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The Economic Value of Adaptive Strategies to Global Change for Water Management in Spain's Jucar Basin

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The Economic Value of Adaptive Strategies to Global Change for Water Management in Spain's Jucar Basin

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Abstract

Although many recent studies have quantified the potential effects of climate change on water resource systems, we face now the challenge of developing methods for assessing and selecting climate change adaptation options. This paper presents a method for assessing impacts and adaptation strategies to global change in a river basin system at different temporal horizons using a hydro-economic model. First, a multi-objective analysis selects climate change projections based on the fitting of the climate models to the historical conditions for the historical period. Inflows for climate change scenarios are generated using calibrated rainfall-runoff models, perturbing observed meteorological time series according to the projected anomalies in mean and standard deviation. Demands are projected for the different scenarios and characterized using economic demand curves. With the new water resource and demand scenarios, the impact of global change on system performance is assessed using a hydro-economic model with reliability and economic indices. A new *Economic Loss Index* is defined to assess the economic equity of the system. Selected adaptation strategies are simulated to compare performance with the business-as-usual scenario. The approach is applied to the Jucar river water resource system, in eastern Spain, using climate projections from

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the EU ENSEMBLES project. Results show that the system is vulnerable to global change, especially in the long-term, and that adaptation actions can save between 3 and 65 M€/year.

Introduction

Despite uncertainties in climate projections, global warming is unequivocal (IPCC 2013) and its impact is an important topic in many fields. Water resource management impacts of climate change and economic assessment of adaptive strategies becomes essential. In Europe, EU water and climate policies require water management to consider adaptation to climate change, with many policy and scientific challenges. Scientific research is essential for ensuring that new river basin management plans will be "climate proof" (Quevauviller et al. 2012), which requires development of adequate methods, planning and governance processes for integrating climate change into water management (EC 2012).

Although many studies quantify potential effects of climate change on water resource systems at basin scale (e.g. review in Vicuna and Dracup, 2007), there is now the challenge of developing methods to assess and select climate change adaptation strategies. Very few studies have addressed the selection and assessment of potential adaptation actions for water resource systems at a basin or system scale.

Closer integration of the assessment of socioeconomic vulnerabilities and adaptive capacity and physical impacts is more likely to yield more robust adaptations to the uncertain future scenarios (Ekstrom et al. 2013; Girard et al. 2015a and 2015b; Wilby et al. 2009). In this sense, hydroeconomic models (HEM) (Harou et al. 2009; Heinz et al. 2007; Pulido-Velazquez et al. 2008) are a step further in the use of water management models to assess and select adaptation strategies, by integrating hydrologic, engineering, environmental and economic aspects of water resources systems.

HEM can help design economically efficient policies, analyze economic impacts of variations in water deliveries in different sectors (economic losses from water scarcity) and assess the benefits of implementing different policies, through the use of economic water demand functions. HEM also has been used to value the potential of different economic policy instruments such as water markets (Erfani et al. 2014; Pulido-Velazquez et al. 2006) or water pricing (Pulido-Velazquez et al. 2013; Macian-Sorribes et al., 2015; Riegels et al. 2013).

Although HEM has been implemented widely with different approaches, few examples have addressed the impacts of climate change on water resource systems (Hurd and Coonrod 2012; Tanaka et al. 2006; Molina et al., 2013; Yang et al. 2013), and fewer studies have assessed not only the costs (as in Girard et al., 2015c) but also the benefits on the selection of potential adaptation actions (Connell-Buck et al. 2011; Medellin-Azuara et al. 2008).

Two challenging issues when using HEMs are to assess climate change impacts are the downscaling and hydrological simulation of climate projections, and the definition of indicators for assessing the system performance.

Regarding the first issue, climate change analyses are often based on climate model predictions, but water resource system analysis requires higher resolution than those provided by global climate models (GCM). Dynamic downscaled climate models using regional climate models (RCM) have been developed last decades for high-resolution applications over the world. European Union (EU) funded project ENSEMBLES runs multiple regional climate models over the same grid to improve the accuracy and reliability of its forecasts (van der Linden and Mitchell 2009). However, the resolution of a RCM is not enough for most hydrological models, and further downscaling and bias-correction is needed (Fowler et al. 2007). Though there is an extensive literature on the strengths and weaknesses of methods for downscaling climatic variables to allow results to be obtained for smaller cells, fewer studies focus on uncertainties related to downscaling to the resolution needed to assess the impacts of climate change on water resources systems (Cayan et al. 2008; Fowler et al. 2007; Seiller and Anctil 2014).

Another key issue is the global assessment of water resource system performance. Several authors propose different indices to condense the outputs of water management models, usually involving the concepts of reliability, vulnerability, sustainability or resilience (Asefa et al. 2014; Ashofteh et al. 2013; Martin-Carrasco and Garrote 2007; El-Baroudy and Simonovic 2004; Hashimoto et al. 1982a and 1982b). However, there is a gap regarding indicators integrating the economic performance of the water system using hydroeconomic models.

In this paper we address these both gaps. We deal with downscaling climate projections and simulating hydrology according to these projections by using for first time in the selected basin a spatially-distributed downscaling method for climate change projections that selects best-fitting models to historic conditions. Secondly, we analyze the performance of the system for addressing climate change vulnerability using performance indices—including a newly defined economic index—to help in the design of adaptive strategies.

This paper develops a framework to assess climate change impacts and the performance of adaptive strategies in water resource systems at different time horizons using a HEM, and applies the model to the Jucar River basin, Spain. Hydrologic inputs are updated to the latest climatic dataset available, analyzing the main output variables of ENSEMBLES project and downscaling them over the basin to include the spatial variability of the climate change effects. Using generated inflows and projecting future demands, we run a simulation model of the Jucar River system developed on the DSS AQUATOOL (Andreu et al. 1996) in order to obtain the system performance for each climate scenario. The economic assessment is obtained by applying scarcity cost functions to the outputs of the water management model. We evaluate the system using indices that condense the general status, using common indices cited in the literature and a new economic index, named *Economic Loss Index*. Finally, we define four adaptive strategies to climate change, using the model for each new strategy-scenario combination to estimate the system performance and corresponding economic impacts.

Some studies have estimated previously the hydrologic impacts of climate change in the Jucar River Basin (Chirivella Osma 2010; Estrela et al. 2012; Ferrer et al. 2012), but it is the first time that the economic impacts and the potential economic benefits of adaptive strategies are assessed in this basin.

In the remainder of the paper, we first present the methods, then we describe the case study, afterwards we present the main results obtained, and finally we discuss the results and conclusions.

Methods

Overall description

Integrated assessment of climate change impacts on water resource systems typically requires a variety of models used sequentially (Wilby et al. 2009; Girard et al., 2015a). The method used here employs climate, hydrology, crop water requirements, statistical, water management and hydro-economic models to obtain final results (Figure 1).

HERE: Figure 1: Flow chart representing the methodological framework applied [double-lined boxes represent input data, dashed boxes denote models or processes applied, and solid boxes indicate intermediate or final results].

Selection of best-fitting regional climate models from ENSEMBLES projections

The development of the future inflow and demand scenarios begin with selecting the climate projections. We based the selection on the climate models' ability to reproduce observed conditions over the historic period. A multi-objective analysis is used to select the best-fitting RCMs from the ENSEMBLES project to the historic data for the Jucar River basin.

Assuming that best-fitting RCMs to historical data provide reliable climate change projections to the local conditions, the selection is based in the comparison of monthly mean and standard deviation of temperature and precipitation of historical data with the RCMs from the ENSEMBLES project, using GIS tools to aggregate spatially the variables.

To summarize the goodness-of-fit of the ENSEMBLES RCMs, we define an index (*Id*) as the sum (over the 12 months of the average year) of the absolute value of relative distance between historic dataset (D) and control period (C) for the mean and the standard deviation of P and T:

$$Id_{\mu} = \sum_{i=1}^{i=12} \frac{\left|\mu_{D_i} - \mu_{C_i}\right|}{\mu_{D_i}} \quad Id_{\sigma} = \sum_{i=1}^{i=12} \frac{\left|\sigma_{D_i} - \sigma_{C_i}\right|}{\sigma_{D_i}}$$

From these results, we develop a multi-objective analysis to find models that are "inferiors" to others in fitting the historical dataset. We compared all the models and discarded models that are "worse" than any other model in all the statistics (sum of absolute value of the relative distance of the mean and standard deviation of temperature and precipitation), i.e., strictly dominated or inferior solutions. We applied this approach to select the best-fit RCMs of ENSEMBLES to the historic dataset.

