Peer Review File

Hydropower system in the Yarlung-Tsangpo Grand Canyon can mitigate flood disasters caused by climate change

Corresponding Author: Professor Peng Hu

This file contains all editorial decision letters in order by version, followed by all author rebuttals in order by version.

Version 0:

Decision Letter:

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Dear Professor Hu,

Your manuscript titled "A large-scale cascade hydropower system with e-flow constraints in the Yarlung-Tsangpo Grand Canyon: How will the water-energy-ecosystem nexus evolve?" has now been seen by 2 reviewers, whose comments are appended below. You will see that they find your work of some potential interest. However, they have raised quite substantial concerns that must be addressed. In light of these comments, we cannot accept the manuscript for publication, but would be interested in considering a revised version that fully addresses these serious concerns.

We hope you will find the reviewers' comments useful as you decide how to proceed. For publication in Communications Earth & Environment to be appropriate, we would need you to provide compelling new insights into trade-offs between water availability, energy generation and ecosystem protection associated with the Yarlung-Tsangpo Grand Canyon hydropower system, including a robust and transparent model validation and statistical analysis.

Should additional work allow you to address this editorial threshold, as well as all the reviewers' criticisms, we would be happy to look at a substantially revised manuscript. If you choose to take up this option, please either highlight all changes in the manuscript text file, or provide a list of the changes to the manuscript with your responses to the reviewers.

When resubmitting, please provide a point-by-point response to the reviewers' comments. Please submit your responses as a separate file, distinct from your cover letter where you can add responses to the Editors' comments that you do not want to be made available to the reviewers. Word files are preferred. We recommend that any figures, tables or graphs that are included in the response to reviewers are also included in the main article or Supplementary Information.

Please bear in mind that we will be reluctant to approach the reviewers again in the absence of substantial revisions.

If the revision process takes significantly longer than three months, we will be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

We are committed to providing a fair and constructive peer-review process. Please do not hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the reviewers' comments with a list of your changes to the manuscript text (which should be in a separate document to any cover letter), a tracked-changes version of the manuscript (as a PDF file) and any completed checklist:

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Please do not hesitate to contact us if you have any questions or would like to discuss the required revisions further. Thank you for the opportunity to review your work.

Best regards,

Heike Langenberg, PhD
Chief Editor
Communications Earth & Environment

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REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

The Cascade hydropower system at the Yarlung-Tsangpo Grand Canyon is an important hydraulic engineering project within China's development plan. Its impact on the water-energy-ecosystem (WEE) nexus is of great interest to the community and governments. This paper employs a distributed hydrological model to simulate runoff processes in different segments of the ML-BXK basin and calculates the storage and runoff processes influenced by the hydropower system using a series of equations. The evolution of the WEE nexus is assessed through various indexes. The findings indicate that environmental flow constraints mitigate ecosystem impacts, maintain flood control capacity, and reduce hydropower generation. Optimal trade-offs in the WEE relationship were identified under reservoir replenishment with medium flow (1000 m3/s) during the dry period. Although the topic is important, the methods compiled in this paper are very common in the field of hydrological modelling and reservoir influence analysis, with little novelty. Besides, I can see substantial room for improvement, in the aspects of model reliability, the insight into the WEE Nexus, and the guidance on project planning. Consequently, I would like to recommend a rejection decision, and please consider the following comments to improve this work.
1. Snow and Glacier Simulation: Snow and glacier meltwater significantly influence runoff in the Yarlung-Tsangpo river basin, particularly in the Nuxia-Pasighat section where many glaciers are located. Although the authors claim that the simulated runoff composition aligns with similar studies, there is a lack of detailed descriptions on how snow and glacier processes are modeled. A simple comparison with other studies does not suffice to validate the model, especially given the significant uncertainties in existing studies, with glacier runoff contributions ranging from 5.7% to 45.3%. The results cannot be considered reliable solely because 22.7% falls within this wide range. I suggest adding detailed descriptions of the snow/glacier module and performing validation using snow/glacier datasets.
2. Trade-off Among WEE Nexus: The results concerning the trade-off among hydropower (HP), flood protection (FP), and ecosystem impact (EI) are a little confusing for me. Trade-off analysis should address questions like “how will an increase/decrease in HP influence FP and EI?” It appears the paper uses a given parameter set to simulate the natural hydrograph and various scenarios to simulate runoff influenced by the hydropower system, then calculates the indexes using a series of equations. Thus, the relationship among the three indexes is not actually analyzed.
For the same reason, the statements about statistical significance (e.g., L296) and Figures 4 and 7 are also unclear for me. What are the samples in the significance analysis, and what does each point in Figures 4 and 7 represent? Please correct me if I am wrong, but I guess each point represents the index in a certain year, since from the method, you didn’t analyze how changes in HP/Fp/EI will influence another two indexes. Consequently, I think these results are only discussing the interannual variability of each index rather than the tradeoff among them.
3. Change of Natural Condition: The impact of the hydropower project on WEE evolution is analyzed based on simulated runoff during historical period, but the project will be completed many years later. The Tibetan Plateau is experiencing significant climate warming, which will affect runoff in the Yarlung-Tsangpo river basin. How will climate and runoff changes influence the WEE, and will the main conclusions hold under future climate conditions when the project is completed? This

