Answer to comments from Referee 2 (anonymous)

N.B.: We responded to each series of comments in separate documents, and provided as supplement the revised manuscript. Since the changes in the manuscript were numerous, we uploaded two versions of it: one with all modifications visible in the revision mode, and the revised version with all proposed modifications accepted, to provide a more readable overlook of the manuscript. Page and line numbers in our responses refer to the document in revision mode.

Referee comment:

In the present form no conclusion of scientific significance has been clearly described. Would the authors clarify the focus of the study, improve the embedding in scientific literature and perform additional model evaluation this could probably be overcome.

Authors' response:

We tried to do so in the introduction (see details below). We also modified the discussion. We did not perform additional model evaluation, rather we indicated in the method more precisely what evaluation was performed and in the discussion section the limitations of such evaluation.

The following references were added:

Boithias, L. Acuña, V., Vergoñós, L., Ziv, G., Marcé, R. & Sabater, S. (2014). Assessment of the water supply:demand ratios in a Mediterranean basin under different global change scenarios and mitigation alternatives. *Sci Tot Environ* 470-471, 567-577.

Kiptala, J.K., Mul, M.L., Mohamed, Y. & van der Zaag, P. (2014). Modelling stream flow and quantifying blue water using modified STREAM model for a heterogeneous, highly utilized and data-scarce river basin in Africa. *Hydrol. Earth Syst. Sci*. 18, 2287-2303.

Lanini, S., Courtois, N., Giraud, F., Petit, V. & Rinaudo, J.D. (2004). Socio-hydrosystem modelling for integrated water-resources management – the Hérault catchment case study, southern France. *Environmental Modelling & Software* 19, 1011-1019.

Lopez Moreno, J.I., Zabalza, J., Vicente-Serrano, S.M., Revuelto, J., Gilaberte, M., Azorin-Molina, C., Morán-Tejeda, E., García-Ruiz, J.M. & Tague, C. (2014). Impact of climate and land use change on water availability and reservoir management: Scenarios in the Upper Aragón River, Spanish Pyrenees. *Sci Tot Environ* 493, 1222-1231.

Montanari, A., Young, G., Savenije, H.H.G., Hughes, D., Wagener, T., Ren, L.L., Koutsoyiannis, D., Cudennec, C., Toth, E., Grimaldi, S., Blöschl, G., Sivapalan, M., Beven, K., Gupta, H., Hipsey, M., Schaefli, B., Arheimer, B., Boegh, E., Schymanski, S.J., Di Baldassarre, G., Yu, B., Hubert, P., Huang, Y., Schumann, A., Post, D., Srinivasan, V., Harman, C., Thompson, S., Rogger, M., Viglione, A., McMillan, H., Characklis, G., Pang, Z., & Belyaev, V. (2014) "Panta Rhei – Everything Flows": Change in hydrology and society – The IAHS Scientific Decade 2013–2022. *Hydrolog. Sci. J.,* 58, 1256 – 1275.

Oudin, L., Hervieu, F., Michel, C., Perrin, C., Andréassian, V., Anctil, F. & Loumagne, C. (2005): Which potential evapotranspiration input for a lumped rainfall-runoff model?: Part 2 – Towards a simple and efficient potential evapotranspiration model for rainfall-runoff modelling, *J. Hydrol*., 303, 290-306.

Pulido-Velazquez, D., Sahuquillo, A., Andreu, J. & Pulido-Velazquez, M (2007). An efficient conceptual model to simulate water body-aquifer interaction in Conjunctive Use Management Model. *Water Resources Research* 43: W07407, doi: 0.1029/2006WR005064

Pulido-Velazquez, D., Sahuquillo, A. & Andreu, J. (2012). A conceptual-numerical model to simulate hydraulic head in aquifers that are hydraulically connected to surface water bodies. *Hydrological Processes* 26, 1435-1448.
Reynard, E., Bonriposi, M., Graefe, O., Homewood, C., Huss, M., Kauzlaric, M., Liniger, H., Rey, E., Rist, S., Schädler, B., Schneider, F. & Weingartner, R. (2014). Interdisciplinary assessment of complex regional water systems and their future evolution: how socioeconomic drivers can matter more than climate. *WIREs Water* 1, 413-426.
Weng P. & Dörfliger N. (2002). Projet PACTES — module: contribution des eaux souterraines aux crues et inondations; site de l'Hérault. BRGM/RP-51718-FR.

Referee comment:

Discussion of the approach on calibration, validation, uncertainties is largely lacking. I find this to be a key requirement for a publication on a modelling study of this kind.