Generation of future climate scenarios

Once the best-fitting RCMs are selected, we obtain the future baseline scenarios of climatic data at the local scale required for assessing impacts on the water resource system using a variation of the statistical delta-change downscaling method (Diaz-Nieto and Wilby 2005; Fowler et al. 2007). We perturbed the observed time series (mean air temperature, T, and precipitation, P, over the 1961-1990 control period) by modifying mean and standard deviation of the original observations through the application to the historical time series of the relative change in those statistics between the control and future time series. For that purpose, we first obtained the monthly relative change of mean and standard deviation for P and T for the short-term scenario (2011-2040), mid-term scenario (2041-2070) and long-term scenario (2071-2100). This procedure, also applied in Pulido-Velazquez et al. (2014), extends a method developed originally for perturbing streamflow series in Pulido-Velazquez et al. (2011), adapted for spatially distributed climatic data. For each cell of the RCMs considered, the procedure involves these steps:

i. First, we standardize the monthly historical data time series h_D (for P and T) using the corresponding monthly means and standard deviations

$$y^{x.j}(h_D) = \frac{\left| {h_D}^{x \cdot j} - \mu^j(h_D) \right|}{\sigma^j(h_D)}$$

where *x* represents years and *j* varies from 1 to 12 representing the months of a year in the series. The product *x.j* represents the number of months in the series. y is the standardized time series

ii. We obtain the average relative change on mean and standard deviation (for the 12 values that correspond to the average year) between the control (c_M)and the future (f_M) series derived from the RCMs

$$\Delta\mu^j = \frac{\left[\mu^j(f_M) - \mu^j(c_M)\right]}{\mu^j(c_M)} \quad \text{and} \quad \Delta\sigma^j = \frac{\left[\sigma^j(f_M) - \sigma^j(c_M)\right]}{\sigma^j(c_M)}$$

iii. Finally, we obtain the future time series (${f_G}^{x \cdot j}$) applying the relatives changes in both statistics to the historical standardized series as

$${f_G}^{x \cdot j} = \sigma^j(f_G) \cdot y_N^{x \cdot j}(h_D) + \mu^j(f_D)$$

where $\sigma^j(f_G) = \sigma^j(h_D) \cdot (1 + \Delta\sigma^j)$ and $\mu^j(f_G) = \mu^j(h_D) \cdot (1 + \Delta\mu^j)$; h_D refers to the historic timeseries and f_G, to the generated climate change or future scenario series.

Generation of future inflow scenarios

For generating the future inflow time series we first calibrate a rainfall-runoff model using the historical data and then the future scenarios are obtained by simulating the modified precipitation and temperature time series through the process described above. The rainfall-runoff model is a lumped, conceptual hydrological model (the Temez model, Temez 1977) that replicates the hydrologic system through balance and transfer equations using just 4 parameters and 2 storage tanks (representing the soil or unsaturated zone and the aquifer). The model is calibrated for each of the 8 sub-basins considered, corresponding to the catchments of the main major reservoirs of the system.

The model assumes that total runoff is generated by the sum of a rapid response—surface runoff—and a slow response—baseflow from the aquifer—. A portion T of the rainfall P becomes rainfall excess while the rest is stored in the soil where is partially lost as evapotranspiration. This process is mainly controlled by 2 parameters: H_{max} (maximum soil moisture capacity) and C (threshold to be exceeded for rainfall to generate runoff). The rainfall excess is divided into 2 components: direct surface runoff and infiltration, which is driven by the parameter I_{max}. The infiltration is considered to recharge the aquifer tank, in which groundwater discharge into the stream (baseflow) follows a negative exponential function that depends on the discharge parameter α (linear reservoir model). Despite its simple formulation, the Temez model has been applied widely in Spanish basins obtaining good results (Estrela and Quintas 1996).

HERE: Figure 2: Schematic of the Temez rainfall-runoff method

Once the model is adjusted, we modify the climatic data using those obtained from perturbed historical data with averaged selected ENSEMBLES RCMs relative changes, and run the rainfall-runoff model to generate the streamflow time series for the future scenarios.

Generation of future demands

Water demands for future scenario have been obtained following two different procedures for urban and irrigated agriculture necessities, assuming that other demands less significant such as power generations and environmental flows remain constant. For urban, we have used statistical projections of populations in agreement with the forcing scenarios assumption of the ENSEMBLES models using current trends of per capita water use in cities to obtain final demands.. For agricultural water requirements, using climate conditions obtained before and assumptions on crop acreage explained in the case study implementation model, we have followed the procedure to compute crop water requirements based on FAO Irrigation and Drainage Paper No. 56 (Allen et al. 1998). Software CropWat 8.0 for Windows, developed by the Land and Water Development Division of FAO, has been used to obtain crop water requirement of each scenario, and total agricultural demand is assessed accounting for the areas of each crop. CropWat calculates crop water requirements and irrigation requirements based on soil, climate and crop data. The program allows the development of irrigation schedules for different management conditions, so it has been used to obtain monthly water demands from the different crops present in the two regions considered.

Simulation of climate change's impacts on the system

To assess the performance of the system we use SIMGES, a simulation model of the generalized DSS shell AQUATOOL (Andreu et al. 1996). SIMGES is a tool for developing integrated simulation models of water resource systems, including elements such as natural streams, aquifers, reservoirs, water conveyance facilities, irrigation, urban, hydropower, and operating rules to manage the system. The model applies an optimization algorithm to deal with monthly decisions of water allocation among competing uses, minimizing the weighted deviations from the water supply and environmental flow targets. The weights are defined accordingly to the priorities of water allocation defined for each demand (Andreu et al. 1996).

For the business-as-usual (BAU) scenario we use the historic time series. Using the inflows derived from the Temez rainfall-runoff model and the demands for the different climatic scenarios, we simulate each scenario (control, short-term, mid-term and long-term scenarios) with a monthly time step, obtaining water shortages, reliability of deliveries to each demand, monthly flows and storages among many other system variables. This is done under the assumption that the same water allocation and system operating rules are maintained in the future.

Economic assessment of climate change impacts

The model uses the demand curves and time series of water allocation to assess the economic losses derived from water shortages in the consumptive demands plus the variable operating costs (e.g. pumping costs).

When a demand is not fully met, the scarcity cost is assessed as the area under the curve of the functions defined above between the maximum demand and the actual water delivered. To assess the scarcity cost in the climate change scenarios, the economic functions for each demand have been modified to include climatic and population changes, and converting annual water deliveries in m3/ha into total deliveries in Mm^3/year.

Assessment of the system performance

Many indexes have been defined to assess water resources system performance after the seminal work of Hashimoto et al. (1982b). Here we use four indices described before (Martin-Carrasco et al. 2013; Pulido-Velazquez et al. 2011, Martin-Carrasco and Garrote 2007):

- The *demand satisfaction index* represents the system's volumetric supply reliability. It is computed by the equation $I_S = S/D$, where S represents the total amount of water supplied and D is the total water demand.
- The *demand reliability index* represents the total delivery provided to the demand under a condition of no failure (S_r) divided by the total water demand of the system, and it is calculated as $I_r = S_r/D$.
- The *withdrawal index* is defined to evaluate the percentage of water resources abstracted from the system (Y) with respect to the total demand, and can be assessed as $I_w = Y/D$.
- The *withdrawal use index* is defined to evaluate the percentage of water resources withdrawn from the system to supply the demand, and it can be computed as $I_u = S/Y$.

To analyze the system performance we first calculate the demand satisfaction and demand reliability indices: when the system has high values for both indices the system, it is performing well; but when one index has intermediate or low values, the system is unreliable (if the demands are satisfied with unreliability) or vulnerable, when the demand is not satisfied regularly. After these indices have been evaluated, we obtain withdrawal indices to analyze if there is sustainability in the water use, or there is excess in withdrawals for the system capacity. Depending on the problems shown by the analysis, the solutions vary from demand management to improvement, better managing the whole system, increasing regulation of system withdrawals or necessity of complementary resources.

Additionally to the indices presented, and following a similar method, we define a new index, the *Economic Loss Index*, to assess the equity of the system assessing the relation between the demands' losses over the potential maximum loss.

$$I_{EL} = \frac{C_e}{L};$$

where C_e is the average annual scarcity cost and L is the maximum annual loss —obtained as the integral under the demand curve between the current water deliveries and the target demand—. This index is used to assess the equity of the system allocating the resources. Furthermore, it can help defining adaptive strategies to improve system's equity.

Adaptive strategies

Based on the analysis of the system performance given, the expected impacts of global change and the ongoing policy debate in the basin, some potential measures for evaluation for the long-term scenario are selected. To assess the effects of these measures we have run the simulation model of water management and the hydro-economic analysis for each strategy and climate change scenario, comparing the results with the BAU scenario.

Case Study Implementation

The Jucar Water Resource System (Jucar WRS), in eastern Spain, is the largest basin (22187 km^2) and the most important system with regards available water resources within the Jucar River Basin District (Jucar RBD or CHJ —Confederación Hidrográfica del Júcar).

The Jucar WRS has a Mediterranean climate, with warm, dry summers, and mild, wet winters. With an annual average precipitation of 494 mm and annual average temperature of 13.8ºC, there is a steep gradient of variation between the inland and coastal regions. Total average available water resources are 1668 Mm^3 per year, mostly from groundwater; a 75% of the average river flow is regulated with surface reservoirs being Alarcon (1118 Mm3 of useful capacity; upper basin) and Tous (378 Mm3, lower basin) the largest one along the river main course, and Contreras (852 Mm3), on the Cabriel river. Annual system total demand is 1639 hm^3, 85% for agriculture, 13% urban uses, and 2% is industrial use (CHJ 2014).

HERE: Figure 3: a) Jucar River Basin location; b) Main features of Jucar Water Resource System.

Most system demands are in the coastal regions, as the historic "Ribera del Júcar" agricultural demands (including the Acequia Real del Jucar, the oldest irrigation district, founded in 1264), coastal urban and industrial city-demands and the demand of the Valencia metropolitan region (with a population over 1,400,000, although not fully located within the basin boundaries, receives Jucar River water). The main inland demands are Albacete city (population over 170,000) and the irrigated regions of Mancha Oriental. Over the last 30 years the progressive transformation of roughly 100,000 ha from dry to irrigated farmland in "Mancha Oriental" regions has accelerated socioeconomic development based on widespread use of groundwater resources overdrafting the aquifer and generating significant water conflicts downstream because of resulting streamflow depletion in the connected Jucar river (Sanz et al. 2011). Climate change will likely exacerbate this issue (Pulido-Velazquez et al. 2014), which demands groundwater abstraction controls, including collective actions; some have been already successfully implemented (Lopez-Gunn 2003). The Jucar RBD has strong interaction between surface and groundwater, which requires an integrated analysis of both and models that include these interactions (Ferrer et al. 2012).

