First of all we would like to thank Referee 1 and Referee 2 for their comments and suggestions, we considered all of them to improve our manuscript. We will respond to the comments point by point, answering them and telling where the changes were integrated in the manuscript.

Referee #1:

This manuscript introduces a methodology to assess the effect of climate change on water resources systems by using a model chain connecting climate model results, a semi-distributed rainfall-runoff model and a water management simulation model. While I think the themes dealt with in this work are relevant and interesting for the scientific community, I am afraid the manuscript requires a severe degree of revision before it can be considered for publication in HESS.

Thank you for the comment. As you considered this work interesting for the scientific community, we carried out an in-depth review of the manuscript to solve all its linguistic and structural weaknesses, as well as clarifying the results.

To be accepted for publication in any journal, the first thing the authors should do is a thorough language and structure revision. At present, the text is clumsy and difficult to read.

We consider that the manuscript was difficult to read as English is not our mother tongue and the process of writing in detail all the steps of the methodology was very complicated. Therefore, we made a linguistic and structural revision to make it more understandable and to ensure that the grammatical structures and the vocabulary used are correct.

In any case, one of the strengths of the HESS journal is the English language copy-editing, so if after our language review it needs further improvement in this sense, we are sure that this problem will be solved before its publication.

In addition, I found some relevant information out of place, e.g., the mention to the improvement introduced in the study in page 4, which should appear in the conclusions section too (I will come back to the added value of the study later), or the description of the drought risk indicator calculation in section 4.3 that should be in methods (I will come back to this too).

We will respond in more detail later, as you come back to this in other comments.

Anyway, in the first case you are referring to this statement (page 4): “The improvement developed in this study lies in the characterization of future natural inflows and the combination of the management and risk assessments.” You are right, we followed your suggestion and we included the main improvement in the conclusions as well, see lines 583-588 and 595-597.

Regarding the description of the drought risk indicator in section 4.3 (Results), we delete it from this part and it can only be found in the new Material and methods section (3.2.4 and 3.2.5). Despite this, we considered that a short clarification was needed to guide the reader in the process, since it is complicated and not easy to understand. Thus, only one sentence (see lines 449-450) refers to the process in the new results section of the drought risk indicator (4.4).

As we said before, we will come back to this later.

Regarding the content of the manuscript, my first major concern is its absolute lack of focus.

Perhaps we did not guide the text to the key points or results in the previous version, as there were many points to be covered, but we solved this problem with your help, as you can see below. The main reason for the apparent lack of focus was the complexity of the study, which has many steps with different options and we did not want to leave any point out or unexplained.

Section 1 introduces a series of concepts mostly disconnected from each other and somehow irrelevant for the rest of the manuscript. Half of the introduction talks about climate services and how to deal with the data they provide, yet no further mention is made to them later in the text either in the discussion of the conclusions section.

Thank you for this comment.

We consider that it is important to highlight the increasing amount of climate services and data available to work with, as well as the lack of a clear rule for handling them. As we said in the introduction, some authors choose to use the ensemble, others select only those that fit with the observed data from the reference period, then correct them or not, etc. With this content we wanted to communicate the complexity of working with climate change projections, not only due to their large number, but also due to the amount of work involved in their selection and subsequent treatment, including their inherent uncertainty and the inconvenience that in Mediterranean areas the skill of these data may be not enough to extract reliable results from them. As in our case, where we obtained scattered results with great uncertainty.

Besides, this information was used to justify the decisions taken during the early stages of the methodology, such as the choice of SWICCA data as inputs (due to the easy download, handling, and confidence in the selection of Europe-wide models made by the SMHI, a prestigious climate services innovation institution). In addition to the need to correct or adjust the data and use all the ensemble members for the study.

Therefore, we do not believe that everything introduced here about climate services and how to work with them is irrelevant. It is, after all, a way of presenting what we use and why in this study, which is now related or justified in several parts of the text: sections 3.1 (lines 179-181), 3.1.1 (lines 211-212), 3.1.2 (lines 219-221), section 4 (lines 312-316), section 4.2.2 (lines 384-389), section 5 (lines 500-518, line 531, lines 536-538, lines 548-556) and section 6 (lines 601-604). Additionally, the introduction was improved as discussed below in order to give more sense to all this information.

The last 20 lines of the introduction more or less describe the problem the authors want to study and one could discern what the research objective is. However, it is not the task of the reader to guess the objectives of research work. The authors must explicit what they want to achieve with their work and communicate this to the reader in an efficient and straightforward way.

You are right. Based on the previous comments, we realized that the introduction needed to be reformulated and improved in a clearer and more direct way. Therefore, we did it and now all previous information and some other statements are related to the main objectives of this study.

These objectives can be seen in lines 49-51, 72-77 and 80-86, which are related to the proposal of an improved methodology that includes climate change projections in the water planning and management process to help decision-makers to cope with future extreme events and to solve some problems related to the uncertainty of these projections.

I would like to add that developing a methodology is not an objective in itself but rather a tool to pursue the answer to a research question. Concluding that the methodology is general enough to be applied in other case studies would be an acceptable conclusion though.

Thank you for the clarification and the suggestion.

We introduced this sentence in the introduction section to clarify once again why we developed this methodology (lines 81-83): "For this reason, the main objective of this study is to provide an answer for some of the before mentioned issues, where an adaptive tool is developed to support and help basin managers to cope with future extreme events such as droughts, which may be more frequent and intense in the future."

In this case, the tool provides decision makers with both deterministic and probabilistic intuitive results for different future periods. Therefore, looking at these results, they have the opportunity to implement measures to avoid or mitigate the potential adverse effects of climate change. Moreover, this tool can also be used to check whether or not the proposed measures improve the future state of the system (see lines 262-263). This is possible by modifying the system conditions when applying the measures and re-simulating the risk assessment model to obtain results on the greater or lesser probabilities of having certain deficits in the demands, or certain volumes of water resources in the basin. All this information clarifies why the general methodology was developed and its applicability to other case studies, although the step of applying the measures and testing them is beyond our scope in this study.

In this new version, the idea of the general method applicable to complex basins was clarified throughout the text, from the introduction to the conclusions, where it was also included in lines 594-596 that an in-depth knowledge of the basin is required to do it.

I do not have major concerns about the methodological approach of the research: climate-hydrology-management, but there is an evident need to improve the clarity of exposition in terms of sections arrangement and description of methods.

You are right, it seems that the problem in the previous manuscript was the way of telling the whole process, which was not clear and a bit unstructured, so we made a great effort to change all these aspects. They are detailed below.

With regard to sections arrangement, I have the impression that sections 2 and 3 are not separated appropriately. I would suggest that the case study was presented first. The Jucar River

Basin is an extensively studied catchment in literature, especially from this research group. Still, I think the system deserves having its own section. Afterward, the whole section 2 and subsections 3.1 through to 3.3 should be merged in a single “materials and methods” section.

Thank you for the suggestion. In the new version we presented the case study in its own Section 2, including more information about the current management of this area. Then, we merged all the related parts of the previous sections 2 and 3 into the new Material and methods section to have all this information in the same place and to avoid duplication.

Coming now to the description of methods, I think the part between lines 89 through to 115 requires a better explanation, including justification of figures 1 and 2. Line 89 reads: “In this section, a distinction between the current assessment in the management of water resources and the analysis of risks was made, despite of being intimately related”. Disregarding the quality of this sentence, there is nothing in section 2 that actually deals with that distinction unless the reader is imaginative to say the least. My assumption is that the authors call one thing (current way) to management made on the basis of current/past climate analysis and they call another thing (risk analysis way?) to the assessment of management under future climate, and they argue that the two approaches should be integrated. I do not understand the reasons for such extravagant differentiation of a traditional present versus future analysis that does not add anything conceptually new to the current state-of-the-art.

We made this differentiation based on how water resources are managed in this basin. Currently, the water allocation model is used for water resources planning over horizons of 6 to 18 years. Then, for real-time management and drought events, water managers use the risk assessment, which is normally used for a horizon of 1 to 12 or 24 months. All this is reflected in the Júcar River Basin District Management Plan (CHJ, 2015) and the Drought Management Plan (CHJ, 2018), which were named in the case study section.

What we were trying to say with these figures is that we can take advantage of both methods for the future by inserting climate change projections. Furthermore, this methodology has not yet been integrated into the River Basin Management Plans design.

Thus, we decided to remove Figure 1 and its explanation, as they were confusing and added nothing new to this specific case. However, part of this information was commented in the introduction and case study sections (lines 75-81, 132-135).

Then, Figure 2 in combination with Figure 3 showed the steps of the methodology to extract the risk and management results. As they were confusing and a bit difficult to understand, we merged both figures in the new Figure 2, which is now clearer and more understandable. This figure combined with the description in the text are ensuring a complete understanding of the process.

Now is when things get spicy. The authors mention that the novelty introduced in this research “lies in the characterization of future natural inflows and the combination of the management and risk assessments”. But, what is new about determining streamflow under future climate conditions and compare it against present conditions? I want to think this must be a writing error from the authors as I do see more value to the results they present further than just comparing two situations.

The point here is the process related to the characterisation of the future river flows and the planning and risk assessments. With this statement, we refer to the whole process involved in the treatment of climate change projections to adapt them to the basin features and then to the modelling chain designed to extract some results that complement each other.

All this was reformulated from the introduction and explained in detail in the Material and methods section, since we are not referring only to the change rates, which we know are very common in this type of studies. However, as we said in the discussion section (lines 548-556), these change rates for the entire basin may be more reliable than those from other studies because we used a reference period adapted to the current situation of the basin. This is another new income that has to be considered as a technical improvement.

Continuing down the line, I think section 3.3 is the core description of the methodology. I suggest it appears earlier in the text and that it uses a more generalized language only mentioning that modules from the Aquatool software will be used (substitute Aquatool modules' names by generic names, e.g., EVALHID rainfall-runoff model, MASHWIN stochastic streamflow series generator, SIMGES water management simulation model).

Thank you for the suggestion. Section 3.3 is where the main part of the methodology was detailed together with Figures 2 and 3. In the new version of the manuscript, this part is the core of the Material and methods section with the help of the new Figure 2. Then, this section was completed in the subsections where the methodology was adapted to the basin. In addition, we replaced the names of the Aquatool modules by the general name of the models and a new section was included to introduce this software and its modules, as you suggested below.

Next, I suggest sections 2.1 and 3.1 are merged into a single 'current and future climate (or better name)' section. Section 3.2 could be a subsection of the new merged section.

We agree, sections 2.1 and 3.1 were merged in the new section 3.1 called "Climate change projections and historical local data" and previous section 3.2 is now a subsection of the new merged section, as you suggested.

By the way, the words precipitation and temperature do not appear so often in the text and are not that long to require using an acronym. I suggest you revise this.

Thank you for the suggestion. We remove the acronyms from the text and figures.

Finally, all the models that are actually part of the Aquatool software would be better together under an 'Aquatool modeling package (or better name)' section.

You are right. In the new section 3.2.1, called "AQUATOOL Decision Support System Shell (DSSS)", we explained in detail the features of this software and the modules used for building the different models. In the rest of the text we used a more generalized language for the models, as we said before.

I would like the authors to clarify their position with regard to bias correction. By the way, figure 3 is an absolute mess, it should be revised for clarity. The authors claim in the discussion that "working with the raw data would lead to unfavorable results for the future since the underestimation of flows in the headwaters is notable, this fact may also lead to alarming conclusions about the future hydrology in this basin". But, in figure 6, we see that bias correction actually changes one problem for another, especially at the resource generating catchments of Alarcon and Contreras. While the uncorrected data fits visually well precipitation between March and September (dry months), underestimating it during the wet months in the winter, the bias-corrected data overestimates spring and summer precipitation while still underestimating winter precipitation. This is potentially a problem if the extra amount of water in the summer introduced with bias correction exceeds the winter deficit of the uncorrected data. I think this might be explored.

We thought that Figure 3 was a good way to present the two options considered in the characterization of natural flows, but it seems that this figure was difficult to understand and we decided to merge Figures 2 and 3 in the new Figure 2 to show all the methodology in the same figure. Thus, this part was more understandable and its description was completed in the text, as mentioned before.

Regarding the bias correction, as we said in section 4.2.2 and lines 514-517 (discussion section), we decided that a bias correction was needed due to the huge underestimation of flows in the Alarcon and Contreras sub-basins, which is a problem from the point of view of water management since there are placed the main reservoirs of the system. This means that if we use this data, we are accepting that the resources we are taking as inputs are much lower than those that actually exist, which is not acceptable in this field.

Thus, we applied the most recommended method in the literature, but the results of the bias correction were not convincing because precipitations and flows were overestimated in the spring and summer months. Despite this, we accepted them because the differences between the averages were minimised and the flows of the headwaters were better fitted to the observed values (sections 4.2.1 and 4.2.2).

However, we consider that the currently available methods of bias correction may not provide satisfactory fittings to the observed series in this area, so we argue this in more detail in the discussion section, starting with line 518.

The descriptions in 4.2.1 and 4.2.2 correspond to the methods section. The authors should limit to describe the results in these sections.

You are right, these descriptions are now in the Material and methods section and in sections 4.2.1 and 4.2.2 only one sentence was kept to guide the reader through the process, as it may be complicated to understand and lead to confusion.

Moreover, I think the section would benefit from merging figures 7 and 8, although I am not sure whether the first column in figure 8 should be maintained for what I will mention next.

We merged Figures 7 and 8 in the new Figure 5.

Figure 9 shows the mean rates of streamflow change for the three future periods with regard to the reference period. Did the authors check the rate of change between reference and future periods of non-corrected flows from option B? I think this might be revealing. Also, the size difference between graph A and graph B in figure 9 should be revised.

We did not check the average change rates of the non-corrected flows because we thought that the underestimation of the upstream flows was unacceptable, so we decided not to work with them, as we discussed above.

However, the flow change rates are available in the SWICCA portal for each future period, but the results without skill in the re-forecast analysis are found in almost the entire basin. Therefore, we thought that using these change rates would not give us realistic results for the future.

On the other hand, Figure 9 was replaced by the new Figure 6, which shows the same information but represented on the basin maps. We believe this is a very good improvement.

Regarding the final step of the methodology, relative to water management simulation, I think the authors should justify better the added value of using stochastic modeling when they already have a reasonable amount of data (several 30 years series from various climate models) to perform the statistics relative to water storage.

We think that only 9 series (one for each ensemble member) are not enough to apply the risk assessment process, even though we divide them in periods of 30 years. The more equiprobable series we generate with the statistical properties of each ensemble member, the more agreement between them, which means more reliable results. This statement is not shown in the risk indicator (Figure 8) as the ensemble members are quite disperse (dry or wet periods) and they complement each other in the ensemble, resulting in almost the same probabilities of being in any volume interval of the total capacity of the system.

We included lines 304-305 to justify the added value of this step.

I think the results from using the water management simulation model should appear before the ones from the stochastic simulation and, in any case, both results should be comparable (e.g., calculating the drought indicator, or the exceedance probability in September).

Thank you for the suggestion. We placed the results of the water management before those of the risk assessment. Actually, they are already comparable because in both cases we are showing the evolution of the water resources of the system, one in form of risk indicator with probabilities for each future period and in the other with mean volumes of the ensemble and the range covered by it for the entire period.

The exceedance probability at the beginning of the irrigation season might be a relevant result too.

You are right, but we focused on September because it is the end of the irrigation season and the end of the hydrological year. Thus, this result is probably the one that best summarizes the final state of each campaign. In addition, this is a meaningful data for the stakeholders because it is better understood by them.

However, we included the exceedance probability at the beginning of the irrigation season (March) because it can be a good way of informing the irrigation associations about the possibilities of having shortages and take measures to avoid them.

Thus, we showed both results in the reviewed manuscript.

Anyway, the results of this section show how the relevance of the bias correction is dampened through the modeling chain. Considering limitations and additional uncertainty introduced by bias correction highlighted by Ehret et al. (2013) and the results of studies like Muerth et al. (2013) who argue about the utility of bias correction in model chains, I think the authors lost a good opportunity to contribute to the existing debate on the added value of bias correction in the modeling of climate change impacts on water resources.

You are right, the debate on the added value of bias correction in the modelling of climate change impacts on water resources is very interesting, but that is not one of the purposes of this study. What is important here is that the raw data were very inappropriate in this case, and we applied the most recommended method to correct them. We know that it has its pros and cons, so we decided to test it on the meteorological data and the flows, just in case there was a notable difference between them and to be able to recommend the better option. But in this case the difference between them was not significant.

However, the papers of Ehret et al. (2012) and Muerth et al. (2013) are very interesting, such as the one by Teutschbein and Seibert (2013) which applies the bias correction in different seasons and the one by Switanek et al. (2017) in which the quantile mapping method for climate change applications was improved. We mentioned all of them in the manuscript (introduction and discussion sections) to go a bit further into the subject of bias correction and discuss its application, but as you will understand, we cannot develop this part in detail since the methodology and its adaptation to the case study are more important on this occasion.

I would not like to finalize my review mentioning that the authors make the wrong use of the term tendency throughout the whole text to my understanding. Mostly because the authors do not show whether their results really follow any trend and whether this is significant.

In this case, the term tendency refers to the decrease of flows as we approach 2100, which is shown in the average change rate of the Júcar River Basin (Figure 6). Perhaps the trend is not so evident because the reduction is relatively low (from 1% to 12%), but considering that we are working with the Júcar River system, these decreases can lead to major problems of water deficits and huge economic losses. Therefore, these small decreases are significant, as the basin is already stressed (demands/resources ≈ 0.9) and this presents a big challenge for decision-makers during extreme events such as droughts.