Authors' response:

The discussion has been deeply modified and we hope that, together with the clarifications brought to the Methods section, this will respond to the referee's concern, particularly concerning the approach on calibration and validation. We also added some elements of discussion on a certain number of points.

However, due to the level of integration proposed in this study through a long-term reconstruction of the balance between water demand and availability over a 40-year period, we hope the referee will agree that a deep analysis on the uncertainties and their propagation is very complex in that case and is out of the scope of the paper. Moreover, the reproduction of influenced streamflow at the outlet of each sub-basin in the two hydrosystems showed very encouraging simulation results when considering the significant anthropological variations that occurred on the basins, with significant variability in water uses (introduction of new storage-dams, changes in their management, changes in irrigation systems' management, new transfers, etc.).

Referee comment:

There is a need for more precise definitions especially in the introduction of the study.

Authors' response:

Agreed. We have added definitions of specific terms throughout the introduction.

Authors' changes in manuscript:

-Water stress was defined at p.3 lines 3-4 as "(…) an imbalance between water demand and availability, i.e. when water demand is greater than supply".

-The term "hydrosystem" was defined at line p.4 lines 32-35: "River basins need to be considered as hydrosystems (i.e. systems made of water and the associated aquatic environments within a delimited geographical entity) that fully incorporate the different water uses and the influence that these uses may have on water resources, including storage and supply facilities."

-Water demand was defined in section 3.1.1 at p. 9 lines 17-19: "Water demand is defined as the amount of water that users would withdraw without restrictions, i.e. the withdrawals that would enable users to have access to optimal amounts of water considering the efficiency of supply networks and irrigation techniques."

Referee comment:

I do not see why the assessment of drivers should be at the river basin management scale. Rather they are assessed at the basin scale.

Authors' response:

We agree the title may have been poorly worded. What we intended to express was the importance of working at the scale of river basins subject to planning documents and managed by water management agencies. However we have changed the title, also to make it more concise.

Authors' changes in manuscript:

Title changed to "Simulating past changes in the balance between water demand and availability and assessing their main drivers at the river basin scale".

Referee comment:

The aim described in the abstract does not correspond to the aims described at the end of the Introduction section. No clear description of scientific relevance, discussion or conclusion.

Authors' response:

Agreed. The abstract and the introduction were modified.

Authors' changes in manuscript:

The abstract was re-written as follows:

"In this study we present an integrative modelling framework aimed at assessing the balance between water demand and availability and its spatial and temporal variability over long time periods. The model was developed and tested over the period 1971–2009 in the Herault (2 500 km2, France) and the Ebro (85 000 km2, Spain) catchments. Natural streamflow was simulated using a conceptual hydrological model. The regulation of river flow was accounted for through a widely applicable demand-driven reservoir management model applied to the largest dam in the Herault basin and to 11 major dams in the Ebro basin. Urban water demand was estimated from population and monthly unit water demand data. Water demand for irrigation was computed from irrigated area, crop and soil data, and climatic forcing. Water shortage was assessed at a 10-day time step by comparing water demand and availability through indicators calculated at strategic resource and demand nodes. The outcome of this study is twofold. First, we were able to correctly simulate variations in influenced streamflow, reservoir levels and water shortage between 1971 and 2009 in both basins, taking into account climatic and anthropogenic pressures and changes in water management strategies over time. Second, we provided information not available through simple data analysis on the influence of withdrawals and consumptive use on streamflow and on the drivers of imbalance between demand and availability. Observed past variations in discharge were explained by separating anthropogenic and climatic pressures in our simulations: 3% (20%) of the decrease in the Herault (Ebro) discharge were linked to anthropogenic changes. Although key areas of the Herault basin were shown to be highly sensitive to hydro-climatic variability, the balance between water demand and availability in the Ebro basin appears to be more critical, owing to high agricultural pressure on water resources. The modelling framework developed and tested in this study will be used to assess water balance under climatic and socio-economic prospective scenarios and to investigate the effectiveness of adaptation policies aimed at maintaining the balance between water demand and availability."

Referee comment:

The terms vulnerability, water stress and hydrosystem are not clearly defined. This makes this section quite hard to understand. What is meant by "the vulnerability of a hydrosystem…" and "vulnerability to water stress"? Is water stress not the effect of a sensitivity to variations, a perturbation or a pressure?

Authors' response:

We agree the introduction section was lacking clear definitions and may have been confusing to read. We have modified and included definitions, trying to use terms in a more consistent way. We tried to be more specific in the definition of some of the terms and clarified a few sentences in the introduction.