The calibration of the rainfall-runoff model was done using gridded climatic data for the region from Herrera et al. (2012) and historical unimpaired streamflow time series from SIMPA, Spanish acronym standing for "Integrated System for Rainfall-Runoff Modeling". We used 1961-1990 as calibration period, validating the model over the period 1991-2000. Total water volume, annual mean error and squared error and Nash-Sutcliffe coefficient were used as metrics to jointly evaluate the goodness-of-fit of the model (the Supporting Information includes further results of the model calibration and validation).

The detailed Jucar River system AQUATOOL model has been developed and perfected over time by the Research Institute of Water and Environmental Engineering (IIAMA) of the Technical University of Valencia (UPV) in a long fruitful collaboration with the Jucar River Basin Authority.

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

Current demands in the basin from CHJ (2009, 2014) include urban supply, agricultural demands, industrial use, energy production uses and environmental flows. Future demands have been estimated for the irrigated agriculture and urban uses, whereas the remaining uses have been considered as constant, due to the low significance of these other demands.

Future urban demands were estimated using statistical projections of population (IVE 2012). Under this statistical projection the population grows till 2050 and after that remains stable, as stated in the UN World Population Prospects Database (UN 2011). This is consistent with the modeling assumptions of the ENSEMBLES projections: all ENSEMBLES models are run under the A1B forcing scenario assumption, that describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, the rapid introduction of new and more efficient technologies, and a balanced generation of energy from fossil and non-fossil fuels. From the projected population, we obtain the total water demand assuming constant per capita water use—a fair assumption, a little conservative though, because per capita use is decreasing a little in the last decade but still in similar levels than in 1995 (INE 2016)—.

Agricultural uses within Jucar River basin are clearly separated spatial and typologically between the inland Albacete region—*"Mancha Oriental"*—, and the flat coastal regions —*"Ribera del Jucar"*—. Climatic data for base case scenario were obtained from the Spain02 project dataset (Herrera et al. 2012) over the 1960-2000 period for both regions, taking into account one representative cell for each region (39N 2W to Mancha Oriental and 39.2N 0.4W for Ribera del Jucar).

We selected as representative crops for the agronomic modelling Mancha Oriental a variety of seasonal crops grown in that region — wheat, barley, corn, grapes, onions and alfalfa— representing more than 70% of total acreage in 2011 (JCRMO 2012), whereas in the Ribera del Jucar we only modeled oranges and rice, by far the main crops in that region. From the climatic and crop acreage data, and using the software CROPWAT explained above, we obtain the water requirements, also assuming that the acreage for the crop mix within the two regions is constant through the different scenarios.

The economic demand functions for the different uses in the Jucar River Basin were developed based on previous economic evaluations for the Jucar River Basin District and adapted for this study. For urban water use, we applied a simple "point-expansion" approach: a constant elasticity curve derived from current water use and water price (1.06 €/m^3) in the region and an estimate of the price elasticity of demand (Jenkins *et al.,* 2003). A demand price-elasticity value of -0.65 was used in all the urban cases, based on the estimate from an econometric model based on panel data for the Valencia region (Garcia Valiñas, 2002). From this point, the demand function was extrapolated assuming that there is a maximum willingness to pay per cubic meter before switching to other water source, assumed 6 €/m^3 in most urban demands, and 7.8 €/m^3 (a 30% increase) in tourist locations because of the higher seasonality.

$$Q = c \cdot P^{\varepsilon}$$

For agricultural demands we developed three different economic functions based on the main crops produced: citrus and rice in the Ribera Baixa area, and cereals in the Mancha Oriental area. The assumptions are adapted from the economic demand functions shown in MAGRAMA (2000) and Sumpsi et al. (1998). Additional information on the development of those curves is provided in the supplementary material.

- For citrus, the water demand in some traditional irrigation sectors in the Jucar region follow a function with three parts: a first inelastic part close to the current demand and price, an exponential part where demands start to decrease, and a final elastic part until the price of crop retirement. We assume a theoretical exponential function, $P=a+b\cdot Q+c\cdot Q^d$, adjusted by three points: current demand and current price (0.001 €/m^3); a second point where price is 0.25 €/m^3 and demand from the first point is quite inelastic; and a third point that is the maximum willingness to pay that is 1 €/m^3.

- For rice, because the higher elasticity and lower profit, we assume a piece-linear function with two stages: the first inelastic part defined by the current demand and current price (0.005 €/m^3) and a second lineal stage defined by this last point and the maximum willingness to pay (0.03 €/m^3).
- For cereals we assume a concave function, $P=a+b\cdot Q+c\cdot Q^2+d/(Q+e)$, adjusted with the maximum willingness to pay (0.6 €/m^3), a point with 30% of maximum water demand with price 0.03 €/m^3 and the point with maximum demand and price null.

The economic functions for hydropower and nuclear water demands, derived from MMA (2004), show a perfectly elastic demand with a price of 0.21 €/m3. A graphical description of all demand functions is included in the Supporting Information.

Results

Best-fitting regional climate models from ENSEMBLES projections

Following the methodology developed above, the best-fitting ENSEMBLES RCMs selected for the Jucar River Basin are: DMI-HIRHAM, GKSSCLM, KNMI RACMO2, MPI M REMO, UCLM-PROMES and OURANOS MRCC. Table 1 shows the results of the multiobjective analysis.

HERE: Table 1: I_d index represents relative distance between historic dataset and base case, as a metric of goodness of fit of the ENSEMBLES RCMs. Selected models, and their metrics, are underlined.

In the Supporting Information a comparison between historical data and the selected ENSEMBLES RCMs outputs for the control period is shown. This study confirms that historical precipitation in the Jucar Basin is overestimated by the RCMs, thus this concern can be significant when climate change impacts on water resources are especially sensitive to precipitation.

Future climate scenarios

Results for the spatially and temporally aggregated monthly key statistics for future scenarios (Figure 4) show that the adjustment of the RCMs in the control scenario respect to the historic scenario is much better in the temperature than in precipitation variables. It can be also seen that whereas the temperature pattern through the different scenarios is a steady increase, the precipitation changes are much more inconsistent.

HERE: Figure 4: Climatic variables variations projected by ENSEMBLES RCMs for all the scenarios.

Future inflow and demand scenarios

Results for monthly averaged runoff show a slight variation in the short-term scenario, with an average reduction of 10 percent for the whole basin. The mid-term scenario has a significant increase on winter runoff caused by higher precipitation, resulting in 5 percent more total annual runoff. Finally, the long-term scenario shows a deep decrease on annual precipitation, decreasing total runoff by 25 percent.

The statistical projection of water demands result in a 3.95% increase of urban demand for the short-term scenario, an 8.30% increase for the mid-term scenario and an 8.46% increase for the long-term scenario. Agricultural demands obtained from Cropwat for future scenarios show an important increase in water requirement because of temperature increase (in the Supporting Information the variation of water requirements for each crop is presented).

Figure 5 presents the average monthly demands and runoff for each scenario considered.

HERE: Figure 5: Monthly runoff and demand for the scenarios considered.

Climate change's impacts on the system

Reliabilities (presented in Table 2) show a decrease from the base case to the long-term scenario when impacts become very significant. Urban and industrial demands are less affected because they have the highest priorities and the impacts on reliability are relatively acceptable, whereas the agricultural demands show larger impacts, with 40% monthly reliability in some demands for the long-term scenario. An exception to this trend is the "Zona Albacete" irrigation sector because it is mostly irrigated with groundwater, and they will pump without accounting for reductions to surface water (at the expenses of a greater groundwater overdrafting).

HERE: Table 2: Scarcity Costs (SC), Monthly Reliability (R) and *Economic Loss Index* (I_{EL}) for each demands and all the climate change scenarios and adaptation strategies simulated for the Jucar River Basin.

In the Supporting Information we present graphically the entire time series for delivery shortages, reservoir storage and hydro-power flows. The trend is the same mentioned earlier, a progressive decrease in the reliability of water supply, especially in long-term scenario as water availability is further reduced while facing increasing demands.

The results of the hydro-economic model in Table 2 show that average scarcity cost increases throughout the temporal scenarios, with a significant increase between the mid- and long-term scenarios. Because of the different allocation priorities, there is a significant difference on the economic impact across demands, where "Ac. Real y Antella" and "Canal J-T" are bearing most of the total scarcity cost, while other demands are less affected. Figure 6, presents the results over the historical time series (60 years) and the results of the perturbed historical time series for the climate change scenarios, aggregating scarcity costs for all the demands in the system, showing a greater impact of drought periods on the mid- and long-term scenarios.

HERE: Figure 6: Total annual scarcity cost for each scenario.

Assessment of the system performance

Table 2 shows the results of the indices evaluated, whereas Table 3 shows the results for the *Economic Loss Index* for each demand in each scenario, showing how some demands are always more damaged than others for all scenarios.

HERE Table 3: Results for system overall indices for each climate change scenario.