However, we did not use the term “tendency”, instead we referred to the “decrease” in order to avoid any misunderstanding.

Referee #2:

First, and from the point of view of the structure of the paper, its title is too long and inaccurate. The work contains, in addition to the methodology, a case study and results obtained after applying the developed methodology.

Thank you for the comment.

In the title we wanted to highlight the importance of the methodology, as it integrates the water planning, the risk assessment, and the possibility of making the bias correction in different ways that lead to the characterisation of natural flows. In this case we did not include the case study since it is a methodology that can be applied to other basins, taking into account its features.

However, as you find it convenient, we changed the title with a more concise format and integrating the case study. We considered these options and the first one was the new title of the manuscript:

- Risk assessment in water resources planning under climate change at the Júcar River Basin.
- Characterisation of natural inflows and modelling chain methodologies for risk assessment in water planning under climate change at the Jucar River Basin.

Second, there is confusion between sections 2, Material and methods, and 3, Case study, since subsections 3.1 and 3.2, and perhaps 3.3, would be better classified as Material and methods.

You are right, the case study was now presented in its own section before the Material and methods section, where previous sections 2 and 3 were merged to reduce the length of the manuscript and avoid replication, giving more sense to the structure of the document.

As for figures, figure 1 does not seem necessary and figure 2 is difficult to understand.

Thank you for the suggestion. Figure 1 was introduced as a small clarification that water management and risk assessment are closely related and how each one works, then in Figure 2 we highlighted the key points of each process. However, we remove Figure 1 and its explanation because you are right, it does not seem necessary. Despite this, we included something about this relationship in the introduction and in the case study sections, as it is part of a specialisation related to water resources management in problematic basins such as the Júcar River Basin, which is stressed due to high exploitation rates (demands/resources ≈ 0.9).

Then, we merged Figure 2 and Figure 3 in the new Figure 2, which is now clearer and understandable jointly with its description in the text that clarifies the key points and guides the reader through the adaptation to the basin in the following sections.

The introduction lacks the reference to similar works that have incorporated climate change projections in decision-making processes in other basins, not just those in the Mediterranean environment. And this is important since the results of the work show a great dispersion (see figure 12).

In this part we decided to focus on Mediterranean studies due to the great dispersion of our results. We justified this in the discussion since most of the authors agree that the skill of climate change projections of this area is very low and usually they are not capable of representing the characteristics of historical droughts (lines 501-503, 536-537).

However, in the reformulation of the introduction section, we named similar studies developed in other areas over the world to justify their inherent dispersion, as those developed by Stagl and Hattermann (2016) and Chatterjee et al. (2018) in the Danube River basin and Kansas, respectively. In addition, we also made statements based on studies developed in other European areas, such as Sweden (Teutschbein and Seibert, 2013).

The Material and methods section is quite robust since this work group has implemented numerous modules, already contrasted, in the Aquatool Decision Support System and now used (hydrological model; management model; water allocation model; stochastic model and risk assessment model). This paper provides the integration of climate projections into the model and its impact on future flows in the basin and on the storage of water in the system. In this sense, it uses nine Ensemble members (table 1) that cause a great dispersion of results, as already mentioned, and an inaccuracy in the conclusions. Would it be possible to use only those that have given better results in the Mediterranean region?

Thank you for the comment. As we said in the text (lines 179-181), we decided to use the ensemble provided by the SWICCA portal (Table 1) because they selected the members that were most suitable for the entire Europe. However, their fitting in this area is not good enough to consider only some of them as they are not able to fit perfectly with the observed data. Moreover, they are not capable of reproducing the statistical characteristics or trends in the average year (new Figures 4 and 5) or over the whole period, neither the characteristics of the historical droughts. For this reason we thought that the use of the whole ensemble would provide us with more options and more robustness to the study based on some authors recommendations (lines 59-65), since increasing the number of ensemble members reduces the sampling uncertainty.

Despite all the efforts we made in the first part of the methodology to reduce the uncertainty provided by the RCMs, such as shortening the reference period to be more in line with the current situation of the basin or correcting both the meteorological and the flow data, this was not possible. Therefore, the results are quite dispersed. This reveals the need to improve the skill of climate projections and the use of more sophisticated bias correction techniques, as we said in the discussion section (lines 521-523 and 531-538).

On the one hand, they work with flow data in the basin between 1980-2012 and, on the other hand, the reference period is reduced to the 1980-2000 period. However, as can be seen in Figure 5, there are differences in the average year inflows between the different periods. Can the use of these different periods have an influence on the results obtained?

Thank you for the suggestion. As we said at the end of Section 2, in this basin it is advisable to work with data from the period 1980-2012, since using series with periods prior to 1980 can lead to an overestimation of water resources due to the so-called “effect 80”, which is a significant decrease in precipitation and inflows in the basin from the 1980s onwards. Thus, this is the reason why we decided to shorten the reference period provided by SWICCA (1971-2000) to 1980-2000, in order to try to better represent the current situation of the basin. In this way, we tried to decrease the uncertainty of the magnitude of future changes when we compare future flows with a reference period that represents the basin, such as the results of the average change rates of the whole basin (new Figure 6).

The new Figure 3 shows how the inflows from both periods (1980-2012 and 1980-2000) can be considered equivalent since the difference between their averages is not significant. However, if we had used the period 1971-2000, we would have a different and unrealistic perception of the basin at this time, since water resources are greater than in reality and by correcting future data this would also be transferred to future periods.

Answering your question, yes, the use of the different periods influences the final results, but in this case the difference between using the period 1980-2012 and 1980-2000 is not notable. Indeed, we published a paper (Suárez-Almiñana et al., 2020) that compares the change rates for the whole basin using the three reference periods named before (1980-2012, 1980-2000 and 1971-2000), among others. In that paper we conclude that the average change rates of the basin are very similar when comparing the future flows of each period (2011-2040, 2041-2070, 2071-2098) with the flows of the reference periods 1980-2012 and 1980-2000. However, when those future periods are compared to the reference period 1971-2000, the average change rates are more drastic (up to -23% at the end of the century), which is logical since this period has more resources available, leading to a more extreme and alarmist conclusion than in this case where the average change rates are between -11% and -12% for the whole basin.

Thus, we think that the shortening of the period was a good decision and the differences between the reference periods 1980-2012 and 1980-2000 are not producing very different results.

The results obtained in figures 6, 7 and 8 are only visually compared. In the text it is written, for example, (lines 353-354): “There can be seen how both HBV models results are generally close to the observed flow values”. Would it be possible to specify, from a statistical point of view, the term "close"?

In this case, the term “close” refers to the visual distance between their averages, but we included the NSE and PBIAS statistics in the updated version of this manuscript. We calculated these statistics to find out the performance of the RCMs and whether they improved with bias correction, as well as the tailoring of the hydrological model to the basin. To do this we based on the performance ratings recommended by Kalin et al. (2010) (daily time step) and Moriasi et al. (2007) (monthly time step), which were shown in Table 2. In addition, these recommendations were described in sections 3.1.2 and 3.2.2.

The results of figure 9 show a great variability between options A and B, mainly in the two head reservoir, Alarcon and Contreras. In view of the results in Figure 12, could one option be recommended over another?

Thank you for this question. Figure 7 from the updated manuscript shows how the average of the ensemble is lower in option B and the shaded area reaches much lower values than in option A. Therefore, although option B is more dispersed, if we chose it we would be working from the point of view of security against future intense drought events, which seem to be more frequent and intense in the future. However, we cannot choose one option over the other due to the high dispersion in both cases. All this was exposed in lines 435-440 and 567-570.

Some minor comments would be: - Figure 2: the acronyms of P and T have not been previously defined - Line 133: the acronym RCM is defined later (see line 236) - Lines 223-226: There are several references to geographical names such as the Albufera of Valencia that are not shown on the map in Figure 4.

Thank you for these comments.

We deleted the P and T acronyms because they did not appear so often in the text. The acronym RCM was previously defined and the irrigated crop areas and the wetland belonging to l'Albufera de Valencia were included in the new Figure 1.

We hope that our responses to the reviewers' comments and the changes we made in the manuscript will be enough to be published in the HESS journal.

Definición de estilo: Texto comentario

~~Methodology based on modelling processes and the characterisation of natural flows for risk~~Risk assessment ~~and~~in water ~~management~~resource planning under ~~the influence of~~ climate change at the Júcar River Basin

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Abstract. Climate change and its possible effects on water resources has become an increasingly near threat. Therefore, the study of these impacts in highly regulated systems and those suffering extreme events is essential to deal with them effectively. This ~~paper~~study responds to the need ~~of~~for an effective ~~methodology that integrates the~~method to integrate climate change projections into water planning and management analysis in order to guide ~~complex basin~~ the decision-making ~~through~~taking into account drought risk ~~and management~~ assessments.

~~In~~Therefore, this ~~study is presented an~~ document presents a general and adaptive ~~method~~methodology based on a ~~model~~modelling chain and correction processes, ~~where the~~whose main outcomes are the impacts on future natural inflows, a drought risk indicator and the simulation of ~~the~~ future water storage ~~of~~in the water resources system (WRS~~) under consideration. The proposed methodology~~).

This method was applied in the Júcar River Basin (JRB) due to its complexity and the multiannual drought events it ~~goes through.~~suffers recurrently. The results ~~shown~~showed a ~~decreasing tendency~~worrying decrease of future inflows ~~to the basin, and the drought risk indicator shows~~, as well as a high probability (≈ 80%) of being under 50% of total capacity of the WRS in the near future~~, but~~. However, the uncertainty ~~is~~of the results was considerable from ~~the middle~~ mid-century onwards, indicating that ~~an improvement in~~ the skill of climate projections ~~is required~~needs to be improved in order to obtain more reliable results. Consequently, this paper also highlights the difficulties of developing this type of methods, taking partial decisions to adapt them as far as possible to the basin in an attempt to obtain clearer conclusions on climate change impact assessments.

~~Thus, this paper also highlights~~Despite the ~~difficulties of developing this type of methods, since~~high uncertainty, the ~~conclusions on climate change impact assessment depend on partial decisions taken during the methodological processes. However, the main~~ results of the JRB call for action ~~in the JRB~~ and the tool developed can be considered as a feasible ~~option~~and robust method to facilitate and support decision-making in complex basins for future water planning and management.

1. Introduction

The studies related to the possible effects of climate change on social, environmental, and economic frameworks have increased exponentially in recent decades. The main reason ~~of~~for this ~~increasing~~increase is the need to improve the adaptability of society and the ~~possibility~~capacity to manage ~~risks~~risk, which ~~were~~was recognized by governments, scientists, and decision~~-~~-makers at the World Climate Conference in 2009 and led to the creation of the Global Framework for Climate Services (GFCS) (Hewitt et al., 2013).

In fact, climate services have evolved over time to reach the wide variety of data that is available today, at the global, continental or national level. Normally, seasonal forecasts and climate projections are freely accessible through Internet portals. ~~One of the most known climate service is~~ CORDEX (Coordinated Regional Climate Downscaling Experiment, https://www.cordex.org/~~),~~) is one of the most known climate services. It is an international database that provides climate projections from all over the world and also has sectoral domains, as the EURO-CORDEX domain for Europe (https://euro-cordex.net/).

However, the massive amount of data provided by these portals need an advanced knowledge ~~to~~for their extraction. In this sense, some portals at continent level facilitate the selection process of ~~selection of~~ models and variables filtering them according to the needs of the user (meteorological and hydrological variables, indicators, graphs, tables, etc.). For example, SWICCA (Service for Water Indicators in Climate Change Adaptation, http://swicca.eu/) is a ~~European~~result of a Copernicus project that offers climate-impact data to speed up the workflow in the climate-change adaptation of water management across Europe. This portal ~~that filtered~~ provides climate projections (~~coming~~ from CORDEX) filtered by the best fitting across Europe ~~and provides~~, as well as a summary of their impacts ~~in graphics~~using graphs, tables, and maps for different space and time scales~~. SWICCA is a Copernicus project that offers readily available climate-impact data to speed up the workflow in climate-change adaptation of water management across Europe~~.

Then, each country has ~~their~~its own regionalised dataset, as ~~that~~the one provided by AEMET (State Meteorological Agency in Spain), which ~~come~~comes from the global models used in the 5th Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2014). In fact, these data were used in the report developed by CEDEX (2017) about the assessment of the climate change impact on water resources and droughts in Spain, which is a reference study at ~~national level, since it is based on the main basins of this country. The general conclusion was the future decrease of water resources and the increase in the number of droughts and their intensity in most Spanish basins~~the national level.

~~Based on~~According to van den Hurk et al. (2016), climate services are essential to boost innovation in the water sector and increase its capacity to adapt to climate change. Hence, this big offer presents the opportunity to develop new ~~methodologies~~tools or to improve the current ones incorporating climate projections in water management ~~by developing tools~~ to extract useful information adapted to specific sectoral needs (Hewitt et al., 2013). ~~However, the process of developing new methods is not easy, especially if it is for a long-term range, since anticipate~~That is exactly what we aim to do in this study, proposing a general methodology inspired on the work of Suárez-Almiñana et al. (2017) to integrate climate projections in the decision process throughout a model chain for water management and drought risk assessments, where the future impacts on inflows and water resources are evaluated.

However, developing new methods is not easy, especially if it is for a long-term range, since anticipating responses to extreme events in a solid decision-making context for a distant future is challenging (van den Hurk et al., 2016). In addition, van den Hurk et al., (2018) ensure that there is a gap between the spatial and temporal scales of the models versus the scales needed in applications and also highlight the need of tailoring climate results to real-world applications. These issues, among many others, may be the reason why so little climate action is taking place despite the wider knowledge of climate change (Naustdalslid, 2011).

~~In this sense, there are~~ Therefore, it seems that some issues ~~that have~~need to be ~~addressed, as~~resolved in order to move forward in the ~~correct way~~process of developing these new methods. The selection of projections and how to handle them correctly are part of these issues, since the ~~projections, taking into account their~~ inherent uncertainty ~~that~~of projections normally determines its use in practice (Lemos and Rood, 2010). ~~Some authors recommend working with the ensemble,~~In this sense, some authors recommend working with the ensemble (Stagl and Hattermann, 2015), since increasing the number of ensemble members reduce the sampling uncertainty (Collados-Lara et al., 2018; Thompson et al., 2017). ~~On the other hand, working only with one ensemble member more fitted to the historical data in the reference period~~Another option is differentiating between the Representative Concentration Pathways (RCPs ~~is not advisable, since the results can lead to erroneous conclusions due to the extreme values (Collados-Lara et al., 2018). Another option is differentiating between the Representative Concentration Pathways (RCP~~) implied in the study (Barranco et al., 2018; Marcos-Garcia et al., 2017) to consider the impacts related to the emission scenarios. However, working with only one ensemble member is not advisable, since the results can lead to erroneous conclusions due to the extreme values (Collados-Lara et al., 2018).~~in order to consider the impacts related to the emission scenarios.~~

~~In addition, van den Hurk et al., 2018 ensure that there is a gap between the spatial and temporal scales of the models versus the scales needed in applications and also highlight the need of tailoring climate results to real-world applications.~~

~~These issues, among many others, may be the reason of~~The need to reduce the uncertainty or increase the skill of these data is also a recurrent topic, but the dispersion of the ensemble members (EMs) is a fact over the world (Stagl and Hattermann, 2016; Chatterjee et al., 2018; Suárez-Almiñana et al., 2020), which would hamper the impact simulations (Teutschbein and Seibert, 2013) and influence the reliability of final results, making decision-makers reluctant to consider these data for water management. The application of correction processes might be a solution to this problem, but these corrections may not provide a satisfactory physical justification (Ehret et al., 2012; Suárez-Almiñana et al., 2017) and it makes more difficult their inclusion in real-world applications.

Here is where the main improvement of the proposed methodology is focussed, the characterisation of future inflows, where correction and adjustment processes are applied to the ensemble in order to strictly adapt it to the case study in an attempt to reduce the uncertainty of simulated flows. Consequently, this step is also related to the proper calibration of the models involved in the modelling chain, which makes easier the complementation of management and risk assessments. All these efforts are related to the aim of obtaining more reliable results for decision-makers to trust these types of tools and to integrate them in the River Basin Management Plans (RBMP).

In fact, our study was focused in the east of Spain, the Júcar River Basin (JRB), where the inclusion of climate change assessment in the RBMP is mandatory, but it is not considered in the decision-making yet.

Thus, the need for an effective methodology that integrates the climate change projections to guide the decision-making is notable in this country and probably in many others. For this reason, the main objective of this study is to provide an answer for some of the above-mentioned issues, where an adaptive tool is developed to support and help basin managers to cope with future extreme events such as droughts, which may be more frequent and intense in the future (CEDEX, 2017; Marcos-Garcia et al., 2017). In addition, testing this tool in the JRB may be challenging, since this basin is heavily regulated and has a high hydrological variability that leads to face recurrent droughts of several years. Hence, the scarcity problems are expected to increase and early decision-making guided by a more accurate impact assessment will be needed.

