First of all, the authors want to thank the referees for the work and time devoted to review the manuscript. We know that all comments will serve to improve the quality and understanding of the work and we hope we have properly answered all the suggestions.

Lines are referred to the cleaned revised version of the manuscript.

Reviewer #1:

Summary

The study demonstrates two operation strategies for flood mitigation in the lower Tagus valley. The Tagus is the largest river on the Iberian Peninsula and the study focuses on flood mitigation by means of regulating the largest dam of the river, the Alcántara dam. The Iber+ model is employed together with a pre-selected digital elevation model (Copernicus) to conduct the simulation of river flow and operating strategies in hindsight at the example of five flood events between 1972 and 1997 with a focus on the major flooding in 1979.

Evaluation and Recommendation

The manuscript is an interesting case study to the highly important field of flood mitigation. The topic of this manuscript is suitable for the journal.

The manuscript is overall well-written and extensively referenced. Data and software that were used are freely available and data sources are referenced. Appealing maps are provided as figures to illustrate the site of investigation.

While the content might be valuable to readers that are interested in flood mitigation operation strategies, the presentation of the material requires some restructuring and elaboration. One of the major points in this respect is that the results section includes many statements that should rather be presented in the introduction and in the methods section. In the current form, the actual results are presented between many of these additional statements and references, and key insights are therefore hard to elicit. Content-wise, the line of thought can be followed but the reader gets the impression that a step beyond is missing: As addition, it would strengthen the manuscript if there were a comparison with other operating strategies that are mentioned (see, e.g. l. 273-275) but not further pursued. Alternatively, an uncertainty analysis using noise that is added to the historic data (like perturbed precipitation data) could demonstrate the applicability of the proposed operating strategies beyond the deterministic hindsight scenario, specifically w.r.t. to the suggested operation strategy 2.

The manuscript bears the potential for being a valuable contribution to the field once the points laid out here are addressed. My recommendation therefore is major revision. In my comments, I suggest changes about restructuring the article. These shall outline one *way to do it and do not have to be followed strictly. Yet, an iterated presentation of the material is required.*

The authors would like to thank the reviewer for the valuable comments.

Following the reviewer's suggestions, the article was restructured and some of the statements previously included in the Results and Discussion section are now included in either the "Introduction" or in the "Data, Models and Methods" sections, hopefully providing better structuring of the manuscript. Additionally, a more in depth analysis and comparison with other operating strategies are also carried out in the new version of the manuscript (lines 259-278).

In addition, the hindsight scenario with historic river flow data was perturbed in order to test more in depth the performance of the dam operation strategies proposed. In this sense, random perturbed series were generated allowing a deviation of ± 25 % from the original values, that is, each real daily value of river flow has been allowed a random variation of ± 25 %. In this sense, as many perturbed random series as total days of the original series (> 17000) were generated to add more robustness to the results. Finally, the average number of floods generated by the river flow of the perturbed series (perturbed natural regime) as well as the associated standard deviation, were presented in table 3. Likewise, the mean number of floods (and the respective standard deviation) generated by the river flow of the perturbed series but applying operating strategies 1 (OS1) and 2 (OS2) was also evaluated and presented in table 3. In all cases, the proposed strategies provide an important reduction in the number of floods, and additionally, the efficiency of OS2 to mitigate the most extreme floods was also confirmed. This corroborates the robustness and the applicability of dam operating strategies proposed under different scenarios of river flow. This information was added in the new version of the manuscript in lines 425-436 and table 3.

Finally, the authors made an effort to make relevant information more accessible and, in particular, the proposed operating strategies were presented in flowcharts for ease of understanding (new figures 2 and 3).

<u>*Specific comments*</u>

- *Abstract: "…several dams…" is stated, but only the major Alcántara* dam *is regulated under historic data, right? Please make sure to not raise wrong expectations in the abstract.*

The reviewer is correct. The statement was not entirely clear in the original abstract. We have changed this sentence to clarify that the dam operating strategies were only applied to the Alcántara dam, the most important for the Tagus river.