System performance is assessed using the indices, showing that the system is performing well in the short- and mid-term scenarios. In the long-term, however, the system becomes very vulnerable, with unreliable supplies and with excess of demand respect to the withdrawal. Additionally, the *economic loss index* shows a lack of equity in water allocation, thus some demands are more affected than others. Therefore, we define and assess potential adaptive options that could be taken to avoid the economic costs of inaction for the long-term.

Definition and assessment of adaptive strategies

We select the following potential measures for evaluation for the long-term scenario:

- Demand Management actions:
    - Efficiency improvement in Ribera del Jucar: the irrigation efficiencies in traditional irrigation areas of the lower Jucar River are under 0.5 (CHJ 2009), whereas irrigation in the Canal Jucar-Turia irrigation district has a efficiency of 0.75, and 0.85 for Mancha Oriental. The first proposal on demand management is to to increase the efficiency of the traditional irrigation demands up to 0.7 through irrigation modernization.

    - Decrease in Mancha Oriental demand: Most producers in Mancha Oriental are subsided by the Common Agricultural Policy (CAP) of the UE. Some experts declare that if the subsides disappear, only 30% of current exploitations would be maintained. Hence, we examine decreasing Mancha Oriental demands, maintaining only the exploitations that are willing to pay more than 0.06 €/m^3 (current average pumping cost), what implies a reduction in 75% of the demand.

- System management actions:
  - Priorities: we examine assigning same priority to all irrigation areas to avoid the differences in relative economic loss and improve system equity.
  - Water Markets: differences in order of magnitude in the willingness to pay for water create the ideal scenario to introduce water markets. Hence, we propose an adaptive management strategy to include this management mechanism.

We run the water management model simulation and hydro-economic analysis for each strategy and for each climate change scenario. Average annual scarcity cost in Table 2 show a significant reduction in the average annual scarcity cost for the strategies considered. The efficiency improvement on irrigations systems in La Ribera del Jucar leads to a reduction of the average annual scarcity cost by 41 M€/year (45.11% reduction with respect to the long-term scenario), agricultural demand reduction in Mancha Oriental has a decrease of 65 M€/year (71.90% reduction), modification on water right priorities has a reduction of 3 M€/year (3.40%) and a redistribution of system equity, and Water Markets implementation could reduce the average annual scarcity cost by 14 M€/year (a 14.47% reduction respect Long-Term scenario).

Figure 7 presents annual scarcity cost time series for the different adaptation scenarios. "Priorities" strategy closely follows the same trend that the long-term scenario, while the other strategies improves the overall economic results for the river basin system, presenting the decrease on Mancha demand the larger economic saving, followed by the Efficiency strategy and finally, the implementation of Water Markets.

HERE: Figure 7: Average Annual Scarcity Cost for each Adaptive Strategy.

Table 2 shows the scarcity cost for each demand changes with the different strategies employed. It is important to note the improved values of the "Priorities" strategy as compared to the BAU long-term scenario, where the most damaged demands in the BAU long term scenario —Canal J-T, Cuatro Pueblos, Cullera and Sueca— are better off. We can therefore conclude that this scenario improves the equity of water allocation between the demands, on economic terms.

Discussion

This study clearly reveals the need of an interdisciplinary research in the analysis of global change impacts and the assessment and selection of adaptation strategies, what requires developing an integrated framework that moves across disciplines. Developing such integrated framework is certainly a complex task that faces numerous theoretical and practical challenges (Girard et al. 2015b; Kragt et al. 2013). In this context, modelling provides "a communicative tool and a valuable methodology to merge the many structures and processes that are involved in interdisciplinary research projects" (Kragt et al. 2013).

A chain of models are used for assessing the impact of climate and global change and for valuing the contribution of adaptation measures to improve the system performance and the economic results. First, we use a pseudo-distributed rainfall-runoff model (lumped per sub-basin) in order to translate future P and T scenarios into new inflow time series. This information is then incorporated into a simulation model of water resource system management, used to simulate the BAU scenarios and the effect of different adaptive measures in a global change setting. Finally, a hydroeconomic approach is used to translate those impacts into economic benefits and economic losses from the changes in water deliveries to the different uses in the basin.

The calibration of the hydrological model requires unimpaired discharge time series in each sub-basin as described in the methods section. There is always uncertain in the process of restitution of the recorded river discharge data into impaired flow. There is as well uncertainty on the potential predictive capability of hydrological models for simulating climate change scenarios (Thirel et al., 2015; Fowler et al., 2016).

Future urban demands we have assumed that the per capita water use remains constant over time. Although per capita use is decreasing a little in the last decade, we decided to use per constant per capita use because some studies have related urban water use with temperature (Maidment et al. 1985), and increased temperatures in the climate change scenarios could induce a higher per capita water use.

For future agricultural demands crop water requirements have been estimated based only on changes in temperature and precipitation. CO_2 effects or other possible dependencies have not been accounted. It is expected that the fertilization effect of rising CO_2 concentrations will offset the crop yield losses (Long et al. 2006). Furthermore crop acreage, the crop mix and yields are expected to change in the future, as crops will respond to new characteristics and farmers will adapt their production functions to new circumstances. Therefore, the results have to be understood under these assumptions, in relative terms respect to the BAU scenario: we are not trying to predict the economic costs of the future, but rather to show that adaptive strategies to climate change for water resources are a useful tool to reduce the potential economic costs of future conditions, showing which adaptation tools are relatively more effective.

Another interesting point to discuss is about the current allocation of water rights among the uses. It is possible that the future potential expansion of the irrigated demand were limited by the existing distribution of water rights, opening potential litigations with other conflicting uses. The results show that citrus trees will suffer a greater increase on water requirements than any other crop, so irrigation districts with citrus would be more affected for this unaccounted legal issue.

In the results of the analysis of the adaptive strategies the last 2 strategies proposed are just changes in management—by modifying priorities or enhancing water markets—that do not need infrastructure investments or reductions in demand. This shows the potential to reduce effects of climate change by improving water management. Other adaptive management strategies could also be analyzed, such as interbasin water transfers, desalination, or improved reservoir and conjunctive use management, being the method described valid for any other action. The integration of bottom-up and top-down approaches (Girard et al. 2015a) could also help to better define the future scenarios and local adaptation strategies to be assessed. In any case, the main goal of that part was to show the framework to analyze the strategies.

Conclusions

We described and applied a framework to evaluate the impacts of climate change on water resource systems and the contribution of potential adaptation measures. The method considers the analysis of the physical response of a basin by selecting the best-fitting RCMs and downscaling the key hydrologic variables in order to obtain future inflows using a rainfall-runoff model. By projecting future agricultural and urban demands, and using water management simulation models, we obtained the system reliability for future scenarios. Assigning economic values to the water uses we economically assess the shortages (scarcity cost). Finally we defined adaptive strategies and evaluate the reliability of the system and the economic response to rank adaptive strategies to deal with global change.

Results show that show the selected RCM models present a good fit to historic temperature but a poorer fit for precipitation. The overall effects of climate change scenarios obtained using the water management model show a progressive decrease in the reliability of supply through time, especially in the long-term.

These expected shortages would increase average annual scarcity cost from roughly 1 M€ in the base case, to 8 M€, 21 M€ and 91 M€ in short-, mid- and long-term scenarios, assuming no changes in the infrastructure or operation of the system (business-as-usual scenarios). Some of the demands—mainly Canal Jucar-Turia and Acequia Real irrigation districts— will be the most economically affected in the future. By using the *Economic Loss Index* we are able to assess the potential of different adaptation options to increase the economic efficiency and equity of the system.

Through the application of different adaptation strategies the system can save from 3 to 65 M€/year of the expected economic losses, depending on the adaptation actions adopted. Some strategies analyzed involve neither demand reduction nor significant additional investments, but only new policies to manage the system in a more efficient way for the new conditions.

Climate change is a global concern. Consequently many institutions are enforcing global efforts and releasing reports and datasets to analyze the potential effects of climate change on natural and human systems. But most water problems are local, and must be addressed locally by proper strategies. Local analyses, as presented in this research, are needed to account for the local adaptation responses. They require interdisciplinary approaches including analyses of climate projections, hydrologic responses to a changing climate, demand projections, and water system performance and economic assessments. Most of the partial studies should be done more accurately but without losing the general insight achieved by the complete method presented.

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TABLES

Table 1: I_d index represents relative distance between historic dataset and base case, as a metric of goodness of fit of the ENSEMBLES RCMs. Selected models, and their metrics, are underlined.

