Interactive comment on “Climate change effects on the hydrology of the headwaters of the Tagus River: implications for the management of the Tagus-Segura transfer” by Francisco Pellicer-Martínez and José Miguel Martínez-Paz.

Anonymous Referee #2

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The paper proposes a methodology for study the effect of climate change and its repercussions on one of the most important water transfers between basins in Europe. To do this, a simple hydrological model (ABCD) is used in the donor basin to analyze the behavior of its components, trying to improve some problems (such as spatial aggregation or incorporate a snow model); after calibrating the model with the algorithm SCE-UA, they simulate and predict the behavior of the system from an ensemble of AR5 models regionalized by the AEMET, observing important reductions in the snowfalls and snow covers, the recharge of aquifers and the available water resources.

Dear Referee,

We would like to thank you for the thorough review and comments. These have helped us to conscientiously review the work and improve it sensibly. We agree with all of them. In addition to the modifications derived from these comments, others have been made motivated by the other reviewer and by errata detected in the review process.

We look forward to any other consideration you consider appropriate.

In the review, the following pattern has been followed:

The replies are in GREEN.

While the new additions to the article are in *ITALICS* and in *BLUE*.

a) GENERAL COMMENTS:

I think it’s a very relevant topic in semi-arid environments. In these areas, water resources play a very important role, affecting all economic sectors. In this sense, transfers in the Iberian Peninsula have become a factor of territorial disputes over water, and science must have a relevant and objective role, and ultimately, as an impartial arbiter.

Therefore, it is important to carry out this type of study. I believe that the results obtained are very relevant, but I also want to highlight the proposed process. The reproducibility of the process to other basins is very important because it can be used as part of integrated water resources management.

Regarding the scientific evaluation of work, I believe that the paper address relevant scientific questions within the scope of HESS. I believe that the topic is of significance

with some degree of originality, and it is relevant to Hydrology and Earth System Sciences.

The authors make a clear and concise description of the research problem considered. The introduction and the state of the art were selected correctly, covering current references. They justified the choice of method and the clear connection with the framework. The information sources were collected correctly. As a result, the research objectives are met, obtaining interesting and relevant results for the problem addressed (transfers between basins and their behavior in the future) that can have a significant impact on the topic.

However, the paper presents some aspects that must be reviewed. I will state the improvements that the authors must attend to.

SPECIFIC COMMENTS:

C.1.- First page: Change Fancisco by Francisco.

Thanks for the appreciation. We have corrected the errata.

1. Introduction.

C.2.- In introduction, the authors introduce the reader to the problem in an appropriate way. However, I believe that the work process is also relevant. After reading the methodology I deduce that they have used Open Source tools. It may be interesting to include this aspect in the objectives: use of Open Source and free tools to obtain a reproducible process.

Thanks for the observation and recommendation. We have used Open Source tools to simulate the semi-distributed abcd model. Both data processing and hydrological modelling with R and QGIS. A software that is free for scientific issues (SIMGES from AQUATOOL) has simulated the water exploitation system, so it can also be considered as Open Source tool for researcher community. We have include a reflection about this issue at the end of the introduction:

"Finally, note that the complete methodology was developed by Open Source tools and by free software for scientific community, which facilities the reproducibility of the work."

Alternatively, they can include this aspect in the conclusions. I believe it is a significant improvement of this work.

Similarly. In the conclusion, we have include a sentence highlighting this aspect as improvement in this work.

"Moreover, the complete methodology has been develop with Open Source tools, facilitating its reproducibility in other areas."

C.3.- Figure 1: Do the authors generate the information? If not, they should refer the source in the title.

Thanks for the question. We have generated the Figure 1 by official source of information. We have referred it in the caption of the Figure 1 *"(CHT, 2018").*

We have included a new reference:

CHT: Centro de descargas de capas en formato shape de la Cuenca Hidrográfica del Tajo. (In Spanish). Confederación Hidrográfica del Tajo Ministerio de Agricultura, Alimentación y

Medio Ambiente. España. Madrid. http://www.chtajo.es/LaCuenca/Paginas/DescargaDCapas.aspx, 2018.