is a question worth investigating.
Specific Comments:
• Title: I suggest using the full name of “e-flow” in the title.
• L33-38: There are three phases, but it's unclear which phase is described in L34-38. Besides, consider changing "phase" to "segment" for consistency with the main text.
• L117: What is meant by "expansive basin area"? If it refers to the drainage area, the number "8 million km^2" is incorrect.
• Method: The methods section lists many parts but lacks clear connections among them, despite the framework diagram. Adding a few sentences or adjusting the diagram to clarify the overall framework and connections between different methods (e.g., how the hydrological model outputs are used in the operation model) is recommended.
• Section 3.3: There are many methods to simulate operation of hydropower station, such as Simple Linear conceptual Model (SLM) and Standard Operation Policy (SOP). Is the conclusion only applicable to the operation rule used in this study, or does the operation rule have little impact on the WEE system? Consider discussing this in the discussion section.
• Section 3.5: Please refer to supplementary section 3 in the main text. Could you explain "representative indicators for operational purposes" in simpler language?
• Section 3.7: Given the scenario settings are divided into two parts, what is the flow size when investigating the influence of QNOR or Qe-flow, and is the discharge flow set as QNOR or Qe-flow when investigating the influence of flow size?
• L344-345: I think only when all indexes in a scenario are better than another scenario, we can say it is an optimal tradeoff. Based on Table 4, only in the 800 scenario, all indexes obtained are worse than the 1000 scenario, while in other scenarios, at least one index is better than 1000 scenario. So I think we cannot simply say which one is the optimal. This depends on which objective the decision-maker values more.
• L487-517: The impact of hydropower system construction on downstream countries is indeed a critical issue, in addition to its influence on the WEE system. Therefore, this section is essential. However, I find that this part primarily provides a general description based on other studies, without directly relating to the results of this study. Could the authors discuss or further analyze transboundary cooperation and downstream impacts based on the findings of this study?

Reviewer #2 (Remarks to the Author):