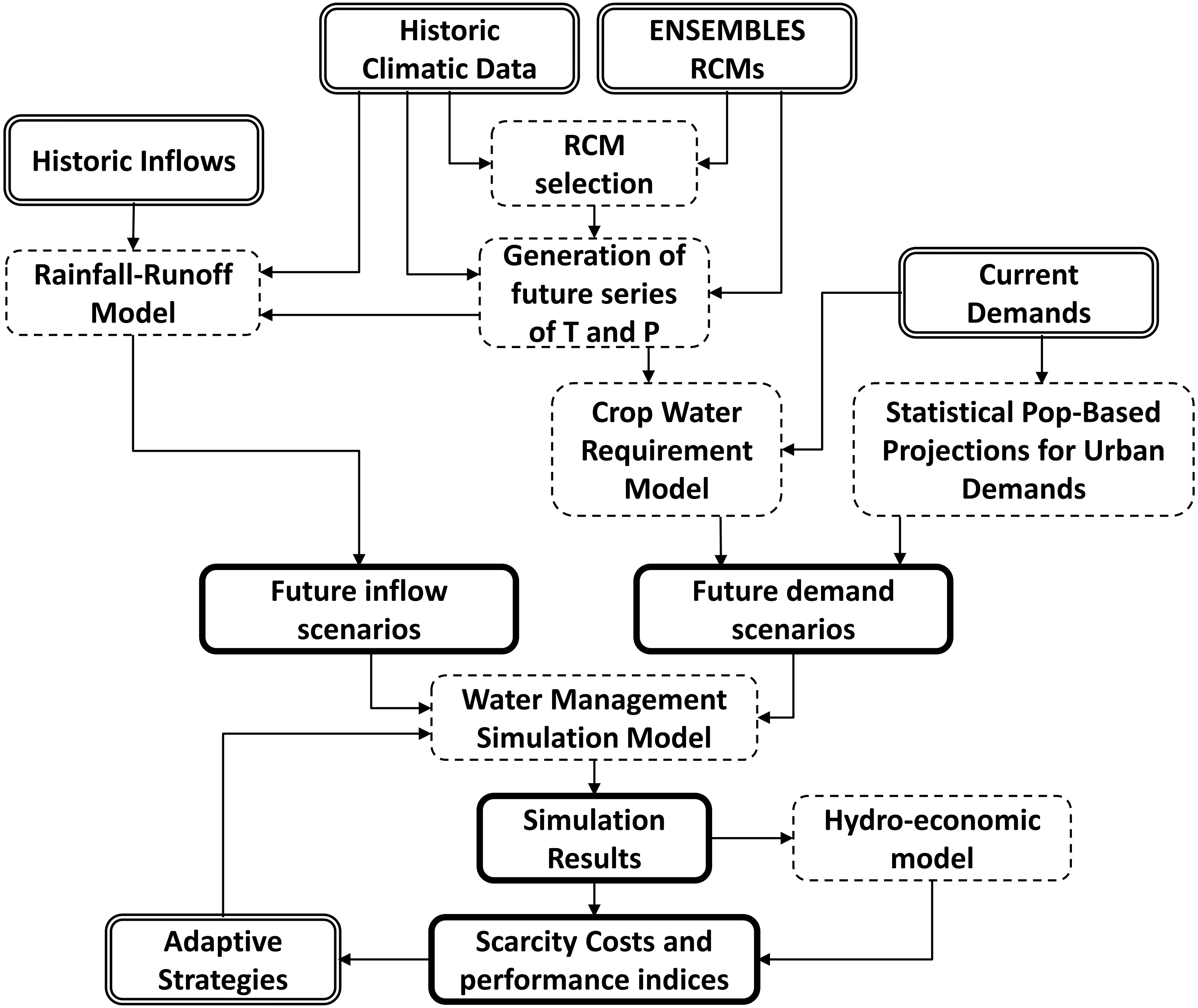
	C4IRCA3	CHMIALADIN	CNRM	DMI HIRHAM	ETHZ CLM	GKSSCLM	METOHC	ICTP REGCM3	KNMI RACMO2	MPI M REMO	SMHIRCA	UCLM PROMES	OURANOSMRCC
$Id_{\mu}T$	1.71	2.28	0.86	0.57	1.03	1.58	3.92	2.00	1.55	0.42	2.01	1.79	2.49
$Id_{\sigma}T$	1.69	1.01	2.05	0.96	1.33	1.48	5.86	0.91	1.13	0.88	1.77	1.40	1.07
$Id_{\mu}P$	4.73	4.13	9.37	2.44	2.75	1.99	22.50	11.78	2.50	3.41	3.91	2.25	8.72
$Id_{\sigma}P$	3.01	5.54	5.75	4.32	5.89	2.36	4.36	8.57	3.22	4.06	3.11	5.14	2.90

Table 2: Scarcity Costs (SC), Monthly Reliability (R) and *Economic Loss Index* (I_{EL}) for each demands and all the climate change scenarios and adaptation strategies simulated for the Jucar River Basin (the spatial description of the water users is included in the Supporting Information, Figure S3)

	Control			**Short-Term**			**Mid-Term**			**Long-Term**			**Efficiency**			**La Mancha Decrease**			**Equal Priorities**			**Water Markets**		
Demand	SC (M€)	R (%)	I_{EL} (%)	SC (M€)	R (%)	I_{EL} (%)	SC (M€)	R (%)	I_{EL} (%)	SC (M€)	R (%)	I_{EL} (%)	SC (M€)	R (%)	I_{EL} (%)	SC (M€)	R (%)	I_{EL} (%)	SC (M€)	R (%)	I_{EL} (%)	SC (M€)	R (%)	I_{EL} (%)
Valencia	-	100	0.0	0.03	100	0.0	0.76	98	0.2	2.50	93	0.7	2.06	95	0.6	0.18	100	0.1	2.53	93	0.7	-	100	0.0
Sagunto	-	100	0.0	0.00	100	0.0	0.08	98	0.2	0.20	94	0.4	0.20	96	0.4	0.02	100	0.0	0.17	96	0.4	-	100	0.0
Albacete	0.01	100	0.0	0.37	98	0.7	0.40	98	0.7	3.29	86	5.6	2.32	90	4.0	0.42	97	0.7	4.12	81	7.1	-	100	0.0
ATS Marina Baja	0.04	100	0.0	1.05	97	0.9	1.17	96	1.0	8.05	81	6.9	5.31	88	4.6	1.51	95	1.3	7.09	81	6.1	-	100	0.0
Cofrentes	-	100	0.0	0.00	100	0.3	0.02	97	2.4	0.07	90	8.9	0.05	93	6.6	0.00	99	0.6	0.07	90	8.9	0.07	90	8.9
Ac Real y Antella	-	83	0.0	0.89	82	0.9	5.36	67	3.9	24.95	68	17.3	10.61	74	10.6	3.70	81	2.6	27.13	68	18.8	24.95	68	17.3
Escalona y Carcagente	-	97	0.0	0.30	71	1.2	1.60	75	4.6	6.83	40	18.7	2.92	55	12.1	1.09	56	3.0	7.09	40	19.5	6.83	40	18.7
Sueca	0.01	97	0.0	0.51	84	3.7	0.98	82	5.1	4.81	48	24.3	1.85	65	14.7	1.19	67	6.0	4.65	48	23.5	4.81	48	24.3
Cuatro Pueblos	0.01	97	0.7	0.08	84	3.8	0.16	82	5.6	0.75	48	25.2	0.28	65	15.1	0.22	67	7.4	0.68	48	23.0	0.75	48	25.2
Cullera	0.05	97	0.7	0.30	84	4.2	0.58	82	5.8	2.69	48	26.0	0.99	65	15.3	0.97	67	9.4	2.57	48	24.9	2.69	48	26.0
Canal J-T	0.79	98	1.4	4.41	89	7.3	9.17	86	10.9	34.85	61	39.8	22.42	74	25.6	15.57	76	17.8	29.84	61	34.1	34.85	61	39.8
Sustitución Mancha	0.01	73	0.4	0.08	89	3.3	0.11	88	4.4	0.46	62	17.9	0.30	75	11.9	0.22	77	8.6	0.43	62	17.0	0.46	62	17.9
Zona Albacete	-	100	0.0	-	100	0.0	-	100	0.0	-	100	0.0	-	100	0.0	-	100	0.0	-	100	0.0	0.02	81	0.1
A Ac Real	0.01	83	0.5	0.04	82	3.1	0.07	72	4.9	0.29	64	20.5	0.11	69	11.5	0.08	78	5.8	0.34	62	24.0	0.29	62	20.5
A Sueca	0.01	97	0.5	0.07	84	3.1	0.11	82	4.3	0.50	48	19.0	0.18	65	10.8	0.16	67	6.0	0.46	48	17.3	0.50	48	19.0
A Cullera	0.01	97	0.5	0.05	84	3.2	0.08	82	4.4	0.35	48	19.2	0.13	65	10.9	0.11	67	6.1	0.32	48	17.6	0.35	48	19.2
A Cuatro Pueblos	0.00	97	0.5	0.01	84	3.2	0.02	82	4.4	0.08	48	19.0	0.03	65	10.8	0.02	67	6.1	0.07	48	17.9	0.08	48	19.0
TOTAL CONSUMPTIVE DEMANDS	0.94	-	-	8.18	-	-	20.66	-	-	90.66	-	-	49.76	-	-	25.48	-	-	87.58	-	-	76.63	-	-
CH Cofrentes	4.86	-	38.0	3.83	-	29.9	5.55	-	43.4	2.37	-	18.5	1.80	-	14.1	6.04	-	47.2	2.36	-	18.5	2.37	-	18.5
CH Cortes II	17.68	-	25.2	15.35	-	21.9	18.20	-	26.0	11.50	-	16.4	10.80	-	15.4	15.01	-	21.4	11.49	-	16.4	11.50	-	16.4
CH Millares	3.36	-	28.5	3.26	-	27.6	1.10	-	9.3	2.73	-	23.1	3.34	-	28.3	2.03	-	17.2	2.73	-	23.1	2.73	-	23.1
TOTAL HYDRO-POWER DEMANDS	25.91	-	-	22.44	-	-	24.85	-	-	16.60	-	-	15.94	-	-	23.08	-	-	16.58	-	-	16.60	-	-

Table 3: Results for system overall indices for each climate change scenario.