Authors' changes in manuscript:

-The sentence "Such strategies need to be based on a thorough understanding of the vulnerability of hydrosystems exposure and sensitivity to climatic and anthropogenic pressures and of the drivers of water stress." Was changed to: "Such strategies aim at maintaining a balance between water demand and availability, i.e. being able to supply enough water to satisfy demand while limiting anthropogenic pressure on water resources to sustainable levels. Therefore they need to be based on a thorough understanding of each region's exposure and sensitivity to climatic and anthropogenic pressures." (p.2 lines 23-27)

-The sentence "The vulnerability of a hydrosystem to climatic and anthropogenic pressures also depends on its ability to face particular dry events, or to adapt to new climatic conditions." Was deleted (p.2 lines 30-32).

-at the end of the first paragraph (p.2 line 32) the expression "vulnerability to water stress" was changed to "vulnerability to climate change".

-The term "hydrosystem" was replaced with "river basin" in the introduction, until the second to last paragraph in which the term is defined (p. 4 lines 32-35): "River basins need to be considered as hydrosystems (i.e. systems made of water and the associated aquatic environments within a delimited geographical entity) that fully incorporate the different water uses and the influence that these uses may have on water resources, including storage and supply facilities."

Referee comment:

Also the term "resource" is used where availability of water seems to be meant. Effort should be made to use terminology in a more consistent way. If the same is meant why would you use both "human" and "anthropogenic"? Why use "physical factors" when you only seem to refer to climatic variations.

Authors' response:

Agreed.

Authors' changes in manuscript:

P. 2 line 37: "the balance between water use and availability" was changed to "the balance between water *demand* and availability".

p. 3 line 1: "human and hydro-climatic data" was change to "socioeconomic and hydro-climatic data".

p. 3 lines 2-3: "the regions that may be most vulnerable to water stress" was changed to "the regions most susceptible to experience water stress."

p. 3 lines 10: “which compared water resources and demand” was changed to “which compared water demand and availability”.
p. 3 line 15: “Studies that compare water demand and resource” was change to “studies that compare water demand and availability”.
p. 3 lines 17-18: we added a clarification of what was meant by “water resources” in brackets: “(i.e. surface streamflow and/or groundwater levels)”.
p. 3 line 28: “human and climatic drivers of water resources and demand” was changed to “anthropogenic and climatic drivers of water availability and demand”.
p. 3 lines 31-32: ‘human and climatic factors” was changed to “anthropogenic and climatic drivers”.
p. 3 line 37-38: “long-term dynamics of resources and demand” was changed to “long-term variations in demand and availability”
p. 4 lines 2-4: “(…) we need to be able to represent long-term dynamics, which implies accounting for the non-stationarity of human and physical factors” was changed to: “(…) we need to be able to represent long-term variations, which implies accounting for the variability of anthropogenic and climatic drivers”.
p. 4 line 38: “the non-stationarity of human and physical factors” was changed to “the variability of anthropogenic and climatic drivers”.
p. 5 line 13: “combine human hydro-climatic data” was changed to “combine socioeconoic and hydro-climatic data”.
p. 7 line 36: “the main human pressures on water resources” was changed to “the main anthropogenic pressures on water resources”.
p. 10 line 5: “variability in climatic and human conditions” was changed to “variability in climatic and anthropogenic drivers”.
p. 23 line 25: “including human and physical drivers” was changed to “including anthropogenic and climatic drivers”.

Referee comment:

The use of the verb “tackle” seems wrong in this context.

Author’s changes in manuscript:

We changed “tackle” to “deal with”.

Referee comment:

Not clear what is mean by “various extents”.

Authors’ changes in manuscript:

We changed “(…) incorporate anthropogenic and climatic drivers of water uses and availability to varying extents” to “(…) rarely fully incorporate anthropogenic and climatic drivers” (p.3 lines 15-16).

Referee comment:

The text on "different perspectives" seems to refer to spatial and temporal scale issues. This should be written more clearly. In this way I don't see how it '… underlined the need to better understand the drivers and dynamics…".

Authors' response:

We believe there was a misunderstanding in the meaning of the paragraph beginning with « Our review of the literature thus underlined… ». This paragraph referred to the whole literature review above, not only the paragraph above. Moreover, the text on "different perspectives" was reworded to clarify its meaning.

Authors' changes in manuscript:

To clarify our statement, we modified the beginning of both paragraphs:

-p. 4 lines 16-18: "Finally, water stress can be considered from different perspectives. It can be represented by indicators that account for the hydrosystem's water balance and its wea knesses."

Was changed to:

"The balance between water demand and availability can be represented by using indicators."

-we added a sentence at the beginning of the paragraph page 4 lines 27-29: "To be able to adapt effectively to future climatic and anthropogenic changes, we need to understand the interactions between the different drivers leading to water shortage or excessive pressure on water resources."