This manuscript studies the reservoir scheduling protocols of the Yarlung-Tsangpo River cascade hydropower system, which will have a good understanding of the relationship between future large-scale activities and the ecological environment in the Tibet Plateau, and has important scientific significance. Here, some issues need to be addressed：
(1)In lines 29-32 This sentence, “Using the WEP-L distributed hydrological model, the research simulated reservoir operations to forecast hydrological changes, flood mitigation, hydropower generation, and impacts on aquatic ecosystems.” has a Chinese style of expression. Please optimise this kind of expression, also elsewhere in the manuscript.
(2)In lines 74-76, the eco-index should be presented for its general applicability rather than its use in the region in the introduction. It is suggested that you remove this phrase-“In the YT River Basin ”
(3)In lines 86-87, please provide evidence (add some references) for this sentence” Cascade hydropower development plays a crucial role in flood control and mitigating river downcutting in the YT Grand Canyon.”
(4)In lines 153-154, “hydrological station” changes into “hydrological stations” in the title of Figure 1
(5)In lines 159-162, good explanation about your hydrological model in supplementary information. However, it isn't easy to visually verify this model in the manuscript. Please provide a few papers to demonstrate the reliability of this model.
(6)In line 259, it should be added a reference or explanation to explain the reason why the indicator represents the flood control operations.
(7)In line 230, getting rid of Monsoon or flood season is better, otherwise it is easier to misunderstand “dry &Normal season” in line 232.
(8)In line 279, please mention the specific serial number of supplementary figures or tables from supplementary information. Please do the same elsewhere in the manuscript.
(9)In lines 284-286, it would be more readable to indicate the values (NSE&RE) of model performance for Nuxia and Dexing stations.
(10)In Figure 3, it should be removed “Annual” to reduce misunderstanding.
(11)Please add the figures for daily discharge calibration and validation after Figure 3.
(12)Statistical analysis: Please make clear what significance analysis and correlation analysis method are used.
(13)In Figure 5 and Figure 8, it should be more harmonized that p values are changed to asterisks “*” and mention the significance level in titles.
(14)In lines 298&317, Please standardize the subscripts, either “e-flow” or “eflow”.
(15)In lines 426-427, For this sentence “From a hydropower generation standpoint, e-flow restrictions significantly reduced generation by 228×108 kWh (9.1%).”, I did not see a significant drop in hydropower generation in the results, please check the results to restate the discussion.
(16)In lines 583-584, Also for this sentence “However, there was a significant reduction in hydropower generation.”, please check the results to restate the conclusion.

benefits**

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Version 1:

Decision Letter:

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Dear Professor Hu,

Your manuscript titled "A large-scale cascade hydropower system with e-flow constraints in the Yarlung-Tsangpo Grand Canyon: How will the water-energy-ecosystem nexus evolve?" has now been seen by 2 reviewers, whose comments are appended below. You will see that they find your work of some potential interest. However, they have raised quite substantial remaining issues. Reviewer #1 is still concerned about the lack of proper validation of the glacier simulations, the choice of the scenario including hydropower development, and the lack of clear and identifiable key results. Reviewer #2 is also not convinced about the choice of the minimum flow value and suggests determining the ecological flow using local biodiversity survey data.

In light of these comments, we cannot accept the manuscript for publication. We feel that not all reviewer comments have been fully considered and that our original editorial thresholds have not been met (Provide compelling new insights into trade-offs between water availability, energy generation and ecosystem protection associated with the Yarlung-Tsangpo Grand Canyon hydropower system, including a robust and transparent model validation and statistical analysis)

Nevertheless, we would be interested in considering a revised version that fully addresses these serious concerns and our editorial thresholds if you think you are able to meet our thresholds.

We hope you will find the reviewers' comments useful as you decide how to proceed. Should additional work allow you to address these criticisms, we would be happy to look at a substantially revised manuscript. If you choose to take up this option, please either highlight all changes in the manuscript text file, or provide a list of the changes to the manuscript with your responses to the reviewers.

When resubmitting, please provide a point-by-point response to the reviewers’ comments. Please submit your responses as a separate file, distinct from your cover letter where you can add responses to the Editors’ comments that you do not want to be made available to the reviewers. Word files are preferred. We recommend that any figures, tables or graphs that are included in the response to reviewers are also included in the main article or Supplementary Information.

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Please do not hesitate to contact us if you have any questions or would like to discuss the required revisions further. Thank you for the opportunity to review your work.

Best regards,

Alienor Lavergne, PhD
Senior Editor
ORCID: 0000-0002-4591-1217
Communications Earth & Environment

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REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

Thank the authors for the efforts of revising the paper. Most of my comments have been addressed. However, I still have some minor to moderate concerns regarding the model validation, nexus analysis and results presentation.

1. The authors have added the validation of snow simulation, without validating glacier simulation. The roles of snow and glacier melt in sustaining water resources are different. Snowmelt mainly comes from the snowfall occurring in the current year, so the partitioning between snowfall and rainfall mainly influences the streamflow seasonality. On the contrary, the glacier melt