	Control	**Short-Term**	**Mid-Term**	**Long-Term**
I_s (satisfaction)	0.99	0.97	0.95	0.82
I_r (reliability)	0.99	0.95	0.92	0.75
I_w (withdrawal)	1.41	1.27	1.18	0.86
I_u (withdrawal use)	0.71	0.76	0.81	0.95
I_{EL} (economic loss)	0.12%	1.01%	2.26%	9.79%


Historic Climatic Data
ENSEMBLES RCMs
Historic Inflows
RCM selection
Rainfall-Runoff Model
Generation of future series of T and P
Current Demands
Crop Water Requirement Model
Statistical Pop-Based Projections for Urban Demands
Future inflow scenarios
Future demand scenarios
Water Management Simulation Model
Simulation Results
Hydro-economic model
Adaptive Strategies
Scarcity Costs and performance indices

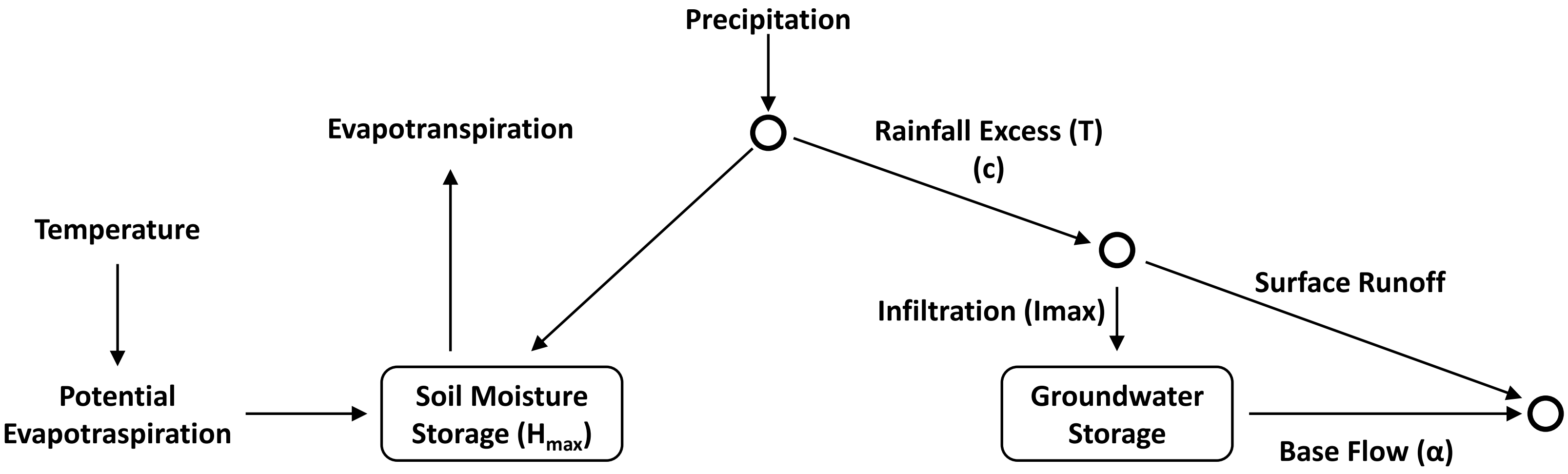
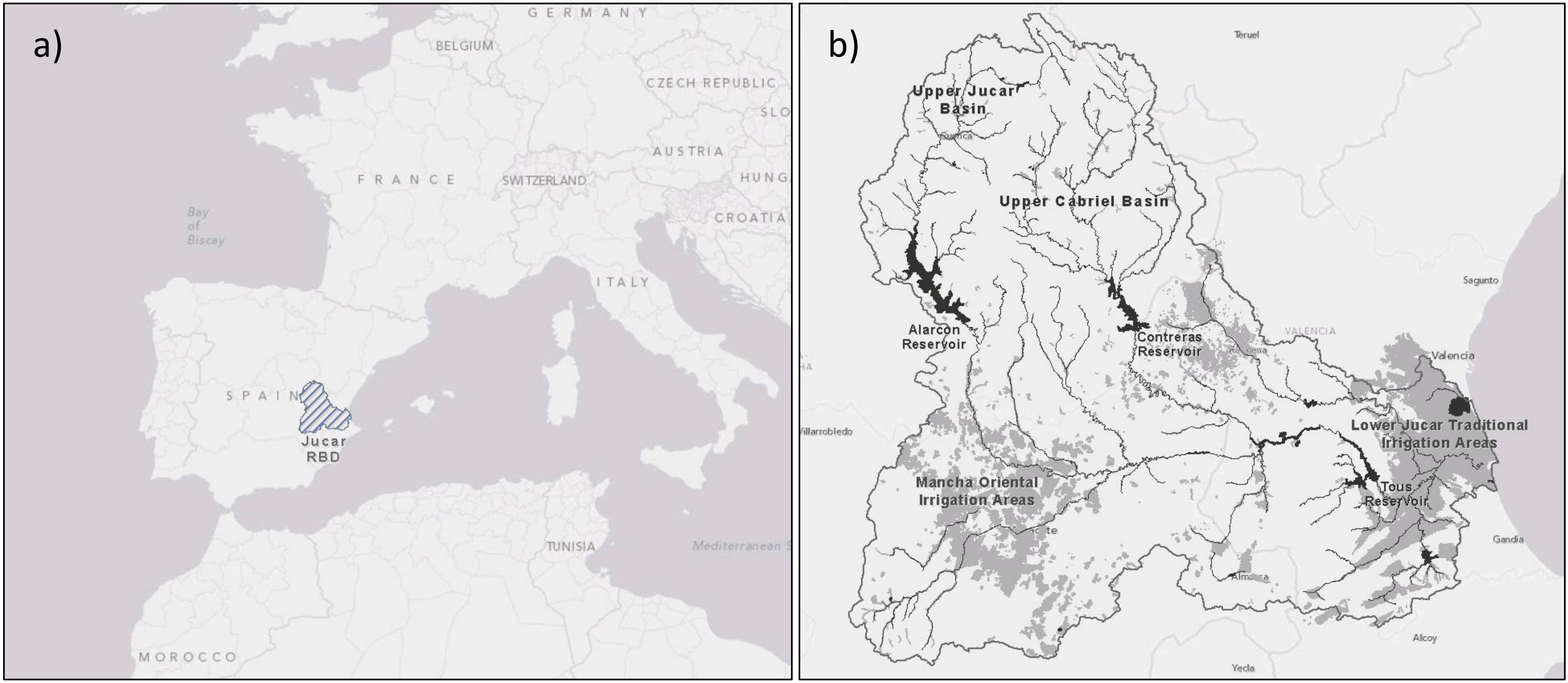

Precipitation
Evapotranspiration
Rainfall Excess (T) (c)
Temperature
Surface Runoff
Infiltration (Imax)
Potential Evapotraspiration
Soil Moisture Storage (H_{max})
Groundwater Storage
Base Flow (α)

Figure3


a)
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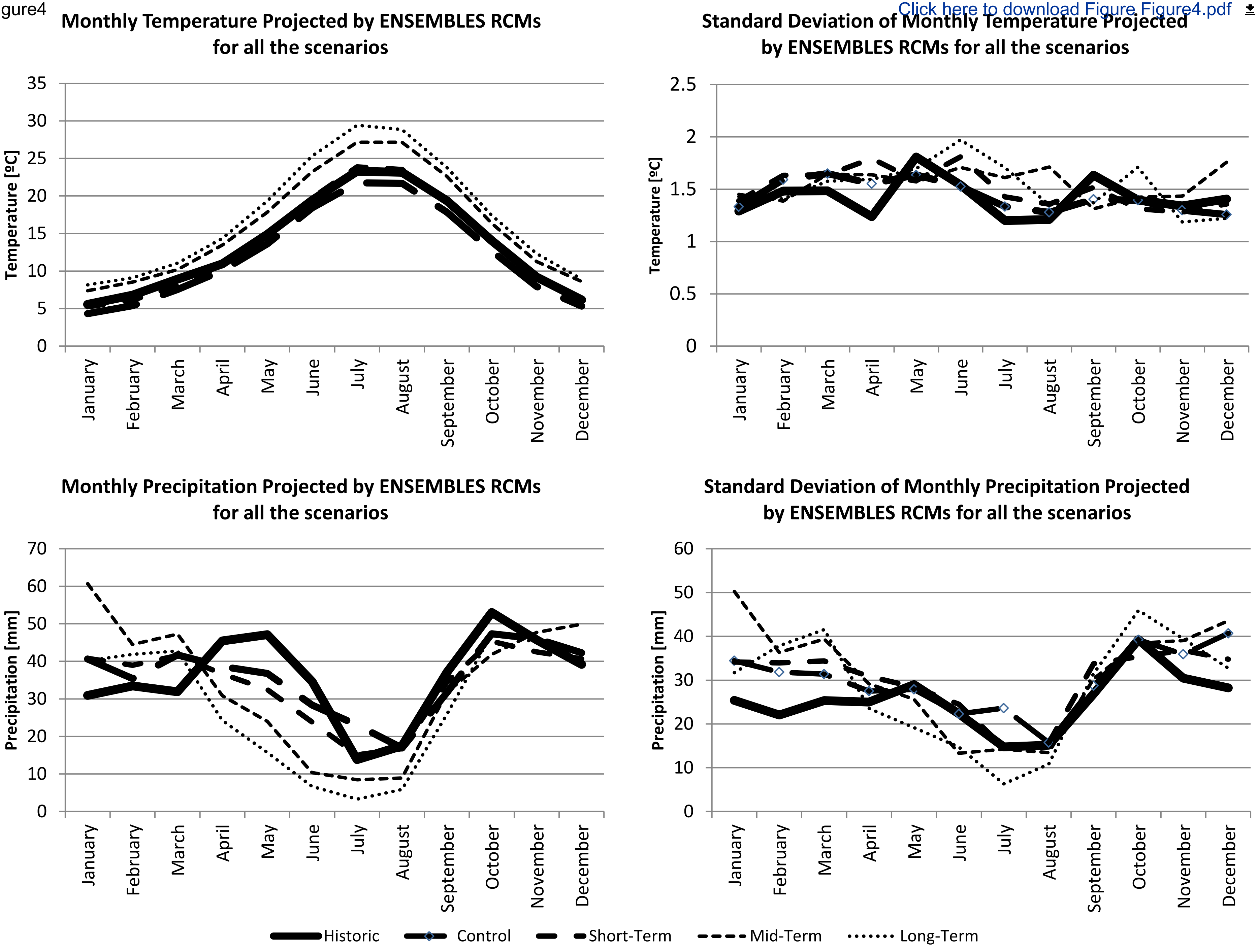
CZECH REPUBLIC
SLO
AUSTRIA
FRANCE
SWITZERLAND
HUNG
CROATIA
Bay of Biscay
ITALY
SPAIN
Jucar RBD
TUNISIA
Mediterranean S
MOROCCO
b)
Teruel
Upper Jucar Basin
Cuenca
Upper Cabriel Basin
Alarcon Reservoir
Contreras Reservoir
VALENCIA
Sagunto
Valencia
Villarrobledo
Lower Jucar Traditional Irrigation Areas
Mancha Oriental Irrigation Areas
Tous Reservoir
Gandia
Almansa
Alcoy
Yecla