C.4.- Figure 2: Include the source.

Thanks for the recommendation. We have include the source in the caption of the Figure 2 *"(BOE, 2014; 2015)".*

BOE: Real Decreto 773/2014, de 12 de septiembre, por el que se aprueban diversas normas reguladoras del trasvase por el acueducto Tajo-Segura. Ministerio de Agricultura, Alimentación y Medio Ambiente. Boletín Oficial del Estado (BOE), 223: 71634-71639. (In Spanish). https://www.boe.es/buscar/doc.php?id=BOE-A-2014-9336, 2014.

BOE: Ley 21/2015, de 20 de julio, por la que se modifica la Ley 43/2003, de 21 de noviembre, de Montes. Jefatura del Estado. Boletín Oficial del Estado (BOE), 173: 60234-600272. (In Spanish). https://www.boe.es/diario_boe/txt.php?id=BOE-A-2015-8146, 2015.

C.5.- Page 6: I think the introduction to this section and Figure 3 are right for a better understanding. However, it should be completed with a paragraph on the implementation of the process: Tools used and interoperability between them, is the process reproducible? They should comment on the programs used (GIS, program for data analysis, etc.)

Thanks for the observation. It is related with the comment 2. We had described the methodology in general way. In this new version of the manuscript, we only name the programs used and their use at the end of the section 3 (Methodology). We also introduce some references. In this point, the DSS SIMGES is named for the first time, which is described later in section "3.2. Simulation of the water resources exploitation system". All the tools used and data is available in internet, so the followed process can be reproducible.

In the section "3. Methodology" we include the following paragraph:

"The methodological framework stages were developed with Open Source tools. QGIS (QGIS Development Team, 2016) were use in the data processing of spatial information, R was employed for data analysis and hydrological modeling (R Core Team, 2016), whereas the DSS SIMGES was used for the simulation of the water resources exploitation system (Pedro-Monzonis et al, 2016a)."

We have included these references:

QGIS Development Team.: QGIS Geographic Information System. Retrieved from http://qgis.osgeo.org., 2016.

R Core Team.: R: A Language and Environment for Statistical Computing. Vienna, Austria. Retrieved from https://www.r-project.org/., 2016.

C.6.- L.8, page 6: I deduce that the authors use ABCD because it is a model that simplifies the process, allowing its understanding with good performance results. I think they should say it in this paragraph, before citing the improvements they make; I agree, it is a model with some problems, such as spatial aggregation.

Thanks for the recommendation. We have tested some lumped water balance model in advance: WAPABA (Wang et al., 2011), WASMOD (Kizza et al., 2011), GR2 (Makhlouf

and Michel, 1994), and Thortwaite-Mather (Alley et al., 1984), and the abcd model was the model which provides the best performance (E_{NS}). As it is a lumped water balance that simplifies the water cycle into two storages using only four parameters, it is possible understand how the model operates.

In addition, we have applied in semi-distributed manner in order to improve the possible deficiencies by spatial aggregation. Therefore, the simple structure of the model allows understanding the followed methodology, which guarantee its reproducibility in other areas.

We have included a reflection about the reproducibility at the end of this paragraph. We consider that it is not appropriate to indicate the performance of the model in advance. The new sentence is:

"This water balance model and this structure were selected in order to facilitate the understanding of the developed process, allowing the possible reproducibility of the work."