- *l. 26: "…with the proposed strategies". Briefly name what is the core idea behind the strategies already in the abstract.*

This was included in the new version of the manuscript.

"… In this sense, dam operating strategies were developed and analyzed for the most important dam along the Tagus river basin in order to propose effective procedures to take advantage of these infrastructures to minimize the effect of floods. Overall, the numerical results indicate a good agreement with water marks and some descriptions of the 1979 flood event, which demonstrates the model capability to evaluate floods in the area under study. Regarding flood mitigation, obtained results indicate that the frequency of floods can be reduced with the proposed strategies, which were focused on providing optimal dam operating rules to mitigate flooding in lower Tagus valley"

- *Provide a clear "Motivation" or "Objective" section. The intention of the paper becomes clear over when reading the article, but it is preferable to have the goals clearly stated at some point – this is also something the final conclusions can relate to. One important motivation that is worth mentioning might be that a thought-through operation strategy is a low-cost approach for flood mitigation compared to additional structures that have to be build.*

Done. A new section 2: Motivation, was developed.

"2 Motivation

The main motivations driving this study are, on the one hand, to improve the knowledge and understanding of flood development in lower Tagus valley, an area especially vulnerable to these events. In this sense, one of the main motivations for carrying out this analysis was the scarcity of studies addressing this issue, especially from a hydrodynamic point of view. For that, different freely available products were tested in order to provide the most accurate tools that can serve as a basis for future studies focused on addressing different aspects related to flooding in lower Tagus valley. On the other hand, the study also intends to provide different strategies to mitigate floods in lower Tagus valley but taking advantage of existing infrastructures, in particular, the dams. To the best of our knowledge, there are no previous studies that have developed this type of strategies for the area under scope, so the strategies presented in this work could represent an important advance in this field. This proposal will allow to provide an affordable new approach to flood mitigation compared to the implementation of additional structural measures that have to be built. For that, dam operating strategies will be proposed and tested in the most important Tagus dam. The benefits provided by the dam strategies proposed in relation to flood mitigation, will be also evaluated. This will also serve as a basis for developing future studies focused on optimizing dam strategies or even interconnecting the strategies of different dams of the Tagus basin to improve the flood mitigation."

- *Section 2: Please explain why the Alcántara dam is the only one considered here and whether there are other operating strategies that include other structures as well.*

The Alcántara dam is, by far, the one with the largest capacity of the dams located along the Tagus basin. Specifically, the Alcántara dam has more than double the

capacity of the next dam by capacity in the main channel of the Tagus river (located upstream of Alcántara dam). The Alcántara dam has a capacity more than 3 times larger than the rest of dams located in the main course of Tagus river. Thus, the large capacity of Alcántara dam, together with its location, on the border between Spain and Portugal, imply that the Tagus river flow in the Portuguese sector is, to a large extent, controlled by this dam. Therefore, taking into account that one of the main objectives of this work is to propose dam strategies to help in the mitigation of floods in lower Tagus sector, we opted to develop and apply dam operating strategies only to this dam. Thus, here we want to show an example of how an adequate regulation of this dam alone could prevent or, at least, strongly mitigate floods in lower Tagus valley. This could provide a basis for further works that can take advantage of the information and results presented here, namely to apply different strategies along the entire Tagus basin, or even interconnect the strategies of different dams, to make improved and more efficient strategies to flood mitigation in Tagus river. This was clarified in the new version of the manuscript (lines 95-102 and 188-191).

- *Section 3: rephrase as "Data, Models and Methods"*

Done.

- *Section 3: merge 3.1 – 3.4 in subsection "Data"*

Done.

- *Section 3: great public resources!*

Thanks. We always try, as far as possible, to conduct the studies with public resources in order to facilitate the transfer of the knowledge acquired.

- *L 92: please add which distance is resembled by 0.1° in km*

Done.