Figure4

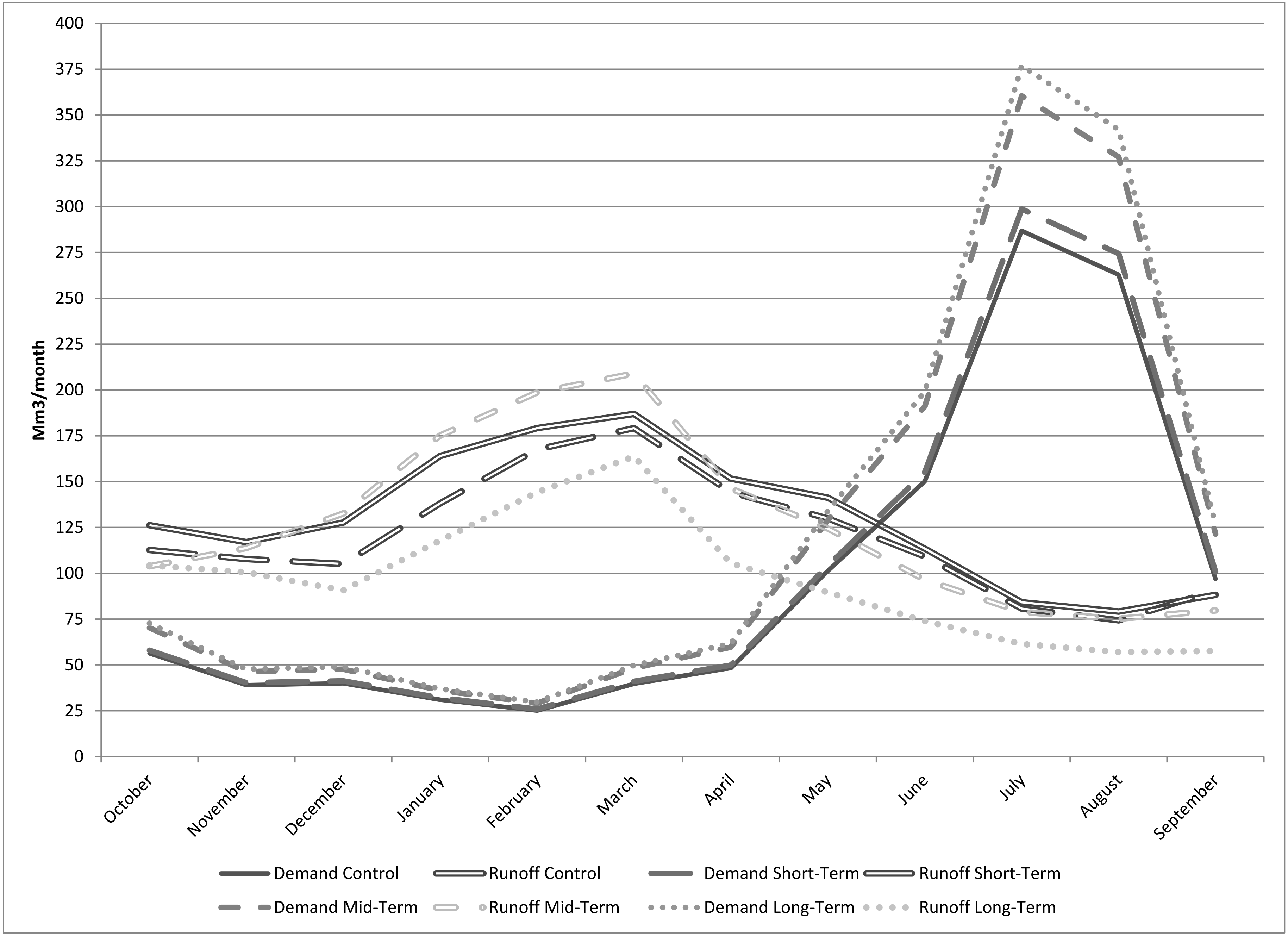


Monthly Temperature Projected by ENSEMBLES RCMs for all the scenarios

Standard Deviation of Monthly Temperature Projected by ENSEMBLES RCMs for all the scenarios

Monthly Precipitation Projected by ENSEMBLES RCMs for all the scenarios

Standard Deviation of Monthly Precipitation Projected by ENSEMBLES RCMs for all the scenarios