-we changed the sentence "Our review of the literature thus underlined the need to better understand the drivers and dynamics of the balance between water uses and water availability in river basins, i.e. at the scale of water management plans" to: "Our review of the literature underlined a lack of integration of anthropogenic and climatic drivers in most modeling studies dealing with the balance between water demand and availability in river basins, i.e. at the scale of water management plans." (p.4 lines 29-32)

Referee comment:

At the final sentence of section 2.2 a reference would be appropriate.

Authors' response:

References to the planning documents of both local water management agencies were added. However, not all the data used in our study was directly available from these documents, it was provided directly to us by our partners in the water management agencies. Consequently we cited the planning documents as "adapted from…".

Authors' changes in manuscript:

References added (p.6 line 38):

CHE: Propuesta de Proyecto de Plan Hidrológico de la Cuenca del Ebro, Memoria, available at: www. Chebro.es (last access: October 2014), 2011.

Syndicat Mixte du Bassin du Fleuve Hérault: Gestion quantitative de la resource, Etat des lieux version 4, SAGE du bassin du fleuve Hérault, France, www.sage.herault.fr (last access: August 2014), 2005.

Referee comment:

It seems that a modeling framework was designed. This framework is then referred to "integrative" and applied. It remains unclear whether this integrative framework was also calibrated/validated or tested/evaluates in any way?

Authors' response:

We believe there is a misunderstanding over the method described here, due to unclear explanations. Therefore we have modified the manuscript to try to clarify the calibration and validation procedure.

Authors' changes in manuscript:

-At the end of section 3.1.1 we added the following sentence (p.10 lines 7-11): "Calibration and validation of the hydrological model was performed over natural streamflow data (see section 3.2.2.), while the simulation of water demand could not be thoroughly validated for lack of data. The simulation of influenced streamflow was validated against observed streamflow data at each resource node (see section 3.3.2)."

-At the end of section 3.2.2 we added the following sentence (p.12 lines 24-26): "The simulation of streamflow influenced by reservoir operations and consumptive use was validated against observed data in a later step (see section 3.3.2)."

-At the end of section 3.3.2 we added the following text (p.14 lines 27-30): "The calculation of these criteria also allowed to validate the whole run of the integrative model. Therefore although the hydrological model was not calibrated over low flows (see section 3.2.2) we validated the simulations of influenced streamflow, including over low flows."

Referee comment:

No description of the interactions between water use (or demand) and the resource system (or hydrosystem or water availability) is presented. Figure 2 does not clarify this. The caption could be amended to become more explanatory in this respect.

Authors' response:

We modified the second paragraph off section 3.1.1 to clarify the interactions between water demand and water resource through water use (withdrawals and consumptive use), and through storage and streamflow regulations dependent on water demand. We also amended the caption of figure 2 as suggested.

Authors' changes in manuscript:

-The second paragraph of section 3.1.1 was replaced with the following paragraph (p.9 lines 23-31):

"At each demand node, water demand is compared to water availability (based on streamflow and reservoir levels). If water availability is equal to or higher than water demand, then water withdrawals are equal to water demand for all types of demand. If water availability is lower than water demand, then restrictions are applied to limit withdrawals. According to the order of priority defined locally (and by EU WFD), restrictions are first applied to AWD, then OWD, then UWD. Water shortage is calculated through the difference between water demand and effective water withdrawal. Only a part of the water withdrawn is actually used, the rest is considered to return to the sub-basin outlet as return flow. The quantification of consumptive use and return flows is explained in section 3.3.2. Natural streamflow is thus modified by dam management, water withdrawals and return flows."

-The caption of figure 2 was amended by adding the following text (p.34): “Water demand and natural streamflow were simulated based on climatic and anthropogenic drivers. Anthropogenic influence on streamflow was assessed through the simulation of demand-driven dam management and consumptive use. Water stress was assessed by comparing demand to availability and characterized through the use of indicators.”

Referee comment:

No clarity on water demand/use is given. The reader is not informed on the nature of the use meant (withdrawal/consumptive).

Authors’ response:

Although our modeling framework does differentiate water demand from withdrawals and consumptive use, we agree this was not explained clearly enough in the original manuscript. We added our definition of water demand in section 3.1.1, and we also believe the modifications on the second paragraph cited above bring clarifications on our treatment of water demand/withdrawals/consumptive use.

Authors’ changes in manuscript:

Section 3.1.1 first paragraph (p.9 lines 17-19): our definition of water demand was added: “Water demand is defined as the amount of water that users would withdraw without restrictions, i.e. the withdrawals that would enable users to have access to optimal amounts of water considering the efficiency of supply networks and irrigation techniques.”