These references are not included in the manuscript:

Wang, Q. J.,et al., 2011. Monthly versus daily water balance models in simulating monthly runoff. Journal of Hydrology, 404(3-4), 166-175. doi: 10.1016/j.jhydrol.2011.04.027

Makhlouf, Z. and Michel, C. 1994. A 2-parameter monthly Water-Balance Model for French watersheds. Journal of Hydrology, 162(3-4), 299-318. doi: 10.1016/0022-1694(94)90233-X

Kizza, M., *et al*., 2011. Modelling catchment inflows into Lake Victoria: uncertainties in rainfall-runoff modelling for the Nzoia River. *Hydrological Sciences Journal-Journal des Sciences Hydrolgiques*, 56(7), 1210-1226. doi: 10.1080/02626667.2011.610323

Alley, W.M., 1984. On the Treatment of Evapotranspiration, soil-moisture accounting, and aquifer recharge in monthly water-balance models. Water Resources Research, 20(8), 1137-1149. doi: 10.1029/WR020i008p01137

C.7.- L.3, page 9: The authors use the DEM but they do not explain why. I think they have used it to generate the sub-basins. They must explain it and cite the method used. For example, the D8 algorithm (O'Callaghan et al., 1984).

Thanks for the feedback and the reference. We have used the DEM to delimitate the catchments and to process the climatic variables. For the case of catchments delimitation, we have used the algorithm D8 since it is already implemented in QGIS software. So, we have include this reference in the text.

We have made a modification in the manuscript at the beginning of the section "4.1. Hydrological modelling of the Tagus Headwaters River Basin".

"The Digital Elevation Model (DEM) employed has a 25-m resolution and is available on the website of the National Geographic Institute of Spain (www.cnig.es). This DEM was used as an auxiliary variable in the interpolation models of the climatic variables, and to delimit the main streams and catchments using D8 algorithm (O'Callaghan et al., 1984). The locations of the 12 gauging stations, which have observed flows in the same period, were used to establish the outlet points of the 12 catchments in which the THRB was divided (Fig. 5)."

This reference has been included:

> O'Callaghan, J. F., Mark, D. M.: The extraction of drainage networks from digital elevation data. Computer Vision, Graphics and Image Processing, 28(1), 328–344, 1984.

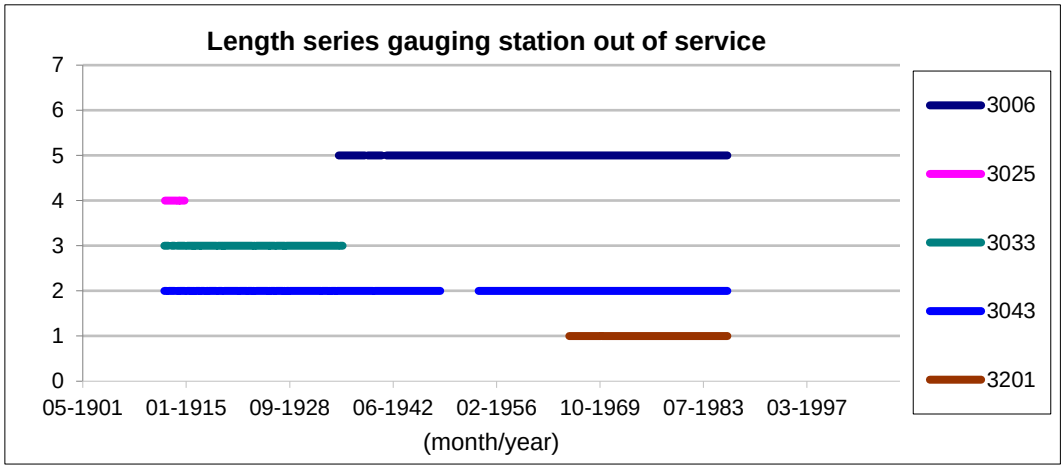
C.8.- L.11-18, page 9: Why do they use the period 1980-2009? The authors must justify it in the text.