~~so little climate action is taking place despite the wider knowledge of climate change (Naustdalslid, 2011).~~ ~~In fact, our study was focused in the east of Spain, where the inclusion of the assessment of possible effects of climate change in the River Basin Management Plans (RBMP) is mandatory, but they are not yet considered in the decision-making. Here, there is a lack of methodology to incorporate climate projections in the RBMP, where climate change effects were assessed by reducing the natural hydrological resources of the basin in a certain percentage for the future hydrological cycles of management (6 to 18 years), based on the results of CEDEX (2010), and then using Decision Support Systems to assess the impact on the water resources system (WRS) (CHJ, 2015).~~

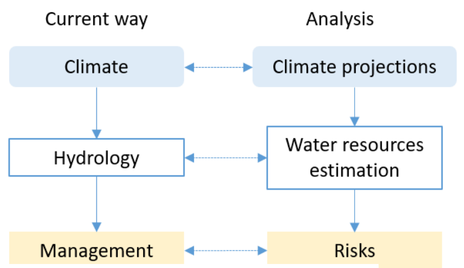
~~Thus, the need of an effective methodology that integrates the climate change projections in order to guide the decision-making is notable in this country and probably in many others. For this reason, we propose a methodology inspired on the work of Suárez-Almiñana et al. (2017) to integrate them in the decision process throughout a model chain, where the impacts on future river flows, and on a drought risk indicator made up of the future total water storage in the system are the main outcomes. Other important improvement of this study lies in the characterisation of future flows, where meteorological data are transformed into river flows using a hydrological model strictly adapted to the case study and different processes of bias correction.~~

~~In this case, the general methodology was adapted to the Júcar River Basin (JRB), focusing our attention in each step and trying to improve and adjust them as much as possible to the basin, which was selected because it is heavily regulated and has a high hydrological variability (typical of Mediterranean climate) that leads to face recurrent droughts of several years. Furthermore, if we take into account that these events may be more frequent and intense in the future (CEDEX, 2017; Marcos-Garcia et al., 2017), it is expected that scarcity problems will increase and early decision-making guided by a more accurate impact assessment will be needed.~~

To this end, in the ~~following~~next section ~~presents~~can be found the ~~proposed~~features of the case study, then the improved methodology is presented, which could be generalized for many basins with similar characteristics as the case study ~~area~~. Next, the ~~characteristics of the case study~~ results are detailed~~, as well as the results~~ and ~~the discussion, where~~ all the partial decisions taken during the process are justified~~.~~ in the discussion. Finally, the conclusion section ~~closes the circle with~~summarises the main outcomes of this study.

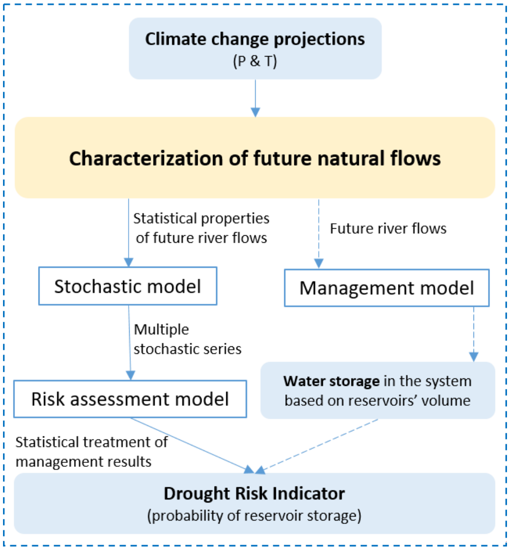
~~2.1. Material and methods~~

~~In this section, a distinction between the current assessment in the management of water resources and the analysis of risks was made, despite of being intimately related. In the current way, attention should be paid to the climate and its related hydrology to manage the water resources, while in the analysis way the focus is on the climate change and the variation in water resources depending on the future hydrology. Then, the environmental and socioeconomic risks related to this variation and the management of the water resources system are evaluated in a probabilistic way. In the Fig. 1 the differences and relations between these ways can be seen.~~



~~**Figure 1. Distinction between management and risk assessments and their relationship.**~~

~~Thus, as a methodology that integrates climate change projections in water planning and management is needed, we tried to incorporate this analysis part using an improved version of the methodology presented by Suárez-Almiñana et al. (2017), which consists in the integration of climate projections into a model chain to assess the risk of drought throughout a probabilistic indicator about the reservoir storage. The improvement developed in this study lies in the characterization of future natural inflows and the combination of the management and risk assessments. The characterisation of flows is the conversion of meteorological data into river flows using a hydrological model and paying attention to some processes, as the bias correction. Then, these future flows are introduced in a management model to simulate the future water storage of the WRS, while their statistical properties are used in a stochastic and risk assessment models to obtain a drought risk indicator that informs about the probable evolution of the future water resources in the entire WRS, as Fig. 2 shows.~~



~~**Figure 2. Methodology for the integration of climate change projections in the risk and management assessments with the aim of obtaining a drought risk indicator to support decision-making.**~~

~~The steps of this methodology are detailed in the next sections.~~

~~2.1 Climate change projections~~

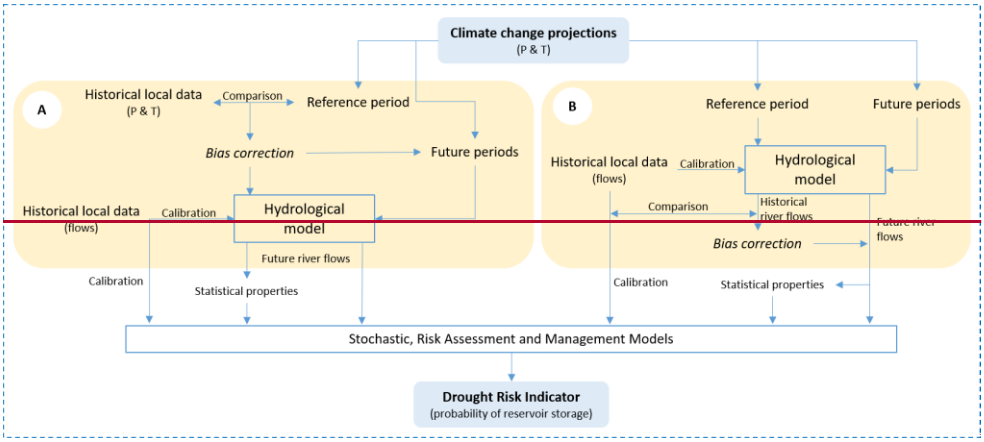
~~The starting point of this methodology are the climate projections. The selection of projections and their associated variables depends on the purposes of the study and the tools available to treat them. It is also important to consider that the final results will depend to a large extent on them. Thus, this first step may be the key for the rest of the process.~~

~~Input data in the framework of water resources can be meteorological, hydrological or many types of indicators, depending on the final purposes. In this case, it was decided to start with meteorological variables instead of flows, despite the fact that the process may be simpler and shorter using hydrological variables. According to our experience, pan-European models do not have yet the capacity of representing the hydrologic characteristics of complex basins (Suárez-Almiñana et al., 2017). This may be due to the wide scale of European hydrological models, where the tight relationship between rivers and aquifers summed to the high anthropization of rivers typical of dry areas are not well represented (Suárez-Almiñana et al., 2017) unless the hydrological model is well tailored to the basin. In this way, the proposed methodology may be used in other basins by using meteorological variables.~~

~~Thus, the meteorological data provided by SWICCA was selected for this study. As it was commented in the introduction section, SWICCA is the result of a Copernicus project that had the aim of having available data related to water resources for Europe and it is managed by the Swedish Meteorological and Hydrological Institute (SMHI). Hence, it allows to download data related to water quantity and quality, precipitation (P), temperature (T), air and socioeconomics in a user-friendly format (.xlsx). Moreover, they made a good selection of RCMs for Europe and there is a huge variety of available data at different temporal and spatial scales.~~

~~2.2 Characterization of natural inflows~~

~~The characterization of flows means to convert meteorological variables into natural flows throughout a hydrological model that strictly represents the characteristics of the area of application. Thus, the hydrological model has to be well calibrated and, if the series from the reference period (either meteorological or hydrological) are not fitted to the observed values (historical local data), they may need a bias correction. In this sense, we proposed two alternatives for this characterisation (A and B) that are shown in Fig. 3. The main difference between A and B options is the correction of meteorological variables before their inclusion into the hydrological model or the correction of flows after the hydrological model run with raw meteorological variables.~~



~~**Figure 3. Detailed workflow for characterising natural flows using a bias correction before (A) and after (B) the use of the hydrological model.**~~

~~In alternative A, the P and T of the reference period are bias corrected using historical local data. Then, this correction is extended to future periods and they are introduced into the hydrological model, which was previously calibrated using~~

~~historical flow data. However, in B option raw P and T of the reference and future periods are introduced into the hydrological model. Afterwards, the hydrological outputs of the reference period are corrected using historical flow data and the correction is extended to the future periods.~~

~~Once future flows were extracted from A and/or B alternatives, their values and statistical properties will be used in the rest of the model chain (stochastic, risk assessment and management models).~~

~~2.2.11.1.1 Hydrological model~~

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~~The hydrological model is used to evaluate the amount of water resources produced in a certain basin. In this case we resorted to the module EVALHID (Paredes-Arquiola et al., 2012) of the AQUATOOL Decision Support System Shell (DSSS) (Andreu et al., 2009, 1996). This software is used at national and international level due to its user-friendly interface and the several modules that has integrated related water resources problems, as quality and management among others. These modules are interconnected between them, an important issue to be considered in this study because the outputs of one model are the inputs of the others, as is expected in a model chain.~~

~~Thus, EVALHID has available several rainfall-runoff models with different structural complexities and parametrization, but all of them have been aggregated with semi distributed applications at the sub-basin scale (García-Romero et al., 2019; Hernández-Bedolla et al., 2019; Suárez-Almiñana et al., 2017).~~

~~As input data, P and potential evapotranspiration (PET) are needed, so T has to be converted to PET before running these type of models. In addition, its calibration is essential in order to represent the characteristics of the basin. To do that, historical local flow data are needed.~~

~~2.3 Management and water allocation model~~

~~In this case, the module SIMGES (Andreu et al., 2007) of AQUATOOL DSSS was used to simulate the future management with the river flows from the previous step. Here, the schematic of the WRS can be drawn and the databases for the definition of its elements (as reservoirs, contributions, demands, returns, aquifers, channels, environmental flows, etc.) can be filled along with the operation rules and the water use priorities in using a friendly graphical interactive interface. All these aspects of the system are used to simulate the water allocation throughout an optimization algorithm for deficits minimization and maximum adaptation to the reservoir objective volume curves.~~

~~2.41.1.1 Stochastic model~~

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~~Other module of AQUATOOL DSSS is MASHWIN (Ochoa-Rivera, 2008, 2002), which allows to create stochastic models in order to generate multiple and equiprobable synthetic series of flows conserving the statistical properties of the flows you want to use as a basis for the generation, in this case flows from future periods. Here are also needed the historical local flows in order to calibrate and validate it. This module is a complement for the risk assessment model, since it needs a high number of flow series to perform the assessment.~~

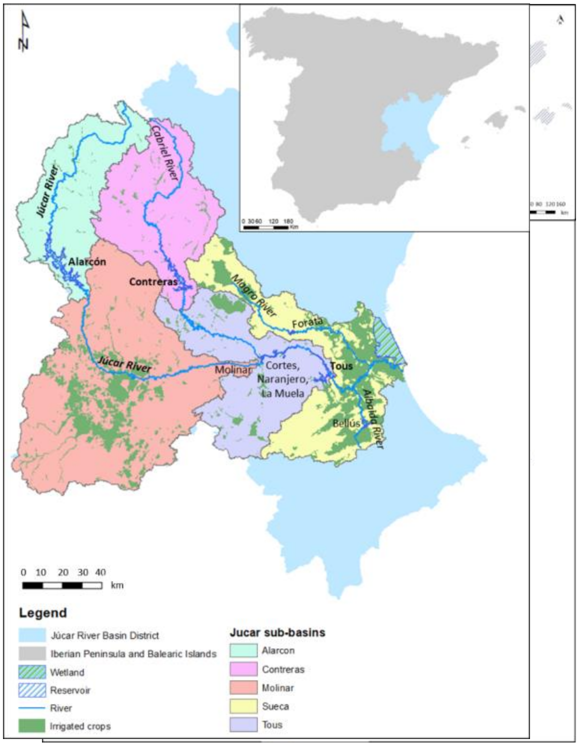
~~2.5 Risk assessment model~~

~~The risk assessment model is integrated in the SIMRISK module (Sánchez-Quispe et al., 2001; Haro-Monteagudo, 2014; Haro-Monteagudo et al., 2017) and needs the previous step to carry out the analysis. This model simulates the management for each generated series and then all these results are treated statistically and aggregated to provide probability distributions for reservoirs storage, among other results, as deficits on consumptive demands.~~

~~This tool can be used at short, medium and long term and its purpose is to inform the decision makers about the probable state of the water resources of the WRS. In this way, they can propose and test different alternatives of management or mitigation measures to minimize possible impacts and choose the most effective ones to try to reduce the impacts (Haro-Monteagudo, 2014).~~

~~3.~~2. Case study: The Júcar River Basin

~~We decided to test the suggested methodology in the~~The Júcar River Basin~~, which~~ is located in the ~~oriental~~eastern part of the Iberian ~~Peninsuls~~Peninsula (Fig.~~4~~ 1) and is the main ~~exploitation~~water resources system (WRS) of the Júcar River Basin District (JRBD). ~~It has the~~Its extension ~~of~~is around 22,187 km^2 and the average volume of water resources generated ~~are~~is around 1,605 hm^3/year (CHJ, 2015). The ~~name of this district~~river is ~~due to the Júcar River (~~512 km long~~), which~~ and the main tributaries are the Cabriel, Albaida, and Magro rivers~~ that pass through the provinces of Cuenca, Teruel, Albacete and Valencia to flow into the Mediterranean Sea~~.



~~As this~~This is a semi-arid area ~~is under~~due to the influence of the Mediterranean climate~~, it is characterised by the semi-aridity of the climate.~~. The average ~~P~~ precipitation is 475.2 mm/year, the ~~PET~~ average potential evapotranspiration (PET) is 926.6 mm/year and the annual average ~~T are~~temperature is between 14 - 16.5 °C, reaching the maximum in summer (June, July, and August), the dry season.

Moreover, ~~there is a~~the high hydrological variability ~~that lead~~of this basin leads to recurrent multiannual droughts, as those experimented in the periods 1981-1986, 1992-1995, 2005-2008, and 2013-2018.

In addition to these hydrological features, consumptive demands are high~~, the~~. The irrigated agriculture accounts for nearly 80% of water demand and other sectors (including urban supply) account for 20%.

These conditions forced to ~~adaptation~~adapt by different management strategies, as water storage infrastructures, conjunctive use of surface and ground waters, and institutional and legal developments. Thus, this water resources system ~~has~~(WRS) is highly regulated having several reservoirs, the more important ~~ones~~ are ~~Alarcón~~Alarcon (1,118 hm^3), Contreras (852 hm^3~~)~~), and Tous (378 hm^3), as ~~it~~ can be seen in Fig. ~~4. In the~~1. The same figure ~~is shown the current division of this basin~~shows how the JRB is divided in five sub-basins~~, which is based on the position of these~~ considering the reservoirs position and the hydrological ~~characteristics~~features of the area.

~~**Figure 4. Location of the Júcar River Basin District and the Júcar River Basin (divided in sub-basins) in Spain. Source: Confederación Hidrográfica del Júcar (CHJ, www.chj.es) and Instituto Geológico y Minero de España (IGME, http://www.igme.es/).**~~

[illegible]

Minero de España (IGME, http://www.igme.es/).

The inland part of the ~~JRB~~basin is a mountainous area and the middle basin is a relatively flat area (high plain) that currently supports the major part of the irrigated agriculture (≈ 100,000 ha). The lower basin lies in the coastal plain, which supports traditionally ~~and relatively~~irrigated areas as well as more recent irrigated areas. ~~In these areas~~There are permeable materials that allow ~~the~~rainfall infiltration ~~of the rainfall~~ to the aquifers of La Mancha Oriental (middle part of the basin, Molinar) and La Plana de Valencia (lower basin~~), which permit the water~~

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~~abstraction.~~, Sueca), where groundwater is abstracted. In addition, there is an important wetland in the coastal area called l'Albufera de Valencia, which has an extension of 21,120 ha including a vast extension of rice crops~~ in the coastal area~~.

~~Consequently,~~Water stress in the WRS is very high, being the ratio between water demands and water resources ~~is tight,~~almost 90%, meaning scarcity and leading to overexploitation of water resources. The institution in charge of the water management in the JRBD is the Júcar River Basin Authority (JRBA~~, Confederación Hidrográfica del Júcar – CHJ in Spanish~~), which is also the responsible ~~of~~for the elaboration of the Júcar River Basin District Management Plan (JRBDMP) (CHJ, 2015) and the Drought Management Plan (~~PES in Spanish~~DMP) (CHJ, 2018).

~~An interesting hydrological feature in the JRBDMP is~~As it was mentioned in the introduction, in this area climate projections were not incorporated explicitly in the analysis made with the aid of Decision Support Systems (CHJ, 2015) for the last version of the JRBDMP, where climate change effects were assessed by reducing the natural inflows in a certain percentage (CEDEX, 2010) for the future hydrological cycles of management (6 to 18 years).

More recently, climate projections were considered in the CEDEX (2017) report (mentioned in the introduction), where change rates of meteorological and hydrological variables were extracted for the main Spanish basins, as this one. The general conclusion for this district was the future decrease of water resources and the increase in the number of droughts and their intensity, but the results of this benchmark study have not yet been used in decision-making.

Additionally, the so-called "80s effect" (Pérez-Martín et al., 2013; Hernández Bedolla et al., 2019)~~,~~ is an interesting hydrological feature of the JRBD, which consists in a significant decrease of the average precipitations and ~~streamflows since the~~ inflows from 1980 ~~and~~ onwards. In fact, the JRBDMP is based upon the 1980-2012 series in order to have a good representation of the current hydrological features of the basin when managing the system.