- *L .120ff: please explain in more detail why the model was operated the chosen way: why was the inlet chosen to be critical/subcritical? Why was the outlet chosen to be supercritical/critical? Are these conditions static or do they change over the time series? Why was the SCS-CN methodology by Mockus (1964) used for getting the infiltration from precipitation – are there no more recent and potentially improved alternatives?*

The inlet of the model was defined by means of the critical/subcritical condition because it allows reproducing the real conditions of the river flow using as input the values of the time series of Tagus river flow registered at the gauge station located in Almourol (inlet area of the numerical domain). Other types of inlet conditions depend on other parameters that can suppose an additional source of uncertainty. The outlet was defined as supercritical/critical condition since it allows reproducing with reasonable accuracy the river flow situation, taking into account that no control stations are located at this point and, therefore, no data of river conditions were recorded. Both boundary conditions (inlet and outlet) allow, in our view, a good balance between accuracy and simplicity, since other conditions can only be defined using more data that, in this case, cannot be accessed. These conditions remain static during the simulations. This kind of inlet and outlet conditions were successfully applied in other works where flood hydraulic simulations were carried out, obtaining accurate results (Fernández-Nóvoa et al., 2020; Santillán et al., 2020; González-Cao et al., 2021; 2022). This rational was further clarified in the new version of the manuscript in lines 132-139.

Regarding the SCS-CN methodology, the reference of Mockus (1964) refers to the initial development of this methodology, which is currently widely used to estimate the runoff in extreme flood events (Wang, 2018; Fernández-Nóvoa et al., 2020). In the new version of the manuscript the bibliography was updated and more information about this methodology was added (lines 139-142).

- *L 124: which sizes: side length or circumference?*

The side length. This was clarified in the new version of the manuscript.

- *L 126: "…tries to reproduce…" Does it only try to reproduce? Of course it is a simulation, but please*

The sentence was rewritten as follows:

"Several simulations were used here. The first (*Simulation_Control_1979*) is focused on reproducing the spatial extension and depth of the flood observed in the lower Tagus section in the 1979 event, considering the historical timing and magnitude of water released by the main dams upstream as well as the precipitation downstream."

- *L 147: please describe why a Taylor diagram was used and how it works, i.e. that it is a tool for visualizing multi-objective optimization*

  A Taylor diagram is a very suitable tool that provides a concise statistical summary of how a pattern matches with other (Taylor et al., 2001). It allows representing multiple statistics in a compact single diagram. In particular, Taylor diagrams provide a way of plotting together three well known model validation

statistics to carry out this comparison, in this case the correlation coefficient, the normalized root mean square difference and the normalized standard deviation. Thus, the correlation coefficient provides information about the similarity pattern of the target and reference series. The normalized root mean square difference allows quantifying the differences between the target and the reference series, complementing the statistical information about the correspondence between the different patterns analyzed. Finally, the normalized standard deviation allows completing the characterization of how a target series corresponds to the reference series. These statistical parameters are widely used in statistical analysis and they are linked to provide a very comprehensive evaluation of the results, allowing to evaluate the degree of correspondence between simulated and observed fields (Taylor et al., 2001). Thus, this diagram has been widely applied to analyze the performance of models in relation with the reality that pretends simulate (e.g., González-Cao et al., 2019; Wijayarathne and Coulibaly, 2020; Muñoz et al., 2022). A more complete description of Taylor diagrams was included in the new version of the manuscript (lines 173-178).

- *Section 4: several parts in the discussion section should clearly be moved to the introduction or methods section because they refer to the conduct of experiments/simulation rather than the presentation and discussion of the results. Large parts thereof also contain various cited references which is typically something earlier in the manuscript. The mentioned parts are e.g.: 176-178, Section 4.2, Section 4.3 (incl subsections) until line 282; l 305-324.*

  We agree with the reviewer in what concerns several of these suggestions.