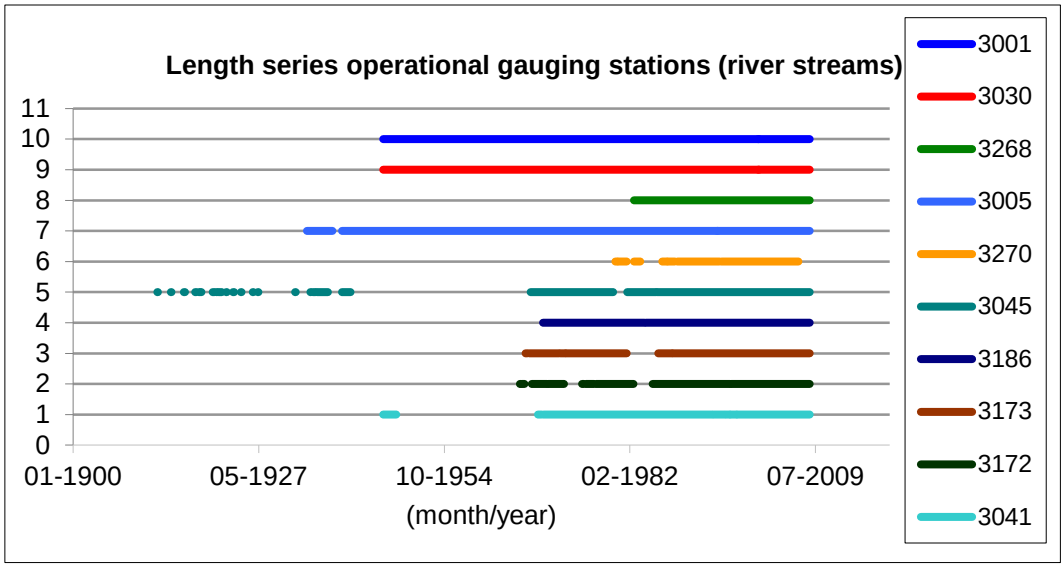
Thanks for the recommendation. We have used this period since there are data for all the gauging stations at the same time. We introduce two sentences clarifying this question in the section "4.1. Hydrological modelling of the Tagus Headwaters River Basin".

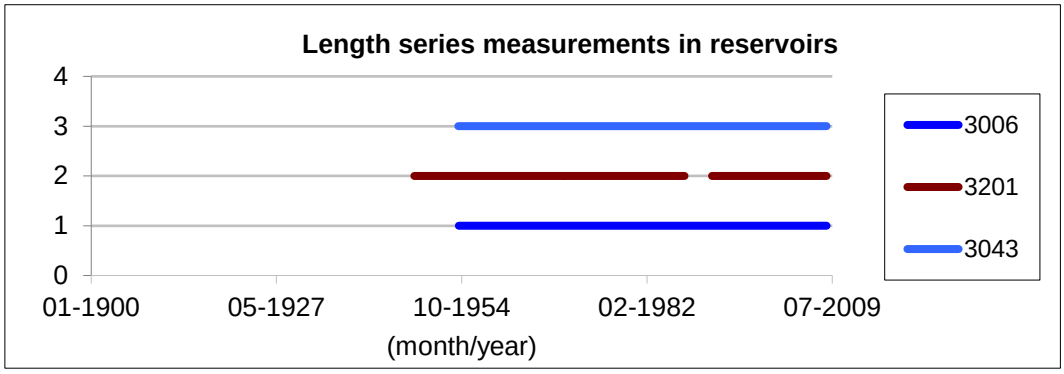
"… The locations of the 12 gauging stations, which have observed flows in the same period, were used to establish the outlet points of the 12 catchments in which the THRB was divided (Fig. 5)… As there are data available to the 12 gauging stations for the same period, it is possible to calibrate the model jointly for all the catchments."

To complete this statement, we present the following reflection:

In the study area, there are the following data of gauging stations and measurements in the reservoirs:







So, to calibrate the abcd model in a semi-distributed way, in order to capture the heterogeneity of the Headwaters of the Tagus River Basin (THRB), we used the period 1985-2010 so that there are data from the 12 gauging stations at the same period.

C.9.- L.11-18, page 9: Why use Spain02v5 ?. The authors must clarify it in the text.

Thanks for the question. The advantages of using Spain02v5 are that their daily series of precipitation and temperature are refined (without outliers and/or inhomogeneities), and that they include the spatial variability of the climatic variables in a grid with a 12.5-km resolution. Thus, as in Tagus Headwater River Basin there are areas without climatic measurements, the spatial variability associated with the climatic variability can be included using this data source, as it is said in Herrera et al. (2016).