3. Material and methods

In this section, the general methodology is presented, as well as how it was adapted to the case study. As mentioned before, it integrates the climate projections into a model chain for future management and drought risk assessments. The main improvement lies in the characterization of natural inflows, where some adjustments and corrections are applied to the ensemble in order to adapt it as much as possible to the current situation of the WRS. The good performance of the hydrological model in this step is also essential, as it has to strictly represent the features of the basin. This model is the first one in the model chain, followed by management, stochastic, and risk assessment models, from which the following results are obtained: i) impacts on future inflows, ii) future water resources in the basin, iii) a drought risk indicator. All of them are complementary and may be very useful to help in the decision-making process.

Fig. 2 shows all the steps of this method in a simplified way. There is depicted that the input data are precipitation and temperature time series from climate change projections, which are divided into reference and future periods.

The next step is the characterization of natural inflows, which is based on the conversion of meteorological data into inflows using a hydrological model and paying attention to some adjustment and/or correction processes. In this sense, if the reference period series are not fitted to the observed values, they may need a bias correction. To this end, we proposed two alternatives for this characterisation, called option A and option B. The main difference between these alternatives is the application of the bias correction before (option A) or after (option B) the use of the hydrological model. In option A, the precipitation and temperature time series of the baseline are bias-corrected using as a reference the observed data. Then, this correction is extended to the future periods and the corrected series are introduced into the hydrological model to extract the inflows series for all periods. Conversely, raw precipitation and temperature time series are introduced into the hydrological model in option B. Afterwards, the hydrological outputs of the reference period are bias-corrected using observed inflow data and the correction is extended to the future periods.

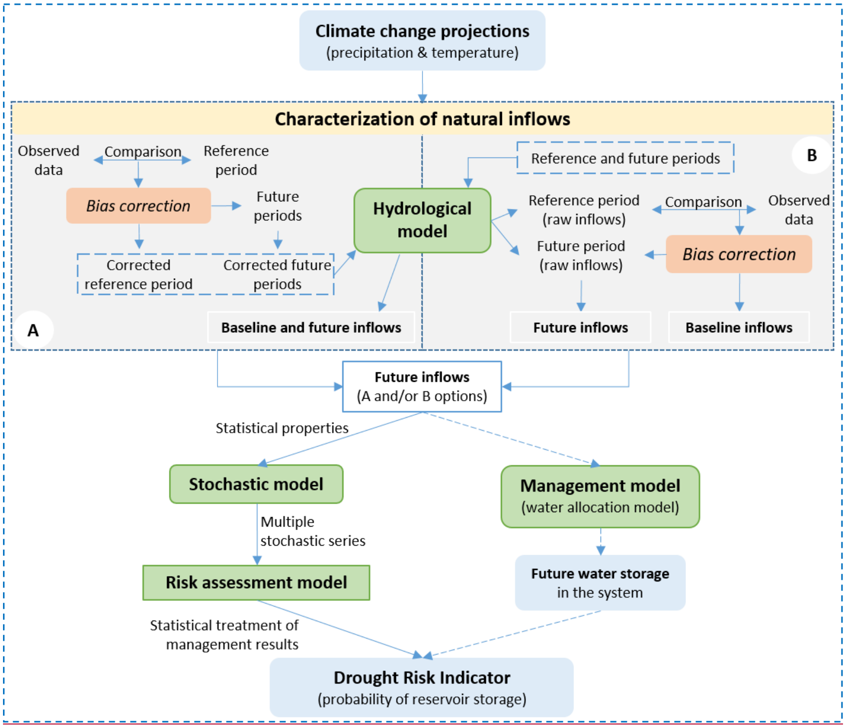

Figure 2. Methodology for the integration of climate change projections into the risk and management assessments to support decision-making.

In this step, the hydrological model has to strictly represent the characteristics of the area of application, so a good calibration of this model using the observed data is essential in this process, as for the other models involved in the modelling chain. Besides that, once the inflows from the baseline and for future periods are extracted, they may be compared to extract the average change rates for the future, in other words, the effects of climate change on future inflows.

Afterwards, future inflows from A and/or B options are introduced in a management model to simulate the future water storage of the WRS, while their statistical properties are used in the stochastic model to generate multiple equiprobable series. Then, these series are inserted in the risk assessment model, where the management is simulated for all of them and the management results are treated statistically to obtain a drought risk indicator.

The steps of this methodology adapted to the JRB are detailed in the next sub-sections.

3.1 Climate change projections and historical local data

In this case, ~~meteorological variables (P and T) of 9~~ the climate projections from SWICCA portal were selected for this study due to the good selection of Regional Climate Models (RCMs) ~~from the Representative Concentration Pathways (~~for Europe it has available and the huge variety of data that can be downloaded at different temporal and spatial scales in a user-friendly format (.xlsx).

Thus, precipitation and temperature time series of 9 RCMs from the RCPs~~)~~ 4.5 ~~(stabilization)~~ and 8.5 ~~(high greenhouse gas scenarios)~~ (IPCC, 2014) were downloaded ~~from the SWICCA website~~ at daily and catchment ~~scale~~scales (mean area 215 km^2). These data came from the E-HYPE model (Hundecha et al., 2016), which uses global databases and Global Monitoring for the Environment and Security (GMES) satellite products as input data and then is forced by the European Centre for Medium-Range Weather Forecasts (ECMWF) and the Swedish Meteorological and Hydrological Institute (SMHI) to obtain meteorological, hydrological and ~~other~~another type of outputs for the entire continent (Hundecha et al., 2016; Suárez-Almiñana et al., 2017).

~~In~~ Table 1~~,~~ shows the characteristics of the ensemble members ~~(EM)~~ used in this work ~~are shown~~. The reference period is 1971-2000 and the future periods are divided into 2011-2040~~,~~ (near future), 2041-2070 (medium future), and 2071-2100~~.~~ (far future). These data were obtained for the 5 sub-basins depicted in Fig.~~4~~ 1 and the last future period was reduced in 2 years due to the lack of data of two EMs.

Table 1. Ensemble member characteristics from SWICCA portal. Modified from: http://swicca.climate.copernicus.eu/wp-content/uploads/2016/10/Metadata_Precipitation_catchment.pdf.

RCP	GCM	RCM	Period	Institute	Name of ensemble members
4.5	EC-EARTH	RCA4	1970-2100	SMHI	SMHI_RCA4_EC-EARTH_rcp45
	EC-EARTH	RACMO22E	1951-2100	KNMI	KNMI_RACMO22E_EC-EARTH_rcp45

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	HadGEM2-ES	RCA4	1970-2098	SMHI	SMHI_RCA4_HadGEM2-ES_rcp45
	MPI-ESM-LR	REMO2009	1951-2100	CSC	CSC_REMO2009_MPI-ESM-LR_rcp45
	CM5A	WRF33	1971-2100	IPSL	IPSL-IPSL-CM5A-MR_rcp45
8.5	EC-EARTH	RCA4	1970-2100	SMHI	SMHI_RCA4_EC-EARTH_rcp85
	EC-EARTH	RACMO22E	1951-2100	KNMI	KNMI_RACMO22E_EC-EARTH_rcp85
	HadGEM2-ES	RCA4	1970-2098	SMHI	SMHI_RCA4_HadGEM2-ES_rcp85
	MPI-ESM-LR	REMO2009	1951-2100	CSC	CSC_REMO2009_MPI-ESM-LR_rcp85

Then, the observed values of ~~P and T~~meteorological variables from the Spain02 v4 dataset (Herrera et al., 2016) were used as the historical local data. Spain02 is a gridded dataset of daily time series and 0.11º of spatial resolution that covers the Iberian Peninsula and the Balearic Islands for the period 1971-2010. Currently, this database is used in this area due to its good performance (Pedro-Monzonís et al., 2016; Suárez-Almiñana et al., 2017; Madrigal et al., 2018; García-Romero et al., 2019)~~.~~

~~As shown in Fig. 3 (option A), these data are~~ and it was needed ~~to analyse and assess~~for the ~~fitting~~bias correction of the climate projections ~~to local scale in the reference period~~(option A) and ~~then proceed to their bias correction, if needed.~~to test the calibration of the hydrological model. Thus, four points of each sub-basin (Fig. ~~4~~1) were taken and averaged~~ in order~~ to obtain a representative time series per sub-basin (Madrigal et al., 2018) for the same reference period provided by the climate projections.

~~On the other hand, the conversion of T into potential evapotranspiration (PET) was done in order to use the hydrological model, since it requires both P and PET as inputs. In order to calculate it, the Hargreaves method (Hargreaves and Samani, 1985) was applied. Despite the huge variety of methods to make this calculation with different skills (Milly and Dunne, 2017), the performance of this method for this area is very valuable (Espadafor et al., 2011; Hernández Bedolla et al., 2019) and the data required to perform it can be easily obtained.~~

Another type of historical local data required in this analysis are ~~flow~~inflow time series, which in this case are in natural regime (as if no anthropogenic modifications of the watercourse were applied) restored from observed data. ~~This dataset is used by the CHJ to report the assessment of water resources in the JRBDMP. Henceforth we will refer to them as natural or observed flows~~These data were used in the calibration of the hydrological, management, and stochastic models, as well as for the bias correction in option B.

This dataset was provided by the JRBA for the period 1980-2012, which is used in the assessment of water resources reported in the JRBDMP, since the inclusion of previous years can lend to an overestimation of the available water resources in the system after the “80s effect”. Henceforth we will refer to these data as natural or observed inflows.

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3.1.1 Adjustment of the reference period

Within the climate projections was provided the reference period 1971-2000, but we proposed to reduce it to 1980-2000 in order to consider the "80s effect". As reported previously, the data series considered most suitable for working in the management of water resources of this basin are those observed from 1980 onwards, in this case from 1980 to 2012 (CHJ, 2015). Thus, the inflow series from the period 1980-2012, the reference period proposed (1980-2000), and the one provided by climate projections (1971-2000) were compared to determine their differences in terms of total water resources, as well as to conclude if the proposed period is representing the current situation of the JRB. This process aims to avoid influencing the future with an excess of water resources through the application of the bias correction.

~~3.2~~3.1.2 Bias correction

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~~If~~As the differences between climate projections and historical local data ~~(either meteorological or hydrological) are~~ were notable in the reference period~~ of both alternatives of Fig. 3~~, a bias correction ~~is~~was advisable to adjust as much as possible the pan-European data to the regional scale.

~~In this case~~ Hence, the correction of ~~P~~precipitation and ~~T~~temperature variables was considered in ~~alternative~~option A and the inflows correction ~~of flows~~ was considered in ~~alternative~~option B~~ (Fig.3).~~.

In this sense, one of the most reputed methods in literature is the quantile mapping, maybe because ~~it~~its application is relatively simple ~~to apply~~ with good results, both for meteorological and ~~flow~~hydrological variables (Grillakis et al., 2017~~;~~; Manne et al., 2017; Teutschbein and Seibert, 2012). ~~It~~This method is based on the distribution function, which tries to keep the mean and standard deviation of the reference series (Collados-Lara et al., 2018). In this case, it is a feasible approach since the observations are of similar spatial resolution as the EMs data (Maraun, 2013).

This process was applied using the R statistical software (https://www.r-project.org/) at ~~the~~ daily (~~for P~~precipitation and ~~T~~temperature time series) and monthly ~~(for flows)~~ timescales (inflows time series) by interpolating the empirical quantiles for variables of the reference period based on the package developed by Gudmundsson et al. (2012). First, the correction ~~is~~was made ~~for the climate projections by its comparison with the local data~~ in the reference period~~,~~ using observed data and then ~~this correction is~~it was extended to the future periods.

In addition, two quantitative statistics can be extracted in order to know the goodness degree of the RCMs concerning the observed data. Thus, the Nash Sutcliffe efficiency (NSE) (Nash and Sutcliffe, 1970) and Percent bias (PBIAS) (Gupta et al., 1999) values from corrected and non-corrected ensembles were obtained (Zambrano-Bigiarini, 2020) to know if the bias correction improved the fitting to historical data based on the performance ratings on daily time scale recommended by Kalin et al. (2010). The optimal values of NSE and PBIAS are 1 and 0 respectively and the proposed ratings are divided in: Very Good: $NSE \geq 0.7$, $|PBIAS| \leq 25\%$; Good: $0.5 \leq NSE < 0.7$, $25\% < |PBIAS| \leq 50\%$; Satisfactory: $0.3 \leq NSE < 0.5$, $50\% < |PBIAS| \leq 70\%$; Unsatisfactory: $NSE < 0.3$, $|PBIAS| > 70\%$.

~~3.3~~3.2 Modelling chain

AQUATOOL Decision Support System Shell (DSSS)~~In this section, the use of the hydrological, stochastic, risk assessment and management models are described. They belong to the EVALHID, MASHWIN, SIMRISK and SIMGES modules of AQUATOOL DSSS (respectively) and can be accessed from the same interface.~~

3.2.1 ~~The~~

To perform the modelling chain we employed the AQUATOOL DSSS (Andreu et al., 1996, 2009), which is a software widely used in the design of Spanish river basin plans, and also in many other basins abroad. It has several modules addressing different aspects of integrated water resources planning and management (WRPM) which are accessed from the same interface and are interconnected between them, an important feature to be considered in this study because the outputs of one model are the inputs of the others, as expected in a model chain.

The modules employed in this study were EVALHID (Paredes-Arquiola et al., 2012), SIMGES (Andreu et al., 2007), MASHWIN (Ochoa-Rivera, 2002, 2008) and SIMRISK (Sánchez-Quispe et al., 2001; Haro-Monteagudo, 2014; Haro-Monteagudo et al., 2017). These modules were used to build the hydrological, management, stochastic, and risk assessment models, respectively.

EVALHID module has available several rainfall-runoff models with different structural complexities and parametrizations, but all of them have been aggregated with semi-distributed applications at the sub-basin scale (García-Romero et al., 2019; Hernández Bedolla et al., 2019; Suárez-Almiñana et al., 2017).

SIMGES module is used to simulate the management of the WRS for water allocation. Here, a simplification of the WRS can be drawn using a friendly interface, where the databases related to all its elements (as reservoirs, contributions, demands, returns, aquifers, channels, environmental flows, etc.) can be filled along with the operating rules and the water use rights and priorities. All these features are considered to simulate the water allocation using an optimization algorithm for deficits minimization and maximum adaptation to the reservoir objective volume curves.

MASHWIN allows the building of multivariate stochastic models to generate multiple and equiprobable synthetic series, preserving the statistical properties of the original series for the generation. It is a complement for SIMRISK, since it needs a high number of flow series to perform the risk assessment.

SIMRISK uses the multiple generated series to extract probabilistic results on reservoirs storage and demand deficits among others. This tool can be used in the short, medium, and long term and its purpose is to inform the decision-makers about the probable state of WRS in the future. In this way, they can propose measures to minimize possible impacts and simulate different management scenarios to choose the most effective ones for reducing the impacts (Haro-Monteagudo, 2014).

3.2.2 Hydrological model

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This model was employed to evaluate the amount of water resources produced in the basin using precipitation and PET time series from the ensemble as input data. The Hargreaves method (Hargreaves and Samani, 1985) was used to convert temperature into PET. In spite of the huge variety of methods with different skills to carry out this conversion (Milly and Dunne, 2017), its performance for this area is very valuable (Espadafor et al., 2011; Hernández Bedolla et al., 2019) and the data needed to apply it can be easily obtained.

In this case, the rainfall-runoff model HBV (Bergström, 1995) was selected ~~in EVALHID module~~ to ~~perform the transformation of P and PET into natural flows due~~extract inflows from input data due to its good performance in this basin at daily scale after a proper calibration~~. This calibration~~, which was ~~made using two optimisation algorithms~~performed by ~~(García-Romero et al., 2019) and the natural flows~~García-Romero et al. (2019) using two optimisation algorithms and the observed inflows from the period 1980-2007, in order to take into account the already mentioned “80s effect”.

~~In option A of Fig. 3 this~~ This model was run using bias~~-~~-corrected ~~P~~time series of precipitation and PET ~~series,~~in option A (Fig. 2), while in option B it was run using non~~-~~-corrected ~~P and PET~~data and then the output ~~flows~~inflows were bias corrected before inserting them in the rest of the models of the chain.

~~On one hand, the statistical properties (mean and standard deviation) of flow~~Thus, corrected and non-corrected precipitation and PET were introduced in the HBV model to assess its performance in the reference period, and then generate future flows for the management and risk assessments. For both options, the simulation of future inflows was made using the time series from 2011 to 2098, in this way, initial conditions for all periods are conserved and maintained, as well as the tendency of the future inflows.

In this case, the values of NSE and PBIAS statistics were also extracted to estimate the performance of the model run with Spain02 data to ensure its good calibration and then see if the bias correction improved the ensemble fitting to observed data. This time we based on the performance rating recommended by Moriasi et al. (2007) because we are comparing inflows at monthly time step. The ratings are divided in: Very Good: $\text{NSE} \geq 0.75$, $|\text{PBIAS}| \leq 10\%$; Good: $0.65 \leq \text{NSE} < 0.75$, $10\% < |\text{PBIAS}| \leq 15\%$; Satisfactory: $0.5 \leq \text{NSE} < 0.65$, $15\% < |\text{PBIAS}| \leq 25\%$; Unsatisfactory: $\text{NSE} < 0.5$, $|\text{PBIAS}| > 25\%$.