Referee comment:

Moreover the groundwater recharge-surface water interactions seem to be taken into account. In this respect it is also not clear what is meant with ‘directly downstream” (p 12325 lines 16 and 21).

Authors’ response:

We agree the list of assumptions in section 3.1.1 in the original manuscript was unclear. In the revised version, we replaced this list by a paragraph explaining the interactions between resource and demand.
As for the groundwater recharge-surface water interactions, we added a paragraph in the Methods section (section 3.3.2) explaining how return flows were considered to return to surface flow at the outlet of the sub-basin in which the water was pumped. This assumes a strong link between surface and groundwater since part of the losses from supply networks and inefficient irrigation techniques were considered to return to surface flow at the outlet of each sub-basin. The part to return to surface flow was determined, as explained in section 3.3.2: “Return flow rates were tested from 0 to 1 with a step of 0.1 and were calibrated by optimizing goodness of fit criteria including NSE on low flows (…)”.

Authors’ changes in manuscript:

-The list of assumptions was replaced with the following paragraph (p.9 lines 23-31):
“At each demand node, water demand is compared to water availability (based on streamflow and reservoir levels). If water availability is equal to or higher than water demand, then water withdrawals are equal to water demand for all types of demand. If water availability is lower than water demand, then restrictions are applied to limit withdrawals. According to the order of priority defined locally, restrictions are first applied to AWD, then OWD, and lastly UWD. Water shortage is calculated through

the difference between water demand and effective water withdrawal. Only a part of the water withdrawn is actually used, the rest is considered to return to the sub-basin outlet as return flow. The quantification of consumptive use and return flows is explained in section 3.3.2. Natural streamflow is thus modified by dam management, water withdrawals and return flows."

-In section 3.3.2 we added the following sentence (p.14 lines 12-14): "For each type of water demand, a part of the water withdrawn was considered to return to the environment and, *in fine*, to the streamflow at the outlet of the sub-basin in which the water was pumped."

Referee comment:

What does 'resource vs. demand" mean? From Figure 3 it is clear that it is not water stress or water scarcity.

Authors' changes in manuscript:

The first sentence of section 3.1.2 was changed to "the spatial distribution of water demand and availability was mapped to correctly reproduce the spatial heterogeneity of water shortage in each study area: water stress assessments can vary depending on the spatial or temporal scale (Boithias et al., 2014). Thus it is essential to properly account for the main heterogeneities in water demand and availability." (p. 10 lines 15-19)

Referee comment:

3.2: it seems to me that the words dynamics, variations and changes are mixed-up here and there.

Authors' response:

Agreed. We tried to use these terms in a more consistent way in the revised manuscript.

Authors' changes in manuscript:

p. 11 line 12: "Annual changes in population" was changed to "Annual variations in population".

p. 17 line 4: "(…) simulated interannual variability of the reservoir levels" was changed to "(…) simulated inter-annual variations of the reservoir levels".

p. 17 lines 6-8: "(…) the variations in the reservoir levels of the Yesa and Grado dams were well reproduced, with NSE values (…)" was changed to "(…) the reservoir levels of the Yesa and Grado dams were rather correctly simulated with NSE values (…)"

-p. 17 line 11: "(…) significant seasonal variability in 1986 (…)" was changed to "(…) significant seasonal variations in 1986 (…)".

Referee comment:

It is unclear how the "natural" and "non-natural" 10-day periods can this easily be separated. The hydrological processes involved take effect in much longer time-frames than seems to be accounted for. From the text I am also not convinced that the upstream-downstream linkages have been properly accounted for in this respect. Even more worrying is the fact that calibration seems to be based on high flows, whereas the effect of withdrawals/demand/consumptive use/reservoir operation is expected to be most relevant under low flow (dry season) conditions.

Authors' response:

We added a clarification of the assumptions made on "natural" and "non-natural" 10-day in the second paragraph of section 3.2.2. The challenge is that no withdrawal data are available at a finer time scale than annual values, and consequently there is no way of reconstructing series of natural streamflow through data analysis. Another way of simulating natural flow would have been to integrate the water withdrawals and return flows in the calibration procedure: simulate natural flows, modify them with simulated withdrawals (according to simulated demand and availability) and return flows, and apply the performance criteria to the influenced flow. Although this method could be conceivable in a simple system of, for example, one or two sub basins with few storage dams, here the calibration on influenced flow would take into account the bias in streamflow regulation, withdrawal simulations, etc. and this would not guarantee that the simulated natural streamflow is the right one. Therefore we decided to calibrate the hydrological model only on natural flows (which indeed usually exclude low flows), and to validate the simulations of influenced low flows against observed data (see section 3.3.2).