  - **Thus, the information provided in lines 176-178 in the previous version of the manuscript has now been placed in "Data, Models and Methods" section (see subsection "4.3 Digital Elevation Models", lines 168-173).**
  - **The information presented in Section 4.3 in the previous version of the manuscript, including the equations related to dam operating strategies, has now been placed in "Data, Models and Methods" section (see "subsection 4.4 Alcántara dam and optimal operating strategies for flood mitigation", in the new version of the manuscript).**
  - **However, most of the information provided in Section 4.2 in the previous version of the manuscript has been maintained in "Results and Discussion" section. In this sense, we consider that this section provides important results because it presents the numerical reconstruction of the 1979 event, even validating more in depth the capability of the model to reproduce floods in lower Tagus by comparing with some information related to the event. The results obtained from simulation are continually compared and discussed with this related information. Therefore, we consider that if some of this information is transferred to other sections then, this section would lose clarity. Therefore, we consider that this information should be kept in this section to facilitate the reading and understanding. However, if the reviewer considers that some parts still need to be moved to other sections we will make the changes.**

In summary, the authors consider that with the information transferred to other sections, as recommended by the reviewer, the new version of the manuscript presents a clearer structure.

- *L. 295ff: clearly state in the methods section that the proposed OS shall be applied to these five selected flood events*

Done (lines 282-288).

- *L. 325-329: Here, the uncertainty associated to anticipate the expected volume for the coming days is mentioned. Why was this topic not addressed in an uncertainty analysis?*

This topic was not addressed because it would imply a complete hydrological procedure along all the years, including the respective atmospheric forecasts, which are not available for the entire period under scope. In addition, the uncertainty depends not only on the precipitation forecasts used, but also on the availability of in situ measurements, and the performance of the hydrological model applied, among others. To tackle in depth all these procedures would imply a complete separate study, being well outside the scope of the present study. However, it is important to mention that currently, new approaches based on the analysis and forecast of atmospheric structures that transport large amounts of moisture (such as atmospheric rivers), which are responsible for most extreme and large intense precipitation events, provide additionally predictability potential for extreme precipitation, especially for the western Iberian Peninsula (Ramos et al., 2015; 2020). However, we agree with the reviewer that further analysis focused on the uncertainty associated to these issues should be developed in future works. This information, included the aforementioned caveats, was added in the new version of the manuscript (lines 251-258).

- *L 370: maximum water velocity – if this is an important aspect, state this already in the methods or objectives section to highlight that it will be assessed in the article. Currently, it is hidden as a side note at the end of the results.*

These important aspects to evaluate in floods, including the maximum water depth and the maximum water velocity, are now well commented in the methods section in the new version of the manuscript (lines 288-293).

- *Section 5: This is in large parts of a summary and no conclusion section. As mentioned above: a specific "Objectives" section might help here to motivate drawn conclusions, e.g. could the stated goals be met? Why, or why not? Are the routes for improvement?*

Following the reviewer's suggestion, we renamed this section as "Summary and Conclusion". In addition, we added information following reviewer's comments.

- *L. 398-405: Acknowledging caveats is an important scientific discussion but should be part of the "results and discussing" section and not of the "conclusions."*

We agree with the reviewer. In the revised manuscript this information was placed in previous sections (see lines 251-258, 379-387).

- *L 415: In the early part of the manuscript, it was mentioned that bad communication between Portuguese and Spanish authorities exacerbated the flood impacts in 1979. Did the EU help here or is there improved bilateral operation? Please elaborate.*

In the 1979 flood event there was a lack of communication between the different authorities that controlled the different dams, coupled with poor dam operations. This provoked that when flow peaks arrived, dams controlling Tagus flow were virtually full therefore hampering the capacity to exert sufficient control on the peak river flow. Both Portugal and Spain were not part of the EU in 1979 as both countries would enter only in 1986. Currently, a bilateral protocol is established to improve the management of dams (Albufeira agreement, in 2000). In the new version of the manuscript we clarified these issues (lines 51-56).

"Agreement on co-operation for the protection and sustainable use of water from the Hispano-Portuguese river basins. Albufeira (Portugal), 30th November 1998. B.O.E. nº37, 12th, February, 2000", in https://www.boe.es/diario_boe/txt.php?id=BOE-A-2000-2882

"Escartín, C.M.: The Agreement between Spain and Portugal for the Sustainable Development of the Shared River Basins. International Conference of Basin Organizations, Madrid, Spain, 4-6 November, 2002".