Afterwards, the future ensembles from each ~~future period were~~ sub-basin, period and option were compared with their respective ensemble baselines (1980-2000) to evaluate the climate change impact on future flows. The average change rates of future periods were obtained from the ensemble mean, not counting the increment or reduction of previous periods.

3.2.3 Management model

On this occasion, a simplified model of the Júcar River WRS was used ~~in the stochastic model (MASHWIN) to generate 1000 synthetic series of 30 years for the~~ to simulate the future water allocation for this basin. The main elements of the WRS were integrated into this model, as well as the operational rules and all the features involved in the current management of the system (CHJ, 2015).

The most interesting result we can extract from this model for the current study is the future water storage for the whole system, which volume was considered as the sum of the Alarcon, Contreras, and Tous reservoirs (1796 hm^3). Thus, the entire ~~ensemble.~~period of future inflow series (2011-2098) from the previous step was used to run this model and extract those results for options A and B. In this way, the future evolution of storage values can be better observed to complement the results of the risk assessment.

3.2.4 Stochastic model

~~case an auto-regressive~~In this case a multivariate autoregressive model of first~~-~~-order AR(1) was enough to generate the series after the time dependence parameter was calibrated using natural ~~flows from 1980-2012 period.~~inflows from the 1980-2012 period. Then, this model was modified to adapt it for the generation of future series, since it was calibrated for the historical scenario. The statistical properties (mean and standard deviation) of future inflows obtained in the previous section (options A and B) were used for this purpose. Hence, based on these future statistical properties, the model generated 1,000 synthetic series per EM and future period (the three considered) in order to feed the risk assessment model. The more series we generate, the more statistically robust results at the end of the process (next step).

3.2.5 ~~Then, in the risk~~Risk assessment model ~~(SIMRISK), based on the Monte-Carlo method, the~~

In this model the water management of the system was simulated for ~~each generated series and the~~ all the series generated in the previous step, based on the Monte-Carlo method. Then, the management outputs ~~are statistically~~ were treated ~~providing probabilistic results. In this case, a~~ statistically to extract the drought risk indicator ~~for the whole ensemble and for the three future periods was extracted. This~~ . This probabilistic indicator ~~takes into account the sum of the water storages at Alarcon, Contreras and Tous reservoirs, and~~ informs about the ~~probable~~ evolution of ~~the water resources of the water exploitation system.~~

~~On the other hand and in order to complement the risk assessment with a more intuitive analysis, the management of the entire future period (2011-2098) was simulated (using previous flow series) to obtain~~ the water storage ~~in~~of the system ~~based on reservoir's volume.~~for the ensemble and the three future periods. As in the previous case, the sum of volumes of the main reservoirs was considered as the total storage of the system.

4. Results

~~4.1.~~ In this section, the ensemble mean and the range covered by all EMs are shown in the figures~~Results~~

~~In this section, the ensemble mean and the range covered by all EMs are shown in the figures~~ ~~for all steps.~~. We decided to work with ~~an~~the ensemble of ~~models belonging to the~~ both RCPs 4.5 and 8.5, since in this way ~~it is possible to approximate~~the approximation to the most likely future scenario (the RCP 6.0) accorded in the Paris Climate Change Conference 2015

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(Barranco et al., 2018)~~. Since the~~ is possible. The RCP 6.0 is an intermediate scenario of those employed, but no projections ~~are~~were available ~~to us~~ for this scenario, so this is a way of approaching it and to simplify the process.

4.1 Analysis of ~~meteorological data~~variables and their bias correction

~~Within the climate projections was provided the reference period 1971-2000, but we proposed to reduce it to 1980-2000 in order to consider the "80s effect".~~ Regarding the proposal of adjusting the reference period, in Fig. 3 is depicted how the average annual inflows observed from the period 1980-2012 and the reference period we proposed (1980-2000) can be considered as equivalent (Suárez-Almiñana et al., 2020), while the reference period provided (1971-2000) has higher total inflows, which we want to avoid in order to have a good representation of the current situation of the JRB.

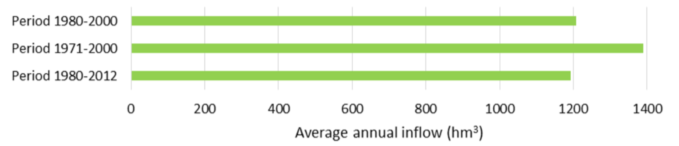
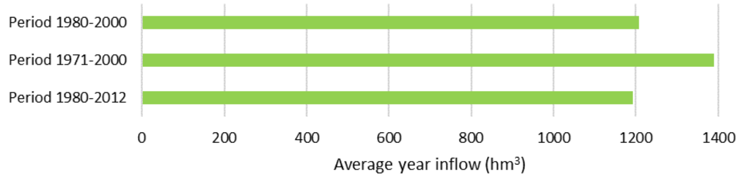


Figure 3. ~~As it was reported previously, the data series considered most suitable for working in the management of water resources of this basin are those observed from the 1980 onwards. In fact, the current version of the JRBDMP is based upon the period 1980-2012, since the inclusion of previous years can lend to an overestimation of the available water resources in the system for water allocation. Figure 5 shows how the total inflows from the period 1980-2012 and the reference period we proposed (1980-2000) can be considered as equivalent (Suárez-Almiñana et al., in press), while the reference period provided (1971-2000) has higher total inflows, which we want to avoid in order to have a good representation of the current situation of the JRB.~~



~~Figure 5. Average year inflows in the Júcar River Basin for different periods. Modified from Suárez-Almiñana et al. (in press).~~

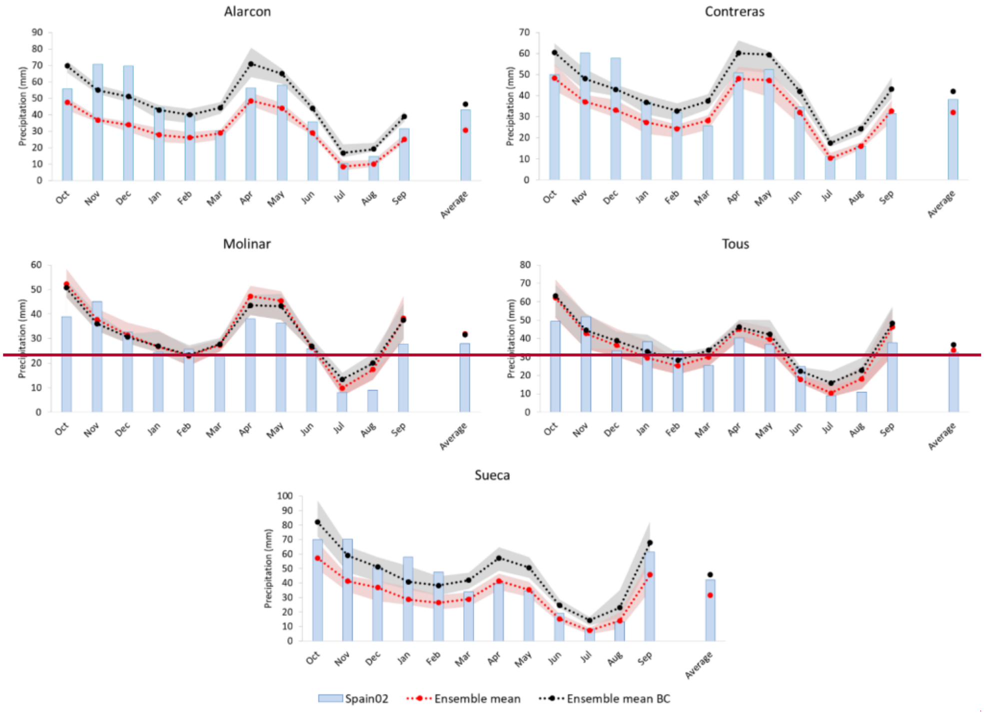
Average annual inflows observed in the Júcar River Basin for different historical periods. Modified from Suárez-Almiñana et al. (2020).

Thus, we proceed with the proposed reference period (1980-2000) to make the comparison between ~~the P~~precipitation and ~~T~~temperature series of the ~~EMs~~ensemble and the ~~historical~~observed data (Spain02). In this comparison a general overestimation of ~~T~~temperature on the average year of this period and an underestimation of ~~P~~precipitation in most of the sub-basins was detected (Fig. ~~6~~4). As these variables were not in the same line, ~~it was decided to apply a~~ the bias correction ~~in~~ was applied to both variables ~~using the quantile mapping technique already mentioned~~.

While the overestimation of ~~T disappeared after the application of this technique, the differences between the corrected ensemble of P and the historical data were minimized (Fig. 6), as well as the average, but it is still overestimated in spring and summer. Moreover, Fig. 6 shows how in Molinar and Tous sub-basins the bias correction provided a little difference favouring some months and affecting others, but very subtly in both cases. However, all these differences can be assumed in order to obtain more reliable flows in the next step.~~ temperature disappeared after the application of this technique, the differences between the corrected ensemble of precipitations and the observed data were minimized (Fig. 4), as well as the average, but it is still overestimated in spring and summer. Moreover, Fig. 4 shows how the bias correction provided a little difference favouring some months and affecting others in Molinar and Tous sub-basins, but very subtly in both cases. However, all these differences can be assumed to obtain more reliable flows in the next step (Fig. 5). In addition, based on the performance rating proposed by Kalin et al. (2010), the values of the PBIAS statistic made Alarcon and Sueca sub-basin go from good to very good performances after the bias correction, while the other sub-basins did not change the very good status but the PBIAS values were more proximal to 0% (the optimal value). Despite this, the NSE values for all sub-basins of non-corrected series were unsatisfactory and the bias correction was not enough to go beyond this threshold value (0.3).

Then, ~~these corrections (P and T) were~~this correction was extended to the future series ~~from 2011 to 2098, since the last period was reduced in 2 years due to the lack of data of two of the EMs (see Table 1).~~

~~In addition, the T from the reference~~ and the ~~future periods~~corrected temperature time series were converted ~~to~~into PET (using the Hargreaves method) to prepare the data for the hydrological model.


Alarcon
Contreras
Molinar
Tous
Sueca
Precipitation (mm)
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Average
Spain02
Ensemble mean
Ensemble mean BC

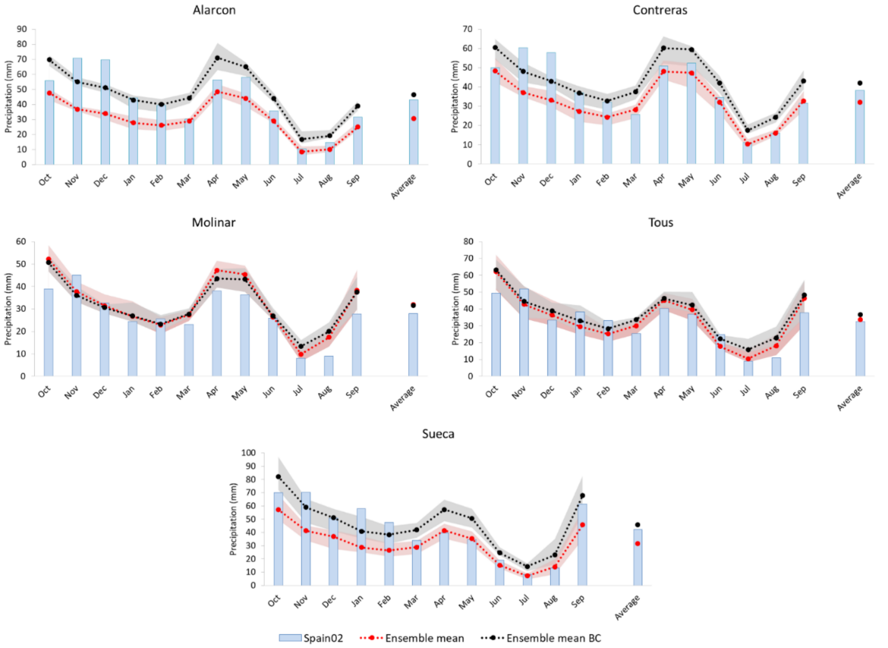


Figure 4. Average ~~year~~monthly and yearly bias~~-~~ corrected precipitation (Ensemble mean BC) compared to the non-corrected precipitation (Ensemble mean) and the historical data (Spain02 data) in the reference period 1980-2000, where the shaded areas represent the entire ensemble.

~~4.2 Characterisation of natural flows~~

4.2 Natural inflows characterisation

In this section, corrected and non-corrected ~~P~~precipitation and PET time series were introduced ~~in~~into the HBV model to assess its performance and then generate future ~~river flows~~inflows for the ~~risk assessment. For both approaches of Fig. 3 (A~~management and ~~B), the simulation of future flows was made using series from 2011 to 2098 and then they were divided into the stipulated future periods.~~risk assessments. In ~~this way, initial conditions~~ the next sub-sections the results for ~~all periods are conserved and maintained, as well as the tendency of the future flows.~~

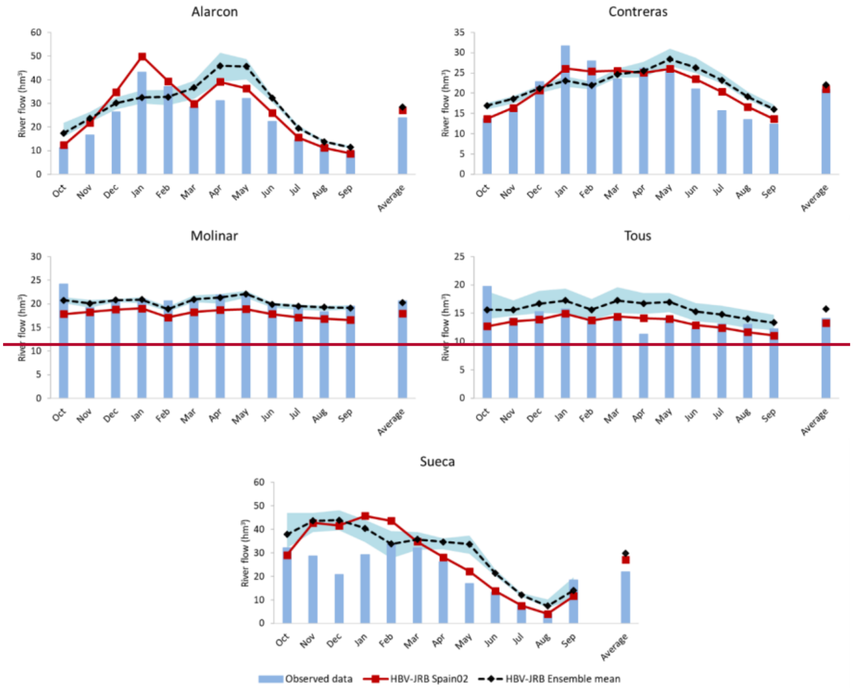
~~In the case of~~ option A ~~(Fig. 3), this model is run using bias corrected data, however, for~~ and option B ~~it is run using raw data and the resulting flows are bias corrected before moving on to the model chain, as depicted in the Fig. 3~~are presented.

4.2.1 Option A: HBV model simulation using bias~~-~~-corrected data

First, the ~~output flows~~inflows obtained from the HBV model ~~using~~fed with meteorological historical data (~~P & PET from~~ Spain02) ~~of the reference period~~ were compared with the observed ~~flows~~inflows to assess ~~their~~its performance and validate it for the JRB. This comparison is illustrated in ~~the Fig. 7, which was completed including the output flows from the ensemble (HBV-JRB Ensemble),~~Fig. 5, where ~~the shade area is the range covered by the EMs. There~~ it can be seen how both ~~HBV model results (HBV-JRB Spain02 and HBV-JRB Ensemble)~~data are generally close ~~to the observed flow values and its average~~, as well as their averages, setting aside some differences that are likely due to its parametrization in the calibration process ~~and the P overestimation during the spring months (bias corrected data). The estimations of the HBV model are more accurate in the headwaters basins (Alarcon and Contreras), where are placed the main reservoirs and therefore a fact to consider from the point of view of management.~~.

In order to assess the performance of the model, the NSE and PBIAS values were obtained for the case of the HBV-JRB Spain02 inflow series. Based on the performance ratings recommended by Moriasi et al. (2007), the NSE values showed very good and good performances for Alarcon and Contreras respectively (Table 2), while the values from the others sub-basins had an unsatisfactory performance. However, the same ratings but based on PBIAS values, shows how Contreras and Molinar have a very good performance, in Alarcon and Tous it performs good and it is satisfactory for Sueca.

Thus, we can say that the HBV model is more accurate in the headwaters basins (Alarcon and Contreras) where the main reservoirs are placed, a fact to be considered from the water management point of view. In this way, the apparent mismatch in the Sueca sub-basin is not relevant for the purposes of this study since it is located in the final stretch of the river, where there is no ~~longer~~reservoir regulation~~.~~



available. In the case of ~~**Figure 7. Average year of river flows from the application of the HBV model using historical (HBV-JRB Spain02) and ensemble data (HBV-JRB Ensemble mean and shaded area) compared to the observed flows in the reference period 1980-2000.**~~

~~In the Alarcon sub-basin, the HBV-JRB Ensemble is underestimating river flows in January and February (as in Contreras), while it is overestimating them in spring months, which are likely related to the outputs of the bias correction process in these months. In the~~ Molinar and Tous ~~sub-basins, these ensemble flows has higher values than HBV-JRB Spain02 and they are closer to the observed ones. In the case of Tous, both setups underestimate river flows~~, inflows were underestimated, but these differences ~~are~~were expected because ~~this~~these sub-~~basin is~~basins are the most heavily regulated and difficult to simulate with hydrological models, mainly due to its intimate relationship with the underground component. ~~In the Sueca sub-basin, both flow series overestimate observed river flows from November to January and the HBV-JRB Ensemble also overestimates spring flows, which may be due to the overestimation in corrected P~~Despite these differences, the performance of the HBV model using historical data can be considered as acceptable and quite good due to the huge complexity of this basin. Thus, it was decided to continue with the study simulating the ensemble inflows for the reference and future periods.