Authors' changes in manuscript:

-A clarification of the assumptions made on "natural" and "non-natural" 10-day periods was added in the second paragraph of section 3.2.2: after "Runoff produced in each downstream sub-basin was computed at a 10-day time step by subtracting the ingoing streamflow from the streamflow measured at the outlet of the section." Two sentences were added (p. 12 lines 12-18): "However these downstream sections are strongly influenced by water withdrawals, and natural streamflow could not be calculated based on observed streamflow and water withdrawal data because withdrawal data were not available with the adequate time step and time depth. Thus assumptions had to be made in order to evaluate when streamflow was natural, i.e. not modified by consumptive use. Since AWD was considered to have the highest consumptive use, we assumed that when negligible AWD was simulated, then consumptive use was negligible and flows were considered natural."

-A sentence was added at the end of section 3.2.2: the sentence "The model was thus calibrated on the time steps when most of the runoff is produced, which allowed for the natural flow to be simulated for the whole year" was changed to:

"Consequently, the calibration did not include the effect of withdrawals and consumptive use, which are most relevant under low flow conditions. The simulation of streamflow influenced by reservoir operations and consumptive use was validated against observed data in a later step (see section 3.3.2)." (p.12 lines 23-26)

- The following paragraph was added in the Limitations section (p.24, line 22-36):

"The widespread anthropogenic influence on streamflow made calibration and validation of natural streamflow difficult, particularly in the Ebro basin. The challenge was that no water withdrawal data were available at a finer time scale than annual values; consequently reconstructing series of natural streamflow through data analysis would have been impossible. Another way of simulating natural flow would have been to integrate the water withdrawals and return flows in the calibration procedure by simulating natural flows, modifying them with simulated withdrawals (according to simulated demand and availability) and return flows, and applying the performance criteria to the influenced flow (e.g. Beck and Bernauer, 2011). Although this method could be conceivable in a simple system of, for example, one or two sub basins with few storage dams, here the calibration on influenced flow would have taken into account the bias in streamflow regulation, withdrawal simulations, etc., thus not guaranteeing the quality of natural streamflow simulations. Since the influence of consumptive use is highest during low flow periods, the hydrological model was mostly calibrated over periods of mid and high flows."

Referee comment:

3.3: it is unclear how the simulated rules compare to actual practice.

Authors' response:

A sentence was added to explain this in section 3.3.1.

Authors' changes in manuscript:

Section 3.3.1, p.12 line 37 to p. 13 line 3:

"In the Ebro basin, reservoirs managed for the supply of irrigation systems are managed with target and minimum levels. In most cases target levels vary throughout the year and the minimum level is fixed and corresponds to a safety reserve of the level of a canal inlet. Water is released to satisfy the demand as long as the reservoir level is above the minimum level. These basic management rules were used to design the dam management model."

Referee comment:

'return to outlet', effectively into the sea. If so, it is not really return flow, is it?

Authors' response:

We believe there was a misunderstanding over the text: the 'outlet of the sub-basin" was meant to express the downstream point of sub-basin under study, i.e. the gauging station, rather than the outlet of the whole basin.

Referee comment:

P 12332 line 4: shouldn't it be 5% rather than 95?

Authors' response:

Indeed, this mistake was corrected in the revised manuscript (p.15 line 8).

Referee comment:

P 12333 line 1 would be good to include those definitions.

Authors' response:

Agreed. This was done in the revised manuscript.

Authors' changes in manuscript:

Additions to the manuscript are indicated in italic (p.15 line 31 – p.16 line 2):

"The definitions of maximum shortage (*the maximum annual shortage over the study period,* also called "vulnerability" in the literature), reliability *(the frequency of years with overall water supply at least at 50% of demand)*, and *resilience (indicating how quickly the system returns into balance, i.e. the inverse of average length of shortage episodes)* were based on the metrics used in previous studies to evaluate the performance of water supply systems (Hashimoto *et al.*, 1982, Fowler *et al.*, 2003). The final indicator was the frequency of occurrence of water sharing conflicts (C). *As stated above, the years with an occurrence of water sharing conflicts were considered to be the years with urban water shortage exceeding 5% of the demand during at least one 10-day time step.* For each indicator, an acceptable range of values was defined according to management criteria in the local basin agencies.

Referee comment:

4.1: I am unable to judge whether the NSE values presented are 'well reproduced' as claimed on p 12334 lines 19-20.

Authors' response:

We meant to say the variations in reservoir levels were well reproduced, rather that the NSE values. The sentence was amended in the revised manuscript to clarify or statement.