Tables and Figures

- *Table 2: Specify caption, e.g. which peak flow – the incoming flood wave?*

Done (see new caption of Table 2).

"Table 2. Hydrologic characteristic of most extreme flood events under different dam configurations. NR is referred to the natural regime (no dam), OS1 is referred to the operation strategy presented in equation (4), and OS2 is referred to the operation strategy focused on extreme events, presented in equation (5). Flood days are referred to the number of days exceeding the flood threshold during each considered event. Peak flow refers to the real maximum daily inflow in the case of the natural regime, whereas it is referred to the maximum daily outflow from the dam under the different operation strategies applied. Percentages are

referred to the differences with respect to the worst scenario (natural regime), which is assigned a percentage of 100 %."

- *Table 2: add percentage reductions as was done in Table 3*

Done.

- *Table 3: very nice overview with absolute and relative reductions!*

Thanks.

- *Figure 2 caption: please add ", respectively" to the end of the sentence*

Done.

- *Figure 6: please add x-axis tick labels, i.e. numbers. And specify number of day since when?*

Done.

<u>*Language*</u>

- *Overall, the manuscript is well-written. Please read over it again to e.g. fill in missing articles (l. 20: [the] Iber+ model; l. 32: [The] Iberian Peninsula;…) or to rephrase very long sentences (e.g. l. 336-339)*

A review of the writing of the entire manuscript was done following reviewer' suggestion.

- *Some rewording suggestions: l. 32: "important" à "intense"; l.49-50: "that can play an important rule in" à "for"; l. 159 "free" à "freely"*

Done.

<u>*References*</u>

- *Complete*

Thanks.

<u>Reviewer #2:</u>

The paper entitled " How to mitigate flood events similar to the 1979 catastrophic floods in lower Tagus" is well written, however, the paper is required major revision as the scientific part is missing:

1. The novelty part of the MS is missing in the MS. Please mention.

Following reviewer' suggestion, and also in accordance with the comments raised by Reviewer 1, we added a new section entitled "Motivation", in which we expose not only the motivation of the study itself, but also the novelty provided. Mainly, we commented that, on the one hand, the development of the work provides new knowledge to better understand the floods in this area since there are a scarcity of studies that address the floods on lower Tagus valley from a hydrodynamic point of view. In addition, the model validation carried out also allows providing adequate tools that can serve as a basis to perform future studies in this area. On the other hand, the proposal of dam operating strategies to take advantage of existing dams to mitigate floods in lower Tagus valley, also provide new insights since there are no previous studies that analyze this issue. Additionally, the dam operating strategies proposed can serve as a basis for future studies that even improve and optimize this proposal.

"2 Motivation

The main motivations driving this study are, on the one hand, to improve the knowledge and understanding of flood development in lower Tagus valley, an area especially vulnerable to these events. In this sense, one of the main motivations for carrying out this analysis was the scarcity of studies addressing this issue, especially from a hydrodynamic point of view. For that, different freely available products were tested in order to provide the most accurate tools that can serve as a basis for future studies focused on addressing different aspects related to flooding in lower Tagus valley. On the other hand, the study also intends to provide different strategies to mitigate floods in lower Tagus valley but taking advantage of existing infrastructures, in particular, the dams. To the best of our knowledge, there are no previous studies that have developed this type of strategies for the area under scope, so the strategies presented in this work could represent an important advance in this field. This proposal will allow to provide an affordable new approach to flood mitigation compared to the implementation of additional structural measures that have to be built. For that, dam operating strategies will be proposed and tested in the most important Tagus dam. The benefits provided by the dam strategies proposed in relation to flood mitigation, will be also evaluated. This will also serve as a basis for developing future studies focused on optimizing dam strategies or even interconnecting the strategies of different dams of the Tagus basin to improve the flood mitigation."