~~Despite these differences, the performance of HBV model can be considered as acceptable and quite good due the huge complexity of this basin. Thus, it was a good option to continue with the study and future flows were simulated with it.~~

In this case, Fig. 5 (middle part) was completed including the inflows from the corrected ensemble (HBV-JRB Ensemble mean A). There, it can be seen how HBV-JRB Ensemble mean A inflows are more or less in line with the observed inflows and its average, setting aside some differences that are likely due to the HBV mismatches and the precipitation overestimation during the spring months coming from the bias-corrected process. The rates of Table 2 show a worse performance than those obtained with the historical data, indicating that the fitting of the corrected ensemble to the historical period is not good enough despite the bias correction and the good calibration of the HBV model.

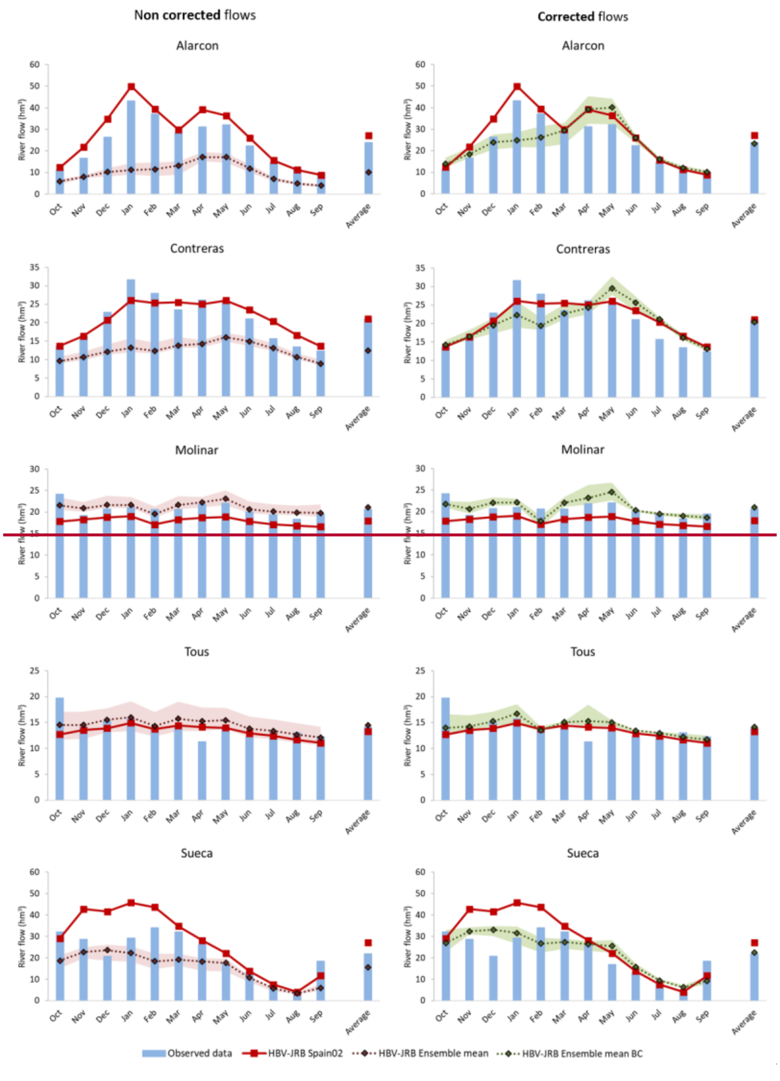
In the Alarcon sub-basin, the ensemble is underestimating river flows in January and February (as in Contreras), while it is overestimating them in spring months, which is likely related to the outputs of the bias correction process in these months. In the Molinar sub-basin, this ensemble has higher values than the HBV-JRB Spain02 inflows and they are closer to the observed ones. In the case of Tous inflows, they are overestimated and in the Sueca sub-basin, both inflow series overestimate observed river flows from November to January and the ensemble also overestimates spring flows, which may be due to the overestimation in corrected precipitation.

4.2.2 Option B: HBV model simulation using raw data and bias correction of flows

In this section, the raw ~~P~~precipitation and PET time series of the reference period were introduced ~~in~~into the HBV model ~~in order~~ to extract the non-corrected ~~flows~~inflows (HBV-JRB Ensemble mean) and evaluate if the previous correction was worth it or not.

Looking at Fig. ~~8~~5 (left) and Table 2, it is evident that a bias correction ~~is~~was needed on ~~P and T~~meteorological or ~~on river flows~~hydrological data, since ~~they~~the non-corrected inflows are not representing the current situation of the basin~~. The raw flows~~, obtaining good performances only in Molinar and Tous sub-basins for PBIAS rates. These inflows of the reference period are highly underestimated in Alarcon and Contreras and if this is extended to future flows, the conclusions on the impacts of climate change can be misleading and have a severe and false view of the future. Thus, in this part was decided to correct ~~raw flows~~those inflows and see the differences between correcting data before and after running the hydrological model ~~from this point onwards.~~

~~The flows~~. These inflows were also corrected using the quantile mapping method and the improvement was notable, particularly in the average fitting~~.~~ (Fig. 5, right) and the ratings for the PBIAS values (Table 2). Despite this, there are some mismatches in accordance to the previous ~~correction.~~section (Fig. 5, middle and right), which are also captured by the NSE statistic. There are some ~~underestimation~~underestimations in January and February in Alarcon and Contreras and spring ~~moths~~months are also overestimated. However, in Tous and Molinar ~~they~~sub-basins the corrected inflows are more or less in line ~~to~~with the observed ~~flows~~ones and in Sueca~~ the months of~~, December and May inflows are overestimated~~, but in general can be considered a good option, as in the case of A approach. Thus, this correction was extended to future flows~~.


Non corrected flows
Corrected flows
Alarcon
Contreras
Molinar
Tous
Sueca
River flow (hm³)
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Average
Observed data
HBV-JRB Spain02
HBV-JRB Ensemble mean
HBV-JRB Ensemble mean BC

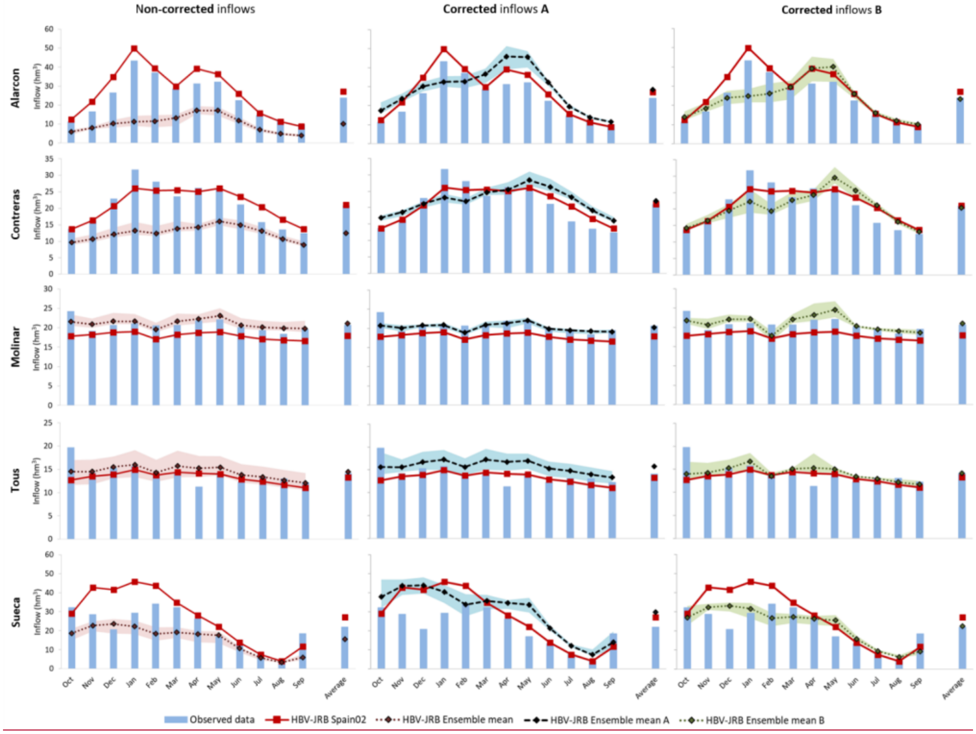


Figure 5. Average ~~year of river flows~~monthly and yearly inflows from the application of the HBV model using historical (HBV-JRB Spain02) and raw ensemble data (HBV-JRB Ensemble mean and shaded area) compared to the observed (Observed data) and corrected inflows (HBV-JRB Ensemble mean ~~BC~~A, HBV-JRB Ensemble mean B and shaded ~~area) flows~~areas) in the reference period 1980-~~2000~~200.

~~4.2.3 Impact of future river flows~~

~~The ensemble of future flows from each sub-basin, period and approach (A and B) were compared with their respective ensemble baselines (1980-2000) to evaluate the impact of climate change on future flows. In this case, the average change rates of future periods were obtained, not counting the increment or reduction of previous periods.~~

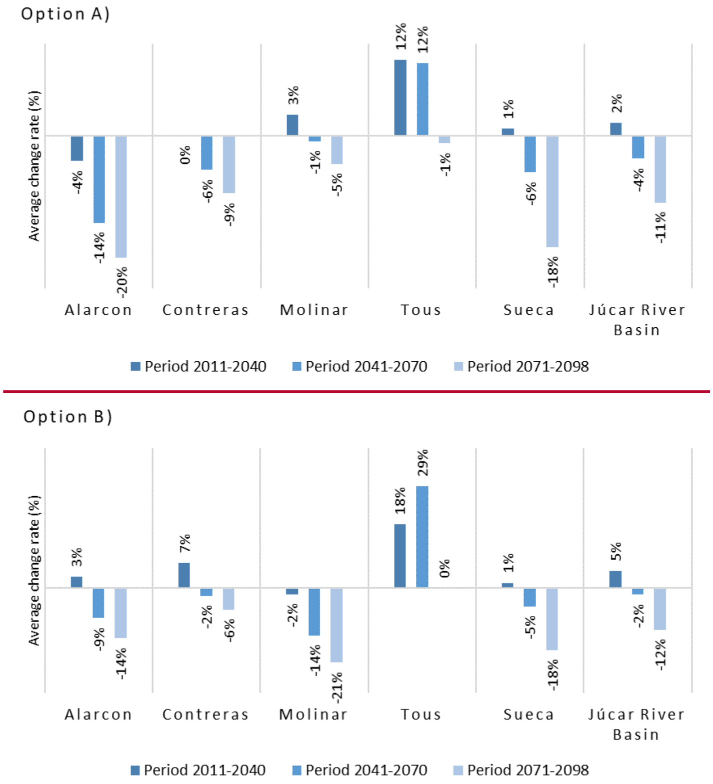
~~The~~In general, these corrections can be considered as acceptable because non-corrected inflows are not an option to follow with the process, mainly due to the underestimation of headwaters inflows. Moreover, at least the PBIAS ratings are better in the corrected options. Thus, these corrections were extended to future inflows.

Table 2. HBV-JRB model performance depending on simulated data and their PBIAS and NSE values based on the classification of the performance ratings recommended by Moriasi et al. (2007) for monthly time steps of streamflows. Where VG is a very good performance, G is good, S is satisfactory, and U is unsatisfactory.

		Alarcon	**Contreras**	**Molinar**	**Tous**	**Sueca**
HBV-JRB Spain02	PBIAS (%)	G	VG	VG	G	S
	NSE	VG	G	U	U	U
HBV-JRB Ensemble mean	PBIAS (%)	U	U	VG	VG	U
	NSE	U	U	U	U	U
HBV-JRB Ensemble mean A	PBIAS (%)	S	VG	VG	G	U
	NSE	U	U	U	U	U
HBV-JRB Ensemble mean B	PBIAS (%)	VG	VG	VG	VG	VG
	NSE	U	U	U	U	U

4.2.3 Impact on future inflows

In Fig. ~~9 shows~~6, the impacts on future inflows are depicted per sub-basin, period, and ~~approach~~option, as well as ~~the mean values~~ for the whole JRB.



~~**Figure 9. Average change rates per sub-basin and the whole JRB for future periods (2011-2040, 2041-2070 and 2071-2098), distinguishing between A (top) and B (bottom) options.**~~

As ~~was~~ expected~~, simulated river flows has a decreasing tendency~~ from other studies, the average year inflows decrease over ~~the years~~future periods, but the average change rates differ from sub-basins and approach. If we compare both results~~,~~ (Fig. 6, top and middle), the reductions in the headwaters ~~(Alarcon and Contreras)~~ are important~~,~~ but more drastic in ~~the A approach~~Alarcon for option A, where ~~they can be reduced~~these change rates reach in average -20% for the ~~last~~far future ~~period in Alarcon.~~(Fig. 6, top right). However, ~~Molinar has a~~ the drastic decrease was found in the ~~B approach (until~~Molinar sub-basin of option B, which reaches -21% ~~at the end of the century), while this tendency is less marked~~as average in the ~~A approach.~~far future (Fig. 6, middle right). Then, the inflows behaviour ~~of flows~~ in Tous is remarkable (in both cases), since there is a large ~~flow~~inflow increase in the near and medium futures (mostly in option B) that ~~then~~later decreases ~~for~~in the last period. ~~This~~The reason for this increase may be the high influence this sub-basin ~~is highly influenced by~~has from the underground component~~ and~~. Moreover, increasing contributions to this sub-basin ~~are~~have been observed in recent years (Hernández Bedolla et al., 2019), ~~so this may be the reason of these increases that~~which may continue and be translated into more contributions to this sub-basin until the second period.

However, the Sueca sub-basin has very similar decreases in both ~~cases~~options, reaching -18% as average in the ~~las~~last future period. The same happens if we look at the JRB as a whole~~,~~, (Fig. 6, bottom), the differences between using A ~~or~~and B approaches are minimal~~.~~, reaching about 3% as average in the near future, -3% in the middle future and -12% in the far future. Hence, we can say that there are important decreases in the headwaters, which may be a great challenge for ~~the~~ future management because ~~there~~in these areas is where the main reservoirs are located. Moreover, ~~there are~~the sharp reductions in ~~the final section of the river (~~Molinar and Sueca~~), where most of the irrigation is located, which~~ sub-basins are also concerning. In Molinar, reduced inputs may lead to ~~increased~~ a decrease in infiltration into the main aquifer in the basin (La Mancha Oriental), while in Sueca this may increase the demand and pressure on irrigation campaigns~~.~~, since this is the area where the most of the irrigated crops are located (Fig. 1).

~~4.31.1 Drought risk indicator~~

~~The statistical properties (mean and standard deviation)~~

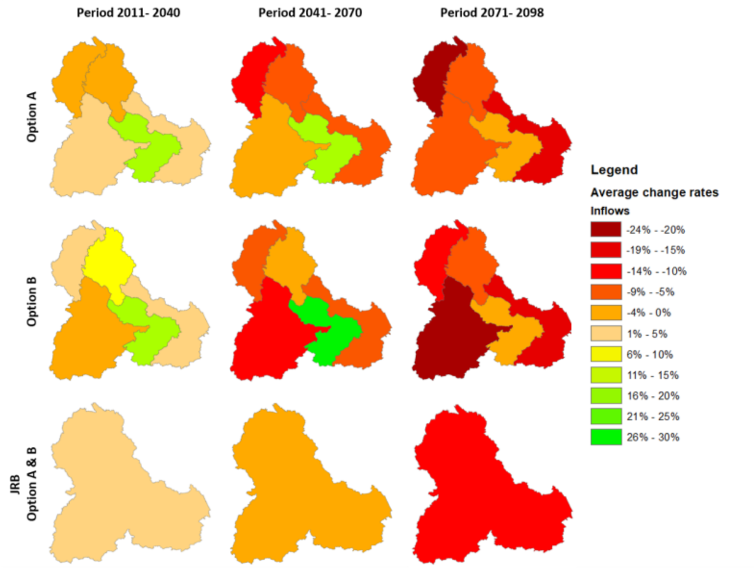


Figure 6. Average change rates of inflows per sub-basin and the whole Júcar River Basin (bottom) for the future periods 2011-2040, 2041-2070, and 2071-2098, distinguishing between options A (top) and B (middle).

4.3 Future water storage in the system

~~future flows obtained in~~ In Fig. 7, the future storage volumes for the ensemble of both options, A and B, were represented taking into account the total capacity of the system (1796 hm3). These results were simulated with the water allocation model using future inflows from the previous section~~ (options A and B) were used~~.

In general, the mean values from option B (Fig. 7, bottom) are lower than those from option A (Fig. 7, up), which may result in worse climate change impacts from the middle century onwards. However, the ensemble results (shaded area) occupies practically the volume of the whole basin, indicating a huge uncertainty for the future. The dispersion of option A is less intense (see shaded area), mainly due to the minimum values of the EMs, which are higher than those of option B, especially until the mid-century. Therefore, the future conditions presented in option A provide more optimistic results, but their large dispersion makes results not reliable for the future, as in the case of option B.