Authors' changes in manuscript:

The sentence "Despite the complexity of their management, the variations in the levels of the Yesa and Grado dams were well reproduced, with NSE values of 0.68 and 0.56 respectively, and mean volume errors of 9% and 8%."
was changed to: "Despite the complexity of their management, the reservoir levels of the Yesa and Grado dams were rather correctly simulated, with NSE values of 0.68 and 0.56 respectively and mean volume errors of 9% and 8%." (p.17 lines 5-8)

Referee comment:

4.2 p 12336 line 19: So, no impact in the 1990s? Figure 9 does not show a clear trend, what does it mean? Could you maybe highlight what the reader should observe?

Authors' response:

Although we are not sure we understood this comment correctly, we agree there may be something unclear in the explanations of figure 9. The paragraph was amended for clarification.
This paragraph was meant to underline the variations in natural streamflow in the Herault and the Ebro basins. Because we characterized the variations in climate over 1971-2009 by separating two periods (a wetter and colder decade in the 1970s, and 30 years of warmer and drier climate), we kept these two periods in the analysis of natural streamflow variations and found, as indicated in the first paragraph of section 4.2.2, that simulated natural streamflow decreased by 20% between 1971-1980 and 1981-2009.

Authors' changes in manuscript:

Clarifications were added (see text in italic) p. 18 lines 30-33:
"Simulated changes in natural streamflow at the outlet of the Herault and the Ebro basins are illustrated in figure 9. The 1980s and 2000s appear to have been particularly dry compared to the *1970s and the 1990s*, mainly in the Herault basin. In both basins, *simulated* natural streamflow decreased by approximately 20% between 1971–1980 and 1981–2009."

Referee comment:

P 12337 line 15 'at a 10 day time step': at one of the time steps?

Authors' response:

In the revised manuscript the whole paragraph was amended to make it clearer.

Authors' changes in manuscript:

"Although the annual anthropogenic impact was higher in the Ebro basin, it reached 30% of natural streamflow at a 10-day time step in the Herault basin between mid-July and mid-August in the 2000s (Fig. 9a). While the impact of human activities was highest in the summer in the Herault basin, the storage role of reservoirs in the Ebro basin is clearly visible in Fig. 9b: in the Ebro basin, anthropogenic impacts decreased in July and August, when withdrawals were made from reservoirs. "

Was changed to:

"In the Herault basin the impact of human activities was highest in the summer: it reached 30% of natural flow between mid-July and mid-August in the 2000s (Fig. 9a).In the Ebro basin the storage role of reservoirs is clearly visible, with anthropogenic impacts decreasing in July and August, when withdrawals were made from reservoirs (Fig. 9b)." (p. 19 lines 20-25)

Referee comment:

P 12337 line 26-28: My interpretation: The impact of water use has become relatively larger because natural runoff decreased that much. If my interpretation is correct, please rephrase your text. Now it seems that the impact of climatic variations is larger.

Authors' response:

The impact of water use in the Ebro basin has become relatively larger for two reasons:

-the first graph of Fig 9b (which title was changed to "Annual consumptive use" in the revised version of the manuscript) shows a slight increase, in absolute terms, of consumptive use.

-also, as stated in section 4.2.2, natural runoff decreased.

The part of natural streamflow and anthropogenic consumptive use variations in the cause of the decrease in streamflow observed was evaluated by comparing variations in simulated natural and influenced streamflow. Results linked 80% of the decrease in influenced discharge simulated at the outlet of the Ebro basin between 1971-1980 and 1981-2009 to a simulated decrease in natural discharge, and 20% to the increase in consumptive use.

Authors' changes in manuscript:

-in the Methods section, the first paragraph of section 3.3.3 was amended to better explain the method used to differentiate climatic from anthropogenic impacts on streamflow:

The sentence "Comparing changes in natural and modified streamflow between 1971 and 2009 enables climate variability to be distinguished from anthropogenic pressure as causes of the decrease in streamflow observed in both basins"

Was changed to:

"The part of natural streamflow and anthropogenic consumptive use variations in the cause of the decrease in streamflow observed was approached by comparing variations in simulated natural and influenced streamflow." (p. 14 line 38 to p. 15 line 2)

-in the Results section, the last paragraph of section 4.2.3 was amended to better explain our interpretation (p.19 lines 26 to p.20 line 2). The paragraph was changed to:

"Simulating natural and influenced streamflow made it possible to distinguish between the impacts of climate and consumptive use variations. In the upstream sections of the Herault basin (Saint-Laurent, Laroque and Lodeve, data not shown) the decrease in streamflow between 1971–1980 and 1981–2009 was linked to a natural decrease in streamflow only, whereas in Gignac and Agde, respectively 1% and 3% of the decrease in annual influenced streamflow was linked an increase in consumptive use. Results linked 80% of the decrease in influenced discharge simulated at the outlet of the Ebro basin between 1971–1980 and 1981–2009 to a simulated decrease in natural discharge, and 20% to the increase in consumptive use. These proportions varied throughout the basin: 75–25% in the Aragon sub-basin, 50–50% in the Cinca sub-basin and a decrease in consumptive use in the Segre sub-basin."