We have included this clarification in the section “4.1. Hydrological modelling of the Tagus Headwaters River Basin”.

*“…The advantages of using Spain02v5 are that the daily series of precipitation and temperature are refined (without outliers and/or inhomogeneities), and that they include the spatial variability of the climatic variables in a grid with a 12.5-km resolution (**Fig. 5**).”*

C.10.- L.19-29, page 9: The authors have done ensembles based on different models. If so, they must include some agreement metrics of the ensemble.

Thanks for the observation. In the manuscript, we have specified the models used to make the ensembles: Simple Average Forecast Combination (SA) and Bias-Corrected Eigenvector Combination (EIG2). In addition, the main results of the goodness of fit in

the adjustments are included (E_{NS}). For example, the E_{NS} values obtained with EIG2 for the temperatures were 0.87, while in the separate models it never exceeded 0.77. For the precipitations, the E_{NS} value was 0.30, while in the models it was always lower than 0.

We have included the name of the ensembles and the metrics in the section "4.1. Hydrological modelling of the Tagus Headwaters River Basin".

"…The 10 models that best fitted for both temperature and precipitation were assembled using the Simple Average Forecast Combination (SA), and Bias-Corrected Eigenvector Forecast Combination (EIG2) (Hsiao and Wan, 2014), available in the R-CRAN package GeomComb (Weiss and Roetzer, 2016). Then, both ensembles have also been compared with Spain02v5 data using the same control period (1971-2005). Finally, the series obtained by EIG2 have been used, with a lower prediction error compared to the rest of series. For example, the E_{NS} values obtained with EIG2 for the temperatures were 0.87, while in the separate models it never exceeded 0.77. For the precipitations, the E_{NS} value was 0.30, while in the models it was always lower than 0. In addition, another advantage of EIG2 method is that it allows to correct the bias produced by predictive models. ..."

C.11.- L.19-29, page 9: The authors perform an interpolation of point data to improve their spatial representation. Although it is not the objective of this work, they should briefly describe this process.

Thanks for the suggestion. The algorithm used to carry out the interpolations of the climatic variables is included in the manuscript (Thin-Plate Splines method), at the end of the section "4.1. Hydrological modelling of the Tagus Headwaters River Basin".

"Once the monthly series of precipitation, temperature and potential evapotranspiration had been calculated, they were spatially interpolated on the cells using the Thin-Plate Splines (TPS) method (Wahba, 1990), which is based on local interpolation from polynomials. This method turns out to be relatively robust against non-compliance with the statistical assumptions necessary in methods such as Kriging, being used with good results for the interpolation of climatic variables such as rainfall (Hutchinson, 1995) and temperatures (McKenney and others, 2006). Finally, each basin was assigned the average value of the cells over which it extends."

C.12.- L.33, page 9: "... no significant differences ...." Is a statistical test performed to evaluate the significant differences? If not, you should change this phrase to: "...relevant differences..."

Thanks for the correction. We have changed "…no significant differences…" by *"…relevant differences…".*

C.13.- Figure 6: The caption is incorrect, this figure represents the SIMGES scheme. Change the caption.

Thanks for the observation. It has been a misprint. We have corrected the title of this Figure that coincided with Figure 5.

The correct caption is:

"Fig. 6. Scheme of the water resources exploitation system of the Tagus Headwaters, as far as Aranjuez"

C.14.- Table 1: The caption of the table and the title of the first row are the same. Authors can shorten the title to improve the presentation of the table.

Thanks for the observation. We have shortened the first row in the Table 1 since the information is duplicated.

Now the first row is:

"Water uses in THWRES"

5 Results

C.15.- Table 2 and paragraphs related to it: I believe that the result of the adjustment is sufficient at the outlet from the basin to use the model with the RCP scenarios. However, they should comment, when describing the behavior of the components of the model, that a greater uncertainty in some sub-basins should be taken into account (it is observed in the agreement in the validation). I believe that there is greater uncertainty in the headwater basins, probably derived from errors in the validation data (the validation series starts in 1985). This fact can explain the agreement of the calibration against the validation in these basins, while in the output the adjustment is greater.