Thus, these deterministic results have to be completed and complemented with probabilistic outcomes from the risk assessment in order to be more trustable from the point of view of decision-makers.

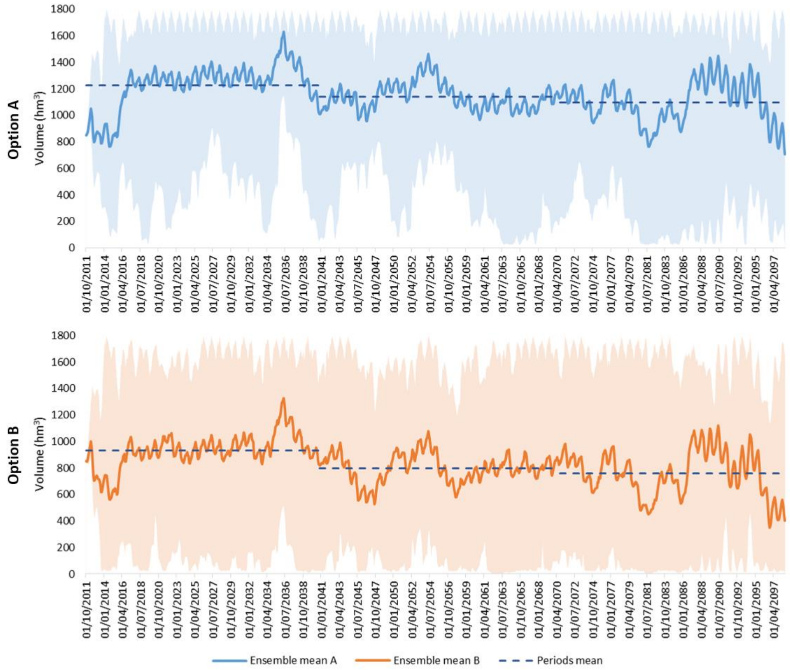


Figure 7. Evolution of the water storage in the Júcar WRS for the ensemble of options A (up) and B (bottom) in the future period 2011-2098.

4.4 Drought risk indicator

~~modify and adapt~~After the generation of multiple synthetic inflow series in the stochastic model ~~(MASHWIN) for the generation of future series, since it was calibrated for the historical series. Then the outputs from this model were integrated~~and their integration in the risk assessment model~~ (SIMRISK), where the drought~~, the probabilistic evolution of the reservoir storage in the system was extracted in form of risk indicator~~ was extracted.~~

~~The adaptation of the AR(1) was made modifying the~~, which can be seen in Fig. 8 for both options A and B. There, the ensemble mean ~~and the standard deviation by those of the future flows. Thus, based on these future statistical properties, the model generated 1,000 synthetic series for each EM and future period, maintaining the mean and the variance from input series. Then, SIMRISK simulate the management for each one of the generated series and the management results were treated statistically to provide probabilities of reservoir storages, which were transformed in the drought risk~~ indicator for ~~the entire system.~~

~~In the Fig. 10 is depicted the resulting ensemble indicator (mean probabilities of all EMs) for~~ each future period and approach~~. It informs about~~ is represented, where the ~~evolution of the reservoir storage of the system, which has a~~ total capacity of the system (1,796 hm3 ~~that~~) was divided ~~in~~into 10 equal intervals~~. Then,~~ and the probability of being in each interval was displayed for each period.

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The probabilities ~~of both alternatives~~ are very similar in all future periods of both alternatives. In both options, the probabilities of being under the 50% of total capacity (898 hm3, medium green colour) is about ~~the~~ 80% in the near future ~~(period 2011-2040),~~, but these probabilities are around 70% and 60% in the medium ~~(period 2041-2070)~~ and far future ~~(period 2071-2098)~~ respectively, a little higher for option B ~~approach~~. This may lead to the conclusion that the probabilities of being at lower intervals are decreasing over the periods despite ~~flow~~the average inflow reductions obtained in Fig. 6 and the mean future volumes observed in Fig. 7, but this is due ~~that as time passes there is a~~to the greater probability of falling in any interval (≈10~~%), as seen from the second period onwards~~%) as time goes on. This indicates a high uncertainty for the future, since there is a large variation in future simulated storage volumes, as was expected from the shaded areas depicted in Fig. 7.

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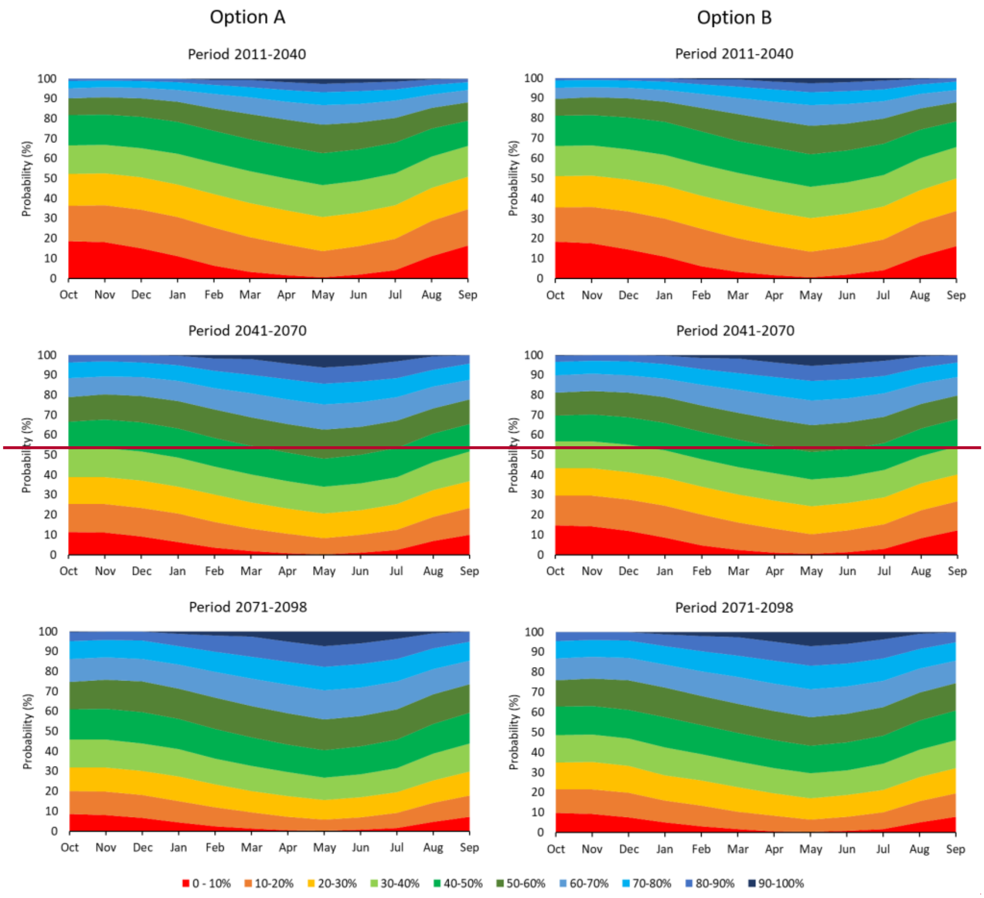
Option A
Option B
Period 2011-2040
Period 2041-2070
Period 2071-2098
Probability (%)
0
10
20
30
40
50
60
70
80
90
100
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
0 - 10%
10-20%
20-30%
30-40%
40-50%
50-60%
60-70%
70-80%
80-90%
90-100%

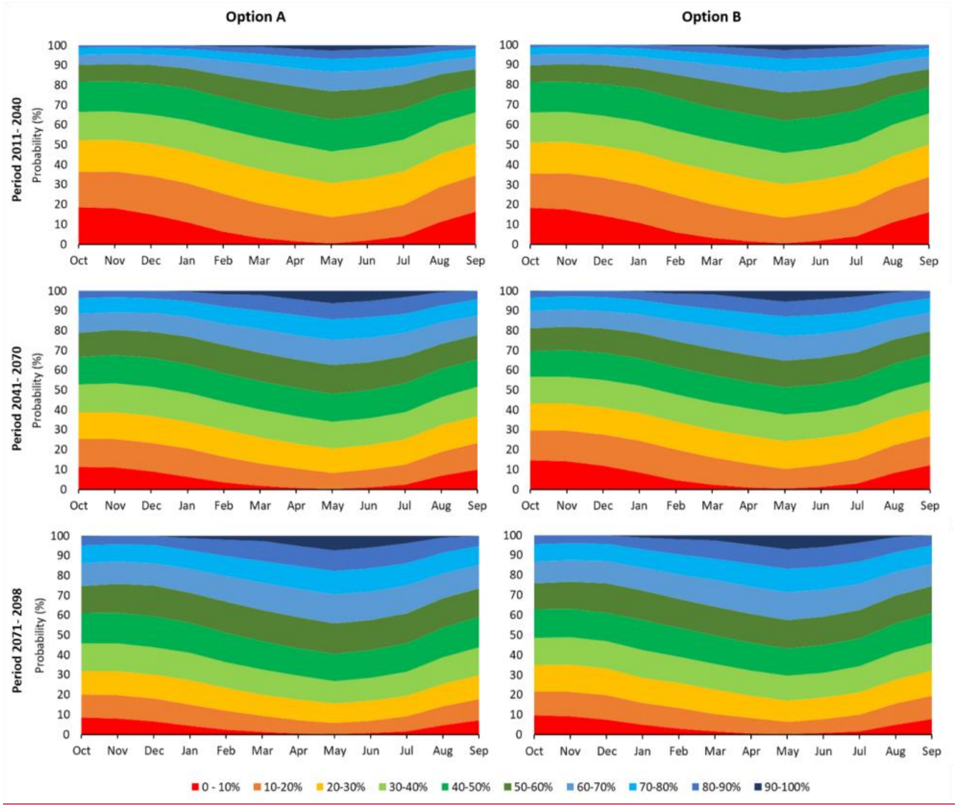

Figure 8. Drought risk indicator of the ensemble mean ~~coming from options~~ per option (A ~~(left)~~ and B ~~(right) for each~~) and future period (2011-2040, 2041-2070, and 2071-2098~~), where the different colours of the legend correspond to the 10 equal intervals in which was divided the total capacity of the system.~~).

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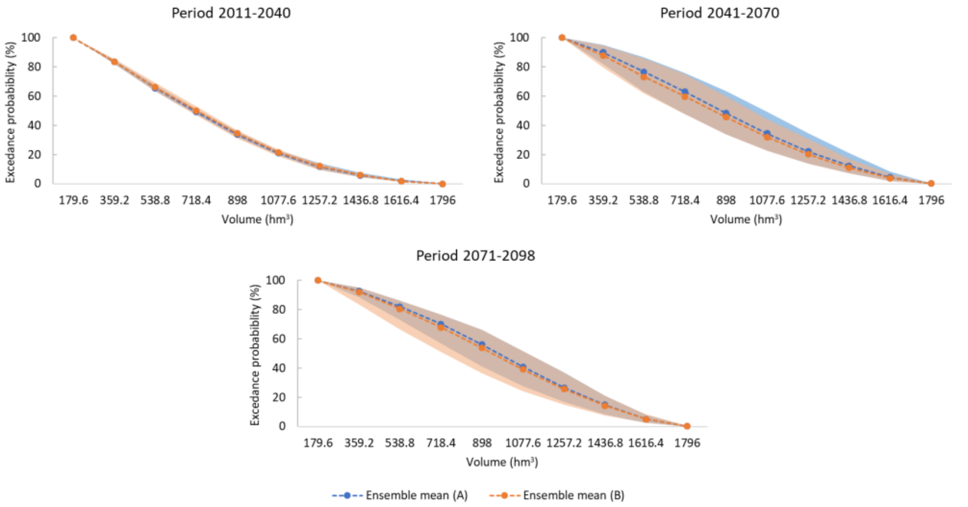
Looking at ~~these~~ the indicator results, we decided to pay attention ~~on~~to the exceedance probabilities of March and September (Fig. ~~11) as it is~~9) as these months coincide with the start and the end of the irrigation season, respectively. In addition, those results for September also inform about the final state of the system for each future period, coinciding with the end of the ~~irrigation season and the~~ hydrological year.



In the first period, the range of exceedance probabilities covered by the ensemble is very tight in both months, coinciding more or less with the ensemble mean of both approaches, while in the other periods this range is wider due to a higher dispersion of the EMs. In general, ensemble results from option A show higher probabilities of exceeding higher storage volumes in both months, as was expected from results shown by Fig. 7 and Fig. 8.

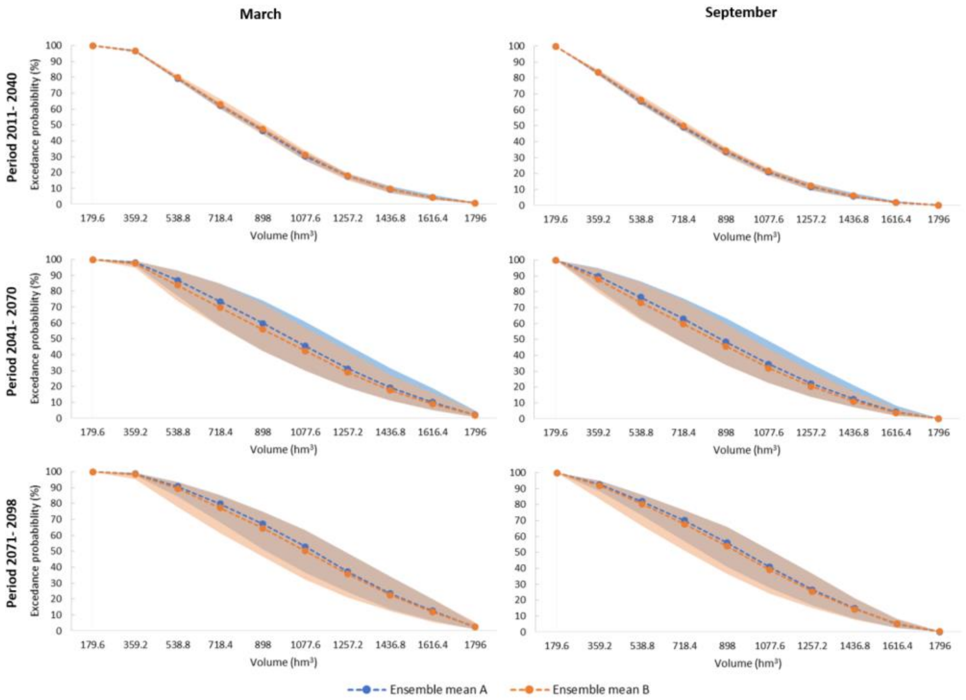


Figure 9. Exceedance probability of the ensembles (shaded areas) coming from options A and B in the start (March) and the end (September) of the irrigation season for the future periods ~~(~~2011-2040, 2041-2070, and 2071-2098~~).~~

~~In the first period, the range of exceedance probabilities covered by the ensemble members is very tight, coinciding with the entire ensemble of both approaches, while in the other periods this range is wider (more dispersion of the EMs), where the ensemble A shows higher probabilities of exceeding higher storage volumes.~~

In addition, March results show higher percentages of exceedance probability for the same volume if they are compared with those from September. These results are logical due to the winter storage that provides more water resources for the start of the irrigation season, while in September these values are lower due to water allocation during this season and the summer period, which normally lacks precipitation incomes.

For example, in the near future of March, the probabilities of exceeding ~~the~~ 50% of total capacity ~~(898 hm³)~~ are ~~as~~on average ~~34~~46% in both approaches, while in ~~the second period~~ September this value is 34%. Then, these probabilities ~~are 48% for~~in the second period of March are 60% (ensemble mean A) and ~~46% for the~~ 56% (ensemble ~~B,~~mean B), but ranges are between

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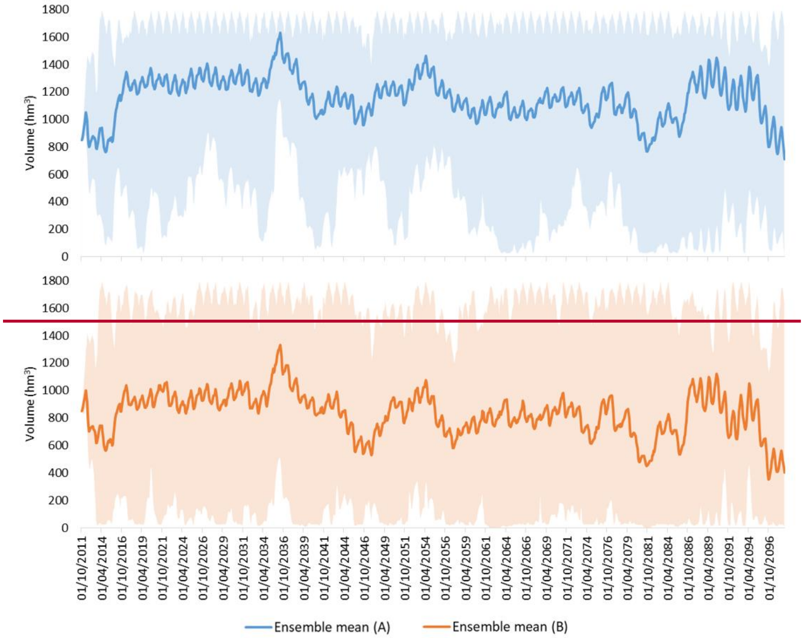
42%-74% and 42%-72%, respectively. In the same period for September these values are 48% (ensemble mean A) and 46% (ensemble mean B), but ranges are between 34~~-~~%-63% and 34~~-~~%-60~~%~~%, respectively. In ~~the same way, the probabilities of exceeding 898 hm^3 for~~ the far future ~~are as average 56%~~ the same happens, higher mean values of exceedance probabilities for the ~~ensemble A~~same volume and ~~54% for the B, with~~wide ranges ~~between 41-66% and 36-66% respectively.~~ covered by the ensemble.

