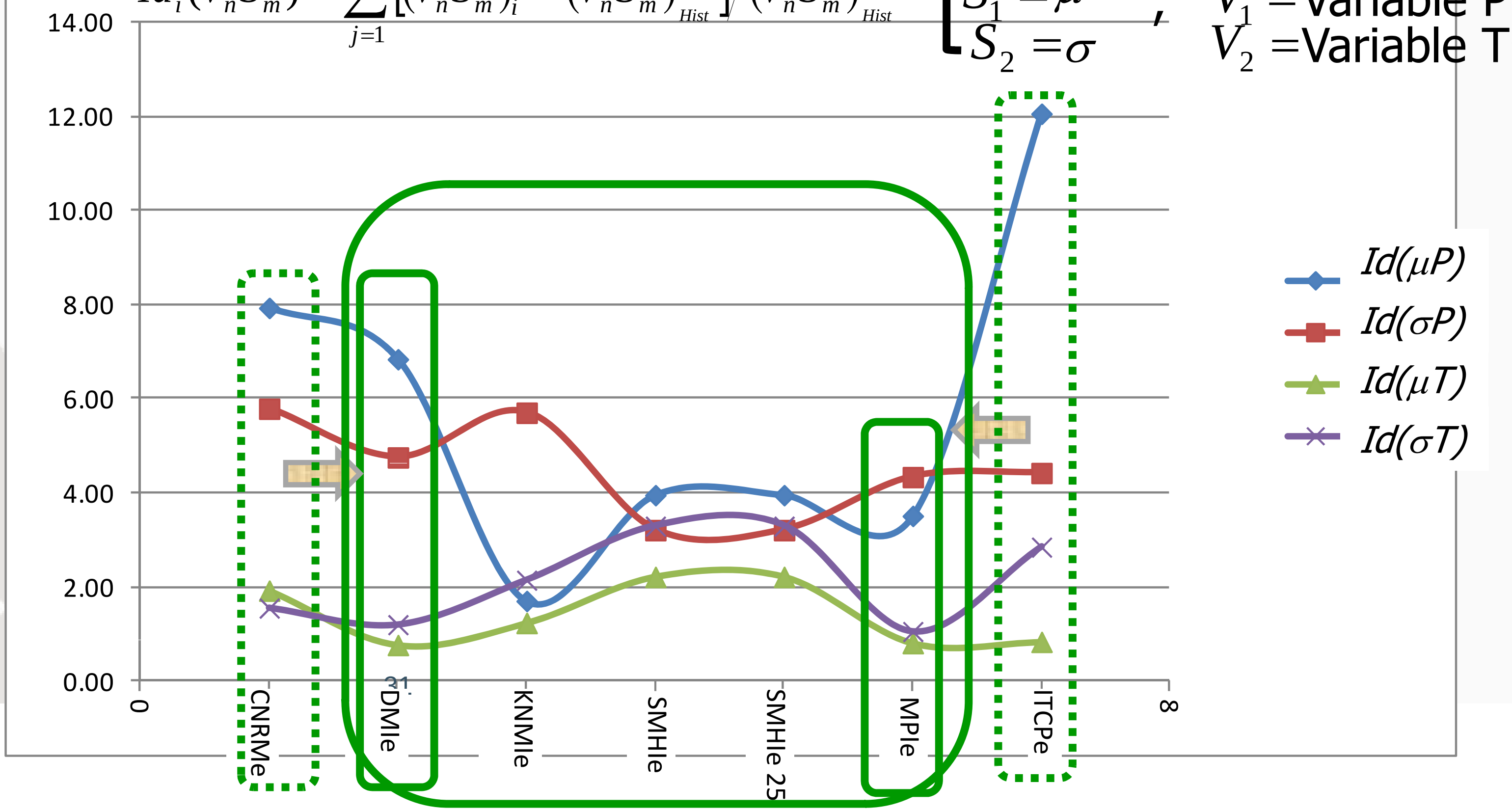
$$Id_i = \sum_{n,m=1}^{2} Id_i(V_n S_m)$$

$$Id_i(V_n S_m) = \sum_{j=1}^{12} \left[(V_n S_m)_i^j - (V_n S_m)_{Hist}^j \right] \Big/ (V_n S_m)_{Hist}^j$$