Referee comment:

Discussion and conclusion: I am not convinced on how your study distinguished between hydro-climatic and human-induced dynamics (p 12341 line 11).

Authors' response:

We hope that, with the changes in the methods and results sections in the revised manuscript, we made it clearer how we distinguished between climate and human-induced dynamics. Indeed the fact that we simulated natural streamflow and influenced it with streamflow regulations and consumptive use enabled us to compare "natural" dynamics (i.e. climate-induced) and human-induced dynamics in observed streamflow.

Referee comment:

-P 12341 line 14: '…satisfactory results'. To who and why?

-P 12341 lines 26-29: So what does this study exactly teach us? What is the added value of using your model?

-P 12342 line 16: I am not sure how you 'reproduced' them. Rather you included them.

Authors' response:

We agree some points needed clarification in the discussion. The discussion was in most part rewritten in the revised version of the manuscript, therefore we will not answer each specific comment regarding this section. Please see revised manuscript for modifications in the discussion section.

Referee comment:

p 12342 line 28: appeared? Or was it real?

Authors' response and changes in the manuscript:

In the sentence "In the Agde section, an imbalance between demand and availability appeared in the 2000s because of the combined increase in AWD and UWD and the decrease in natural streamflow" refers to the historical reconstruction of water demand satisfaction over the past 40 years. Therefore, the expression "appeared" was indeed meant to say that an imbalance emerged in this area in the 2000s, whereas before then water demand had always been satisfied. It was replaced with "emerged" in the revised manuscript. (p. 23 line 37)

Referee comment:

Discussion of the approach on calibration, validation, uncertainties is largely lacking. I find this to be a key requirement for a publication on a modelling study of this kind.

Authors' response:

The discussion was amended in the revised paper. We invite the referee to pages 24-26 for discussion on the approach on calibration, validation, and limits to the efficiency of the modeling framework. However, as we stated earlier, due to the level of integration proposed in this study we hope the referee will agree that a deep analysis on the uncertainties and their propagation is very complex and almost constitutes a study in its own right. Moreover, the ability in reproducing influenced streamflow at the outlet of each sub-basin in the two hydrosystems studied showed very encouraging simulation results when considering the significant anthropological variations that occurred on the basins, with significant variability in water uses (introduction of new storage-dams, changes in their management, changes in irrigation systems' management, new transfers, etc.).

Referee comment:

No conclusion of scientific significance is clearly described.

Authors' response:

The outcome of this study is twofold:

-first, the presented modelling framework was shown to efficiently simulate influenced streamflow and water stress in complex hydrosystems facing significant water use and climate variability;

-second, the simulations distinguishing anthropological from climate drivers provided knowledge on the processes leading to water stress, which was not available through simple data analysis.

The identification and simulation of the drivers of water stress, especially in basins facing rapid climatic and anthropogenic changes, is at the heart of the challenges put forward in the Panta Rhei hydrological scientific decade of IAHS (Montanari *et al.*, 2014). Moreover, this study contributes to filling a gap in studies of the balance between water demand and availability on the hydrological mesoscale. We also believe that it provides valuable input to the discussion of how climate variability and change will impact water stress at the river basin scale, in combination with socio-economic changes.

Reference:

Montanari, A., Young, G., Savenije, H.H.G., Hughes, D., Wagener, T., Ren, L.L., Koutsoyiannis, D., Cudennec, C., Toth, E., Grimaldi, S., Blöschl, G., Sivapalan, M., Beven, K., Gupta, H., Hipsey, M., Schaefli, B., Arheimer, B., Boegh, E., Schymanski, S.J., Di Baldassarre, G., Yu, B., Hubert, P., Huang, Y., Schumann, A., Post, D., Srinivasan, V., Harman, C., Thompson, S., Rogger, M., Viglione, A., McMillan, H., Characklis, G., Pang, Z., & Belyaev, V. (2014) "Panta Rhei – Everything Flows": Change in hydrology and society – The IAHS Scientific Decade 2013–2022. Hydrolog. Sci. J., 58, 1256 – 1275.