In this period it is probable that the data observed in the output have higher quality compared to the intermediate stations, due to the importance of monitoring at the beginning of the Tajo-Segura transfer. In this period, the data observed are probably more reliable in the output compared to the intermediate stations, due to the importance of monitoring the Tajo-Segura transfer (initiated in the 1980s). However, the reliability of monitoring stations has improved today.

Thanks for this interesting reflection. The referee #1 also refers to this question. The uncertainty of the data of observed flows could explain a low adjustment in some upper catchments, as you point out. Although the data series used come from official sources (yearbook of Official Gauging Station Network of Spain) and they have been purified before publication. If there would be errors in the measurements, they would be more probable in the older data since the gauging stations could be not properly calibrated. It could explain the results of the simulation of the Buendía reservoirs inflows by Lobanova et al. (2016). They obtained a worse goodness of fit in the calibration (NSE = 0.39 for the period 1987-1993) than the validation period (NSE = 0.76 for the period 1994-1999). In addition to this, if there would be errors, they can have more influence on the results in the gauging stations of the upper catchments since they have lower flows.

To this, we can add the fact of using the validation period just after the warming up period (the last being the calibration period). Thereby, it can cause that, in some catchments, the warming up period can extend to a part of the validation period. This would entail that the calibration process used the warming up period and a part of the validation to adjust the initial parameters, obtaining worse adjustments in the validation of the model. The union of both sources of uncertainty may be the reasons why the validation yields low values in the goodness of fit. However, as the ultimate goal is to use a calibrated model for the last few years, so the result obtained in the performance is considered as good.

The first paragraph in the section "5.1. Climate change effects on the hydrology of the Tagus Headwaters River Basin" is:

"The values of the criterion coefficients calculated in the hydrological modelling show that the model employed reproduced properly the surface flows in the THRB in the calibration period: high values of E_{NS} and R^2, together with low relative errors (E_{RMS}) and volume errors (P_{BIAS}). However, in the validation period, there are some low values for the goodness of fit coefficients calculated, indicating that the results of these catchments have greater uncertainty. These results can be explained by the fact that of using the validation period just after the warming up. Thereby, it could cause that, in some catchments, the warming up can extend to a part of the validation period. This would entail that the calibration process used a part of the validation to adjust the initial

*parameters, obtaining worse adjustments in the validation of the model. But, it is important to highlight that the parameters used in the simulations are adjusted with the more recent data, providing a good performance of the surface flows in the THRB. In addition, the best performance in calibration corresponded to the outlets of the catchments of Entrepeñas and Buendía, which were the flows used as the input in the subsequent simulation of the water resources exploitation system. In fact, both catchments had N_{SE} values around 0.80 and low P_{BIAS} (**Table 2**).”*

C.16.- Figures 8 and 9: Authors should consider improving the quality of figures. 7

Thanks for the observation. We have improved the quality of Figure 7.

Conclusions

C.17.- L.4-6, page 19: The authors could include in this paragraph the recommendation in commentary C.2.

Thanks for the recommendation. We have included this reflection in the section “7. Conclusion”.

“Moreover, the complete methodology has been develop with Open Source tools, facilitating its reproducibility in other areas.”

References:

C.18.- The authors should review the format of the references, there are some problems.

For example, capital letters in the name of some articles.

Thanks for the recommendation. We have reviewed the references.

c.19.- Reference Gomariz-Castillo et al. (2015): The authors should change this reference by:

Gomariz-Castillo, F., Alonso-Sarría, F. & Cabezas-Calvo-Rubio, F.: Calibration and spatial modelling of daily ET0 in semiarid areas using Hargreaves equation, Earth Science Informatics, 15, 1–16, https://doi.org/10.1007/s12145-017-0327-1. 2017

Thanks for the observation. We have updated this reference.