$_i =$ RCM$_i$; $_j =$ months for a mean year

$S_1 = \mu$; $V_1 =$ Variable P

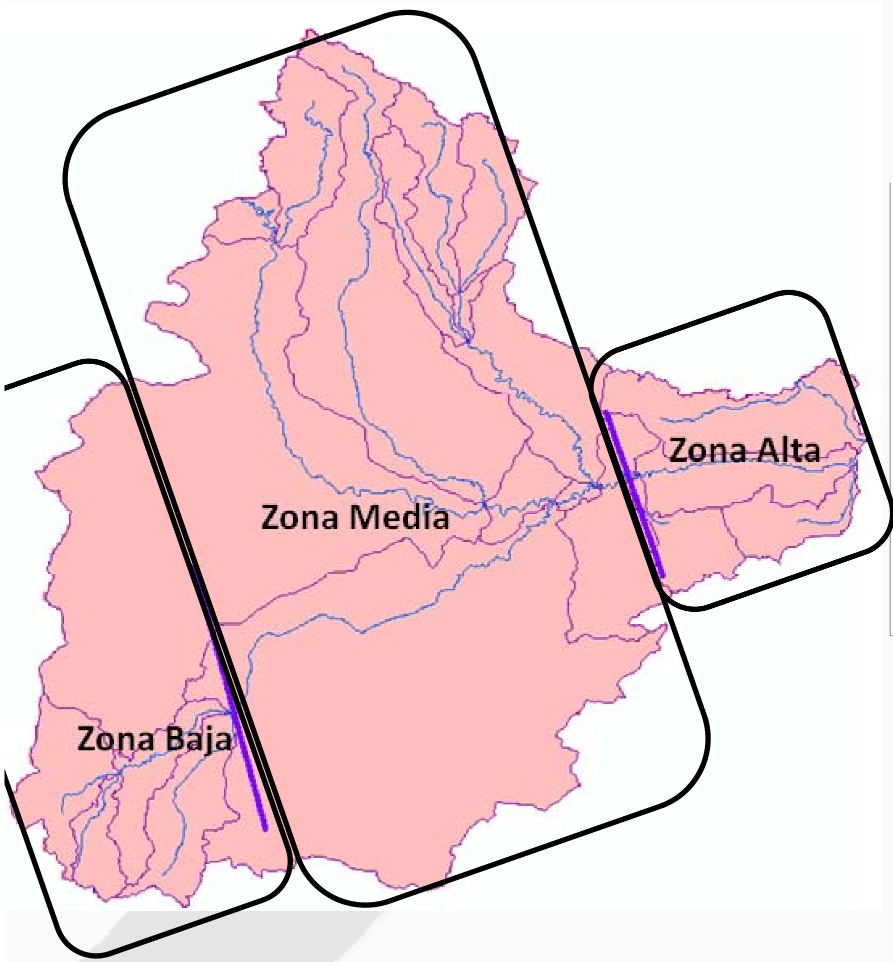
$S_2 = \sigma$; $V_2 =$ Variable Tª

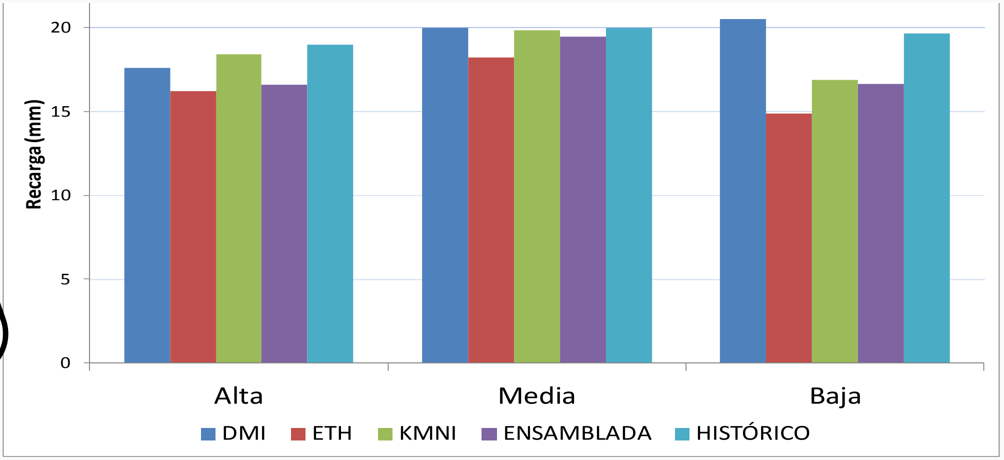


IMPACT & ADAPTATION STRATEGIES.
(3) Sensitivity of GW recharge ⇨ Serral Salinas
Mancha Oriental

- ❑ S ≈ 7400 km^2
- ❑Mean historical rainfall (1960-1990)= 300 mm(south)-550 mm(north)

DISTRIBUTED analysis of GW RECHARGE. (SWAT, 2007)





IMPACT & ADAPTATION STRATEGIES.
(1) CONCLUSIONS

(1) INTRODUCTION: Legal, social & technical framework

- **Necessity of CU management models** (MM) of WR at basin scale
- **TECHNICAL PROBLEMS** for **accurate** CU MANAGEMENT **analysis**:

\- Efficient and accurate **CU simulation** (Advantages of Eig. approaches)
\- Generation of **future hydrological series** (usually limited to μ anomalies)

(2) A **method** to diagnose climate change impacts, vulnerability and adaptation strategies in **CU** systems at **basin scale** (Pulido-Velazquez et al., 2011)

- Method to Generate **future hydrological scenarios** (basin scale MM) = monthly μ **&** σ anomalies
- **Method**, based on some **indices** (obtained from a CU system MM) can be applied to identify **problems and solutions** to CC in a WR system
- Case studies: **Serpis** and **Jucar River Basin**

IMPACT & ADAPTATION STRATEGIES.

(1) CONCLUSIONS

(3) **Sensitivity of Groundwater recharge** to climate change

- Method to Generate **future recharge scenarios** (basin scale MM) = monthly μ **&** σ anomalies
- A lumped analysis of CC impacts has ben performed in Serral Salinas
- A distributed analysis of CC impacts has ben performed in Mancha Oriental

Thank you very much for your attention!

Instituto Geológico
y Minero de España

David Pulido Velázquez
Spanish Geological Survey (IGME); Unidad de Granada; Departamento
de Infraestructura Geocientífica y Servicios

ASSESSMENT OF FUTURE IMPACTS AND ADAPTATION STRATEGIES TO CLIMATE CHANGE IN SEMI-ARID REGIONS

David Pulido Velázquez
Spanish Geological Survey (IGME); Unidad de Granada; Departamento de Infraestructura Geocientífica y Servicios

Granada, June 25 2013