Mm3/month
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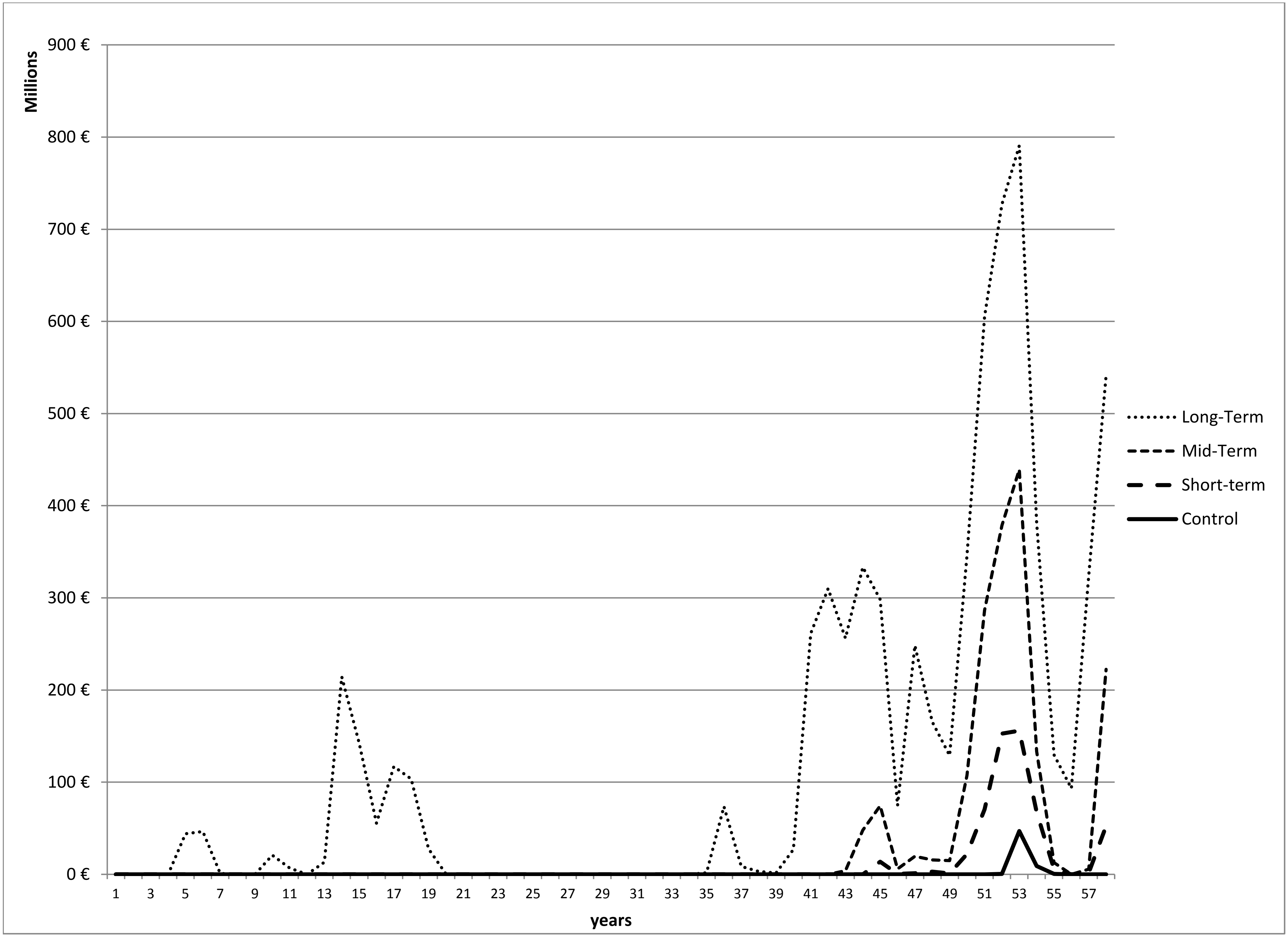
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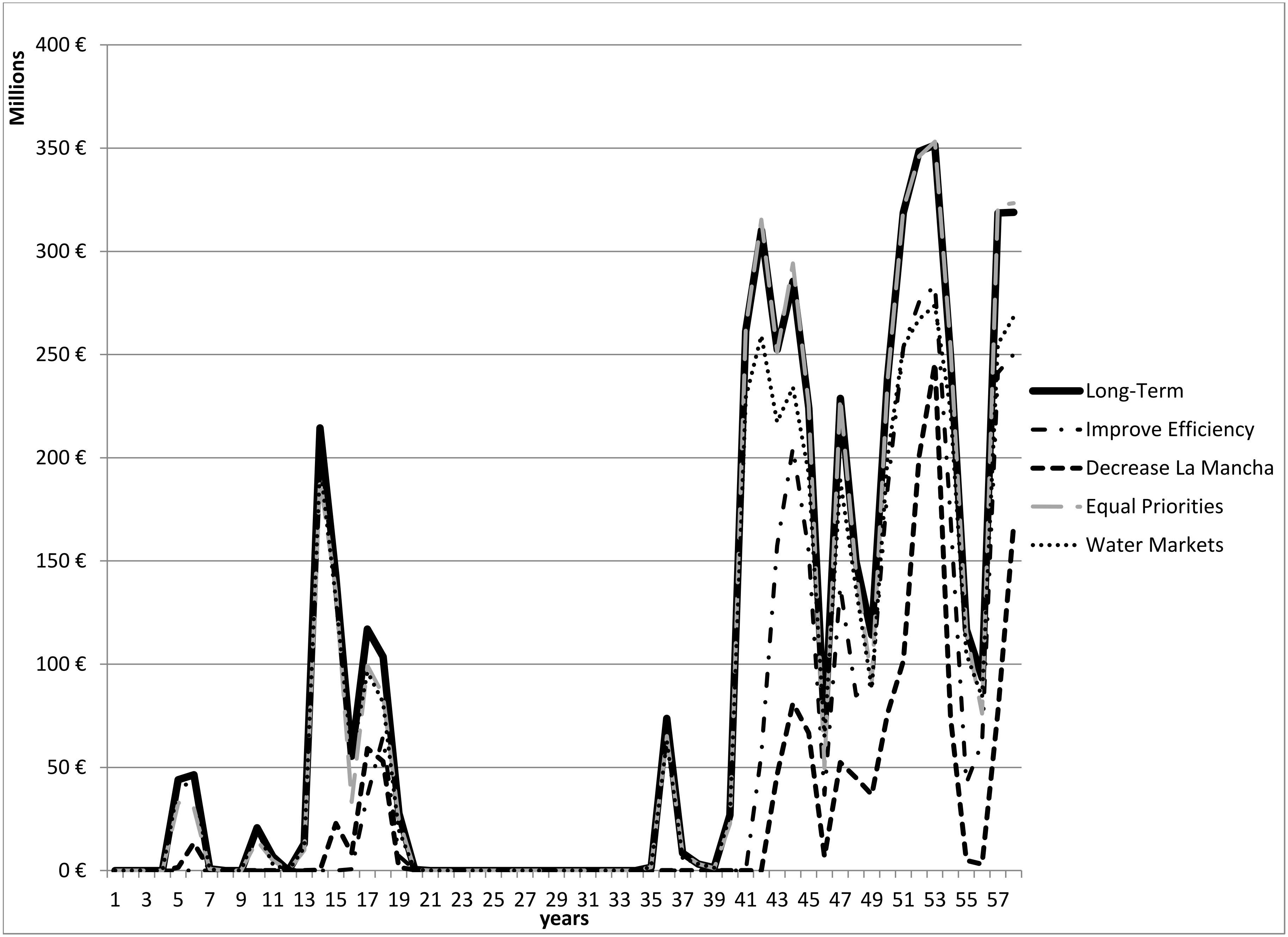
Mid-Term
Short-term
Control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Long-Term
Improve Efficiency
Decrease La Mancha
Equal Priorities
Water Markets

Supplemental Data File

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The Economic Value of Adaptive Strategies to Global Change for Water Management in Spain's Jucar Basin

Alvar Escriva-Bou, Ph.D.[1]; Manuel Pulido-Velazquez, Ph.D.[2]; and David Pulido-Velazquez Ph.D. [3] [4]

List of changes

Reviewers' comments:

Editor: See remaining comments below. The authors are requested to review the recent research literature (including web published In Press, Just Released, and Posted Ahead of Print papers) and include them in their revised submission.

We would like to thank the Editor for her/his comments. We have updated the manuscript according to her/his suggestions.

AE: Both reviewers recommended to accept the revised manuscript for publication. The Reviewer #1 did have a few minor comments, I would suggest the authors to properly address them in the manuscript.

We would like to thank the Associate Editor for her/his comments. We have updated the manuscript according to her/his suggestions.

Moreover, I would like to agree with the Reviewer #1 that "the methodology (used in the paper) is standard as they have presented in past work." I would suggest the authors to highlight methodological contributions of this paper to the literature, and/or additional insights that this study

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[2] Research Institute of Water and Environmental Engineering, IIAMA, Universitat Politècnica de València, València, Spain

[3] Instituto Geológico y Minero de España (IGME), Granada, Spain

[4] Departamento de Ciencias Politécnicas, Escuela Universitaria Politécnica, UCAM Universidad Católica San Antonio de Murcia, Murcia, Spain

can provide to water resource planning and management of the Jucar Basin, compared with relevant existing studies.

We have highlighted the methodologic and site-specific contributions of the paper in the introduction.

- **Methodologic:**

Two challenging issues when using HEMs are to assess climate change impacts are the downscaling and hydrological simulation of climate projections, and the definition of indicators for assessing the system performance.

Regarding the first issue, climate change analyses are often based on climate model predictions, but water resource system analysis requires higher resolution than those provided by global climate models (GCM). Dynamic downscaled climate models using regional climate models (RCM) have been developed last decades for high-resolution applications over the world. European Union (EU) funded project ENSEMBLES runs multiple regional climate models over the same grid to improve the accuracy and reliability of its forecasts (van der Linden and Mitchell 2009). However, the resolution of a RCM is not enough for most hydrological models, and further downscaling and bias-correction is needed (Fowler et al. 2007). Though there is an extensive literature on the strengths and weaknesses of methods for downscaling climatic variables to allow results to be obtained for smaller cells, fewer studies focus on uncertainties related to downscaling to the resolution needed to assess the impacts of climate change on water resources systems (Cayan et al. 2008; Fowler et al. 2007; Seiller and Anctil 2014).

Another key issue is the global assessment of water resource system performance. Several authors propose different indices to condense the outputs of water management models, usually involving the concepts of reliability, vulnerability, sustainability or resilience (Asefa et al. 2014; Ashofteh et al. 2013; Martin-Carrasco and Garrote 2007; El-Baroudy and Simonovic 2004; Hashimoto et al. 1982a and 1982b). However, there is a gap regarding indicators integrating the economic performance of the water system using hydroeconomic models.

In this paper we address these both gaps. We deal with downscaling climate projections and simulating hydrology according to these projections by using for first time in the selected basin a spatially-distributed

downscaling method for climate change projections that selects best-fitting models to historic conditions. Secondly, we analyze the performance of the system for addressing climate change vulnerability using performance indices—including a newly defined economic index—to help in the design of adaptive strategies.

- **Site-specific:**

Some studies have estimated previously the hydrologic impacts of climate change in the Jucar River Basin (Chirivella Osma 2010; Estrela et al. 2012; Ferrer et al. 2012), but it is the first time that the economic impacts and the potential economic benefits of adaptive strategies are assessed in this basin.

In addition, in Table 2, the unit of water scarcity cost, M€, can be introduced in the title of the table to avoid adding it after each cost number in the table.

We have modified Table 2, excluding the units from the result cells and adding them in the title.

Reviewer #1: I appreciate the substantial work that the authors have done reorganizing the paper and describing important methodological details. The paper reads better and aligns with the format and organization expected in a journal article. The methodology is standard as they have presented in past work. The additional comments I have are nitpicky, mostly requests for additional caveats and explanation associated with the methodological assumptions, which upon reflection will have only marginal impact on the quality of the paper, and therefore I will hold them. I think that at this point it is fair to recommend publication.

We really thank the reviewer for a thorough and constructive review.

A few minor editorial issues:

- Symbols in demand functions (lines 318, lines 327, lines 335) are not defined

We have included the symbols in the demand functions.

- Table 2 lists a large number of water users without contextual information about their location, nature, size, etc. A scheme (perhaps in Figure 3) with the topology of the network, and the extraction would help interpret the table.

The spatial definition of the water users is included in the Supporting Information (Figure S3). We added this to table caption.

Reviewer #2: The authors have submitted a revised version of the manuscript. They have reorganized the paper in a more logical way and I am fully satisfied by their reply to my suggestions. In my opinion, the paper can be accepted as is.

We really thank the reviewer for a thorough and constructive review.