2. The authors have mentioned the 2D hydrodynamic model (Iber+ numerical model). Is this model is open source? Please specify.

The model is freely available for download from its official website (https://iberaula.es), as we stated in the manuscript, but the code is not open source. The code in only accessible for the collaborators on its development, which are specified in the web page. This information was added in the "Code and data availability" section. In the text it was also specified that what is freely available is the executable version of the model (lines 130-131).

3. Please mention the comparative analysis of simulated model with Iber+ numerical model to check the accuracy of model.

The comparison analysis to check the accuracy of the model was better mentioned and explained in the new version of the manuscript (lines 146-149 and 311-332).

4. The statistical analysis is missing in the MS.

The performance of the model to simulate floods was evaluated through the statistical analysis provided by the Taylor Diagrams. This was better explained in the new version of the manuscript in lines 168-179, where the Taylor method is described, and in lines 311-318, where the statistical results obtained are presented and discussed. In addition, following the reviewer's comment, a more detailed statistical analysis of the comparison between the DEMs under scope and the original elevation data, was performed (see Supplementary Material: Table S2). In particular, several statistical indicators were calculated to assess the differences between the leveling benchmark altitudes and the corresponding pixel values in each DEM. These indicators include the Mean Absolute Error (MAE), which is calculated by determining the average of the absolute differences between the DEM and the benchmarks. Additionally, the Standard Deviation (SD) was computed to measure the spread of the differences between the DEM and the benchmarks. The Root Mean Squared Error (RMSE) was also computed by taking the square root of the average of the squared differences between the DEM and the benchmarks. Moreover, the Mean Error (ME) was computed as a measure of the bias between the DEM and the benchmarks, which is determined by averaging those differences. A positive ME indicates that the DEM is overestimating the elevation, while a negative ME indicates that the DEM is underestimating the elevation. This information was summarized in the new version of the manuscript (lines 318-328), and was detailed in the Supplementary Material, which increases the robustness to the validation performed.

5. Please do the sensitivity analysis of the model.

Following a similar suggestion provided by both reviewers, a sensitive analysis was performed to analyze the effectiveness of the proposed strategies to mitigate floods in lower Tagus valley under different river flow scenarios, taking into account that these strategies suppose the main tool developed to address flood mitigation. For

that, the original series of river flow was randomly perturbed allowing a deviation of ± 25 %, that is, each real daily value of river flow has been allowed a random variation of ± 25 %. In this sense, as many perturbed series as the original number of data were generated (> 17000) to add more robustness to the evaluation. The average number of floods generated by the river flow of the perturbed series as well as the associated standard deviation were presented in table 3. The respective average number of floods resulting from applying the dam operating strategies proposed to the perturbed series, as well as the associated standard deviation, were also evaluated (table 3). The efficiency of both proposed strategies was clearly maintained in terms of reducing the total number of floods. In addition, the effectiveness of OS2 to mitigate the most extreme floods was also confirmed. The results obtained corroborate the robustness of dam operating strategies proposed under different scenarios of river flow. This information was added in the manuscript in lines 425-436 and new table 3.

6. Kindly, separate the discussion section and mention the limitation and recommendation of the study.

Following similar suggestions by both reviewers, we have restructured the manuscript to a certain extent. In this sense, and following also the comments of reviewer 1, some parts of the "Results and Discussion" section, more related to conduct experiments or simulations, as well as some statements or information that are not specifically a result, have now been placed in previous sections ("Introduction" and "Data, Models and Methods" sections).

The limitations and recommendations of the study were also clarified in the revised version of the manuscript. The limitations and caveats are now exposed in the corresponding sections (see lines 251-258, 379-387), while the recommendations were placed both in the "Motivation" section and also in the "Summary and Conclusions" section.

We consider that the new version of the manuscript now presents a clearer structure. However, if the reviewer considers that more changes are needed, we will make the proposed additional changes.

Reviewer #3:

I consider this report shows an excellent research about flooding mitigation in the Lower Tagus.

The authors would like to thank the referee for reviewing the article and we sincerely appreciate the positive feedback.