Hence, the dispersion and uncertainty beyond the first period is considerable, as was noted in Fig. 8, and the probabilities of exceeding 50% of total capacity are around 10% higher in March than in September for all periods, indicating more probabilities of water availability in March that may not compromise the irrigation season.

~~4.4~~1.1 ~~Future water storage in the system~~

~~The future output flows from the Sect. 4.2 (both options A and B) were inserted in the management model (SIMGES) to simulate the water allocation for the entire future period (2011-2098). In this way, the future tendencies and the continuous evolution of storage values can be better observed to complement the results of previous section.~~

~~In Fig. 12 is represented the average volumes of the ensemble (lines) and the range of volumes covered by all EMs (shaded areas) in the total storage of the system (1796 hm^3).~~



~~**Figure 12. Evolution of the water storage in the Júcar River Water Resources System for the ensemble (shaded area) of A (up) and B (down) options in the future period 2011-2098.**~~

~~In general, the option B (Fig. 12, bottom) presents lower average values than option A (Fig. 12, up), which may result in worst climate change impacts from the middle century onwards. However, the shaded area of the ensemble occupies practically the entire volume under consideration, indicating a huge uncertainty for the future and coinciding with the statement made in previous section. However, the dispersion (shaded area) of the option A is less intense, mainly due to the minimum values of the EMs, which are higher than in the option B, especially until mid-century. Therefore, the conditions presented in option A provide a more favourable average, but still not reliable due to the large dispersion of results, as in the case of option B.~~

5. Discussion

This work has highlighted ~~all~~ the most relevant points ~~that need attention in order to integrate~~to be considered for integrating climate projections into decision-making processes. The proposed methodology is easy to ~~follow but~~understand and to replicate but it has to be adapted to the features of the case study, so a high level of knowledge of the WRS ~~in question~~ is an important requirement to ~~use and understand it (Haro-Monteagudo et al., 2017).~~implement it. In this case, ~~which is~~it was adapted to a Mediterranean basin with water scarcity problems and long periods of drought. Consequently, the more attention we pay to each step, the better the results. In spite of this, the ~~indicators~~indicator did not provide conclusive results due to the great dispersion of climatic projections, especially in the last two future periods. ~~It is therefore~~Therefore, it seems necessary to discuss the process step by step to estimate possible mistakes and improvements.

First, the data from SWICCA were selected ~~because there was made a~~ due to the pre-processing they made of filtering the models that best fit in the European area. Despite this, it is stated in the literature~~ it is stated~~ that for the Mediterranean area it is very difficult to find reliable data or with enough skill to work with them with confidence (Barranco et al., 2018; Collados-Lara et al., 2018), especially if these are hydrological data (Suárez-Almiñana et al., 2017). This is why we decided to work with meteorological variables, even though the process may be simpler and shorter using hydrological variables. In Suárez-Almiñana et al. (2017) it was stated that pan-European models do not have yet the capacity of representing the hydrologic characteristics of complex basins. This may be due to the wide-scale of the European hydrological models, where the tight relationship between rivers and aquifers coupled with the high anthropization of rivers (typical of dry areas) is not well represented unless the hydrological model was well tailored to the basin. In addition, it is also important to consider that final results will depend on the input data selected, so this first step may be the key for the rest of the process. In this way, the proposed methodology would be used in other basins incorporating meteorological variables to avoid this problem.

~~Looking al~~On the other hand, we believe that the reduction of the reference period is a good choice to start with data more in line with the current situation of the basin. This fact has also been demonstrated in Suárez-Almiñana et al. (2020), where the uncertainty about the effects of climate change on the future inflows of this basin was minimized.

Then, looking at Fig. ~~6~~4 and Fig. ~~8~~5, where raw and corrected ~~P~~precipitation and ~~flows~~inflows are shown, there is no doubt that the application of some kind of bias correction was necessary. Working with the raw data would lead to unfavourable results for the future, since the underestimation of flows in the headwaters (where the major reservoirs are located) are notable, this fact may also lead to alarming conclusions about the future hydrology in this basin~~.~~, which may not be correct. Therefore, the quantile mapping technique was applied ~~in~~for both ~~cases (P~~options A and ~~flows).~~B. This technique is highly recommended in the literature (Grillakis et al., 2017; Collados-Lara et al., 2018; Manne et al., 2017; Teutschbein and Seibert, 2012), but after having tried other simpler techniques such as month-specific correction factors (Suárez-Almiñana et al., 2017), the differences between their performances are not significant, although the fitting ~~is improved especially in the annual average. It seems that the currently available methods of correction may not provide a fully satisfactory correction of P and flows. A future consideration might be the application of a seasonal correction, which may be more relevant for water management and especially in this area totally conditioned by the irrigation seasons.~~was improved especially in the annual average. It seems that the currently available methods of bias correction may not provide fully satisfactory results, neither a satisfactory physical justification, since they may hide uncertainty rather than reduce it (Ehret et al., 2012).

The combination of NSE and PBIAS statistics also showed how the bias correction did not improve much more the goodness of fit of the ensemble, despite the good calibration of the hydrological model. In fact, they have to be used with caution because

PBIAS may be influenced by the uncertainty (Moriasi et al., 2007) and the rating values recommended for the NSE may be too restrictive, since only negative values of NSE indicate an inacceptable performance (Moriasi et al., 2007) and this did not happen in the case of Molinar, Tous, and Sueca when the HBV was tested with historical data, even though they were very low (≈ 0.2). The hydrological model is another source of uncertainty and it has to be considered (Muerth et al., 2013), but it is significantly less important than that provided by the RCMs (Vetter et al., 2014).

All these suggest that the skill of climate change projections needs to be improved in order to work with them effectively. Based on Ehret et al., (2012) this would be achieved by increasing the RCMs resolutions at the convection-permitting scale in combination with ensemble predictions based on sophisticated approaches for ensemble perturbation.

Meanwhile, a future consideration might be the application of improved bias correction methods (Switanek et al., 2017) or a seasonal correction, which may be more relevant for water management and especially in this area, totally conditioned by the irrigation season. However, some authors say that in some cases, the RCMs are not able to reproduce drought statistics from the observed series (Collados-Lara et al., 2018; Cook et al., 2008; Seager et al., 2008), so a correction focussed on drought statistics is also a feasible solution to try to leave out the mismatches between reference periods.

~~On the other hand, we believe that the reduction of the reference period is a good choice to start with data more in line to the current situation of the basin. This fact has also been demonstrated in Suárez-Almiñana et al., (in press), where the uncertainty about the impact of future flows on this basin was minimized.~~

~~Regarding the future impacts on flows, the average change rate of the ensemble was shown in an attempt to represent the RCP 6.0, which is the most probable scenario for the future (as was reported previously), as well as to try to reduce the uncertainty considering all EMs (Collados-Lara et al., 2018). However, the main differences between RCPs are only notable in the far future, where the range covered by them is between -7% (RCP 4.5) and -17% (RCP 8.5) for the A approach, and from -5% (RCP 4.5) to -21% (RCP 8.5) for option B.~~

~~The trends for future flows were decreasing in both options (A and B),~~Regarding the impacts on future inflows, they experimented decreases in both options, which is consistent with several studies conducted in this area (Barranco et al., 2018; CEDEX, 2017; Marcos-Garcia et al., 2017). But the behaviour of Tous sub-basin is remarkable~~, which~~ because the rate increases ~~flows~~ until the second period. As mentioned above, this may be conditioned by its relationship with the aquifer and the increase in contributions observed in recent years (Hernández Bedolla et al., 2019). This increase in contributions seems to be captured by the models, since the rainfall rate also increases ~~by an average of 2%~~ in the first period ~~and maintains~~, maintaining the average of the ~~reference period~~baseline until the second period~~, after which it sinks by -6%.~~ and sinking in the last period. This increase in rainfall combined with the increasing contributions from the groundwater (~~contemplated~~included in the hydrological model) and the ~~reference period scarce in~~low water resources of the baseline may lead to ~~that percentage~~those increments in ~~both cases (A and B).~~percentage. In any case, the variability of changes between sub-basins is not an isolated case (Folton et al., 2019).

However, if we focus on the average change rates of the whole JRB (Fig. 6, bottom), their values may seem rather low when they are compared to the benchmark study of the CEDEX (2017). This study estimates average reductions (RCPs 4.5 and 8.5) of -7% (near future), -18% (medium future) and -28% (far future) for the entire JRBD, although it is indicated that change rates can be applied to all its points (Barranco et al., 2018). The main reasons for these differences may lie in the reference period of the report (1960-2000) and the lack of bias correction, even though precipitation on the Mediterranean side was underestimated (Barranco et al., 2018). ~~changes concerning the whole basin of Fig. 9 (between 2% (A) and 5% (B) for the first period, from -4% (A) to -2% (B) in the second period and from -11(A) to -12 (B) in the last period), may seem rather low when compared to the benchmark study of~~In that reference period, the data before the 80s provides a much more favourable scenario in terms of the availability of water resources compared to the current one. Therefore, when future change rates are obtained, the decreases for the future are more drastic. These simple premises may explain why the change rates of this work are lower or more “optimistic” than those provided by the CEDEX (2017).~~ This study estimates average reductions (RCPs 4.5 and 8.5) of -7%, -18% and -28% for the entire JRBD, although it is indicated that change rates can be applied to all its points (Barranco et al., 2018). The principal reasons of these differences may lead in the reference period, which in that study is 1960-2000, and the not correction of data despite the fact that precipitation on the Mediterranean side was underestimated (Barranco et al., 2018). Thus, there was not considered the “80s effect” and the data before the 1980 may lead to a much more favourable scenario in terms of availability of water resources than the current one, therefore the decreases are more drastic in the future. These simple premises may explain why the change rates of this work are lower than those provided by the CEDEX (2017) and therefore the results tend to be more “optimistic” regarding the water resources of the future.~~

Then, it was decided to continue with the statistical characteristics of future flows to obtain the drought risk indicators, ~~however this negative trend~~where the decreasing behaviour observed in ~~flows~~the inflows was not equally evident ~~in the indicators (options A and B), which are very similar to each other~~ (Fig.~~10~~ 8). Only in the first period ~~can be seen~~ a complicated scenario in which the ~~probabilities~~probability of being below 50% of the total storage capacity of the system are 80~~%, however~~% can be seen. However, in the rest of the periods the probabilities of being in any of the intervals is practically the same (≈10%). The reason for this is most clearly seen in the probabilities of exceedance capacity (Fig. ~~11~~9), where the range of probabilities covered by the ensemble is very wide, indicating that their dispersion from the second period onwards is very high and no conclusions can be drawn from them.

The results from the simulation of the future water management supports the dispersion theories extracted from the evaluation of the indicators and the exceedance probabilities, since in Fig. ~~12~~7 the ensemble is occupying practically the entire storage volume ~~under consideration~~of the WRS in both options (larger in option B), indicating that anything could happen and confirming that the uncertainty of climate projections is considerable. In addition, looking at Fig. ~~12~~7, it seems that the bias correction of ~~river~~ flows provide more dispersion ~~to results despite conserving~~and also lower average values of water storage, which from the ~~mean of~~ point of view of water management is more interesting since the ~~average year~~worst scenarios were considered, but the uncertainty is so high that any option can be chosen. In this way, we can understand why it is better to work in ~~the reference period (Fig. 8).~~terms of probabilities when the future is so uncertain.

~~In this way, the results obtained on the risk assessment branch (Fig. 2) can be better understood, as well as why it is better to work in terms of probabilities when the future is so uncertain.~~ Furthermore, the fact of choosing the dammed volumes and

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their evolution as a reference is motivated by the great influence that these volumes have on the ~~Jucar River Basin~~JRB drought indicator~~ system~~ (CHJ, 2018), representing almost 50% of the ~~indicators~~indicator’s value (Haro-Monteagudo et al., 2017). So that, the proposed indicator can serve as an approximation of the current drought indicator and complement it.

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Although the results are not conclusive, ~~we think that~~ the proposed methodology~~ applied~~ is feasible when integrating future projections in the decision-making processes, but for this area the skill of climate projections ~~need~~needs to be improved~~, since the~~. This uncertainty ~~makes~~and the absence of a clear and real danger leads the decision~~ making more complex~~-makers to justify inaction (Lemos and Rood, 2010)~~. According to Lemos and Rood (2010), this uncertainty and the absence of a clear and real danger leads the decision makers to justify inaction, but the decreasing tendencies of future flows and the indicator for the near future are signals to be considered, since taking preventive measures may be the key to avoid severe impacts on the environment, the society and the economy.~~

~~It should also be noted that decisions made on the basis of knowledge of the basin may not be correct and the models may have some parameterization flaws that increase the initial uncertainty, although every effort made to adapt them to the conditions of the basin. In addition,~~, but the decreasing tendencies of future flows and the indicator for the near future are signals to be considered, since taking preventive measures may be the key to avoid severe socioeconomic and environmental impacts.

Finally, we would like to point out that all the simulations were made ~~considering~~taking into account the current conditions of ~~demands and other limitations for water allocation (as the ecological flows regulation),~~the system, which may change in the future and affect ~~the~~ water availability~~ at the expense or benefit of certain uses~~.

6. Conclusion

In this paper~~-~~, a robust and adaptive methodology was presented ~~a complete and adaptable methodology for the~~ to support the decision-making process in complex basins, taking into account the influence of climate change in WRPM. The new perspective of this method regarding current approaches lies in the integration of climate change projections ~~in the decision-making. The aim of this specific case was the~~ into a model chain to perform future management and drought risk ~~assessment in a highly regulated basing from the Mediterranean area.~~assessments, with an emphasis on improving the process with the characterisation of natural inflows. This ~~method is completely applicable to other basins without forgetting~~approach introduces an important advantage trying to fit climate data to the WRS through some adjustment and bias correction processes, which are essential to adapt climate data and models as much as possible to the basin features.

All the process was designed with the objective in mind of transforming the information provided by climate services into useful information for decision-making, in order to be understood and trusted by stakeholders and decision-makers. Hence, the key outcomes that ~~an intimate~~can be extracted at different points of the model chain (future change rates, water storage, and drought risk indicator) are presented in intuitive formats to be easily understood. In this way, it is expected that the existing gap between climate services and WRPM decision-making will be reduced, contributing to a better adaptation to climate change.

The application of this methodology to the JRB has shown how it can be tailored to systems affected by high hydrologic variability and recurrent droughts, taking into account that a good knowledge of ~~their~~the WRS features is ~~necessary.~~ ~~After the characterization of river flows applying~~essential to get good results. In this case, after the adjustment of the reference period to incorporate an abrupt decrease in average precipitation ("80s effect") and the application of both types of bias correction (to meteorological and hydrological variables~~) it~~), a concerning decrease of future inflows was ~~concluded that the tendency of future flows in the JRB is decreasing and very similar in both approaches. However, the average change rates are not as drastic as other reference studies, due to the decisions made during the process of adaptation to the basin, as the reduction of the reference period to avoid the "80s effect", which was more scarce in water resources, as the current state of this basin.~~ observed. These decreasing ~~tendencies~~rates were ~~not~~also reflected in the drought risk ~~indicators and the future water storage~~indicator for the near future, where the very high probability of having values of the total water stored in the WRS less than half of the total storage capacity calls for action.

Unfortunately, the results from the middle century onwards are not conclusive due to the high dispersion of the EMs, indicating that ~~anything could happened from the middle century onwards. Thus, the~~ there is a much higher uncertainty in ~~this basin was considerable since the beginning of the process and it also seems to grow during the model chain procedure, despite the attempts of diminish it by taking decisions to adapt it to the basin.~~ ~~All this~~ predicting the future more than 30 years in advance. This leads to the conclusion that ~~more research is needed, and the~~the skill of climate projections ~~need~~needs to be improved ~~for the Mediterranean area. Hence, when that occurs this methodology will be ready to be implemented with some improvements for the future decision-making. Meanwhile, the decreasing tendency of future river flows is concerning, as is confirmed in many other studies of~~ to overcome the difficulties to extract robust and reliable results from them. In this way, another branch of the above-mentioned gap could be reduced. Despite this ~~area, so this paper may help to be aware of what will happen if no measures are taken from now on,~~, the improved methodology constitutes a step forward in the inclusion of climate projections in the WRPM decision-making process. And for the JRB case of study, results obtained show that it is time for action to mitigate the impacts in the near future.

7. Data availability

The full Spain02 v4 dataset is freely distributed (in NetCDF format) for research purposes (http://www.meteo.unican.es/files/images/copyright_en.pdf) from the Escenarios-PNACC dataset from the UC climate data service. It is available at http://www.meteo.unican.es/datasets/spain02.

The climate projection from SWICCA portal can be freely downloaded at http://swicca.climate.copernicus.eu/indicator-interface/graphs-and-download/ under Creative Commons Attribution-ShareAlike 4.0 International (CC BY-SA 4.0) license conditions.

The natural flows from the Júcar River Basin were provided by the ~~CHJ~~JRBA for research purposes.

8. Author contribution

SSA, AS and JM collected the data. SSA, AS, JPA and ~~AS~~JA designed the methodology. SSA performed the calculations and analysed the results with AS and JA. SSA prepared the manuscript with contributions from all co-authors: JPA, JM, JA, and AS.

9. Competing interests

The authors declare that they have no conflict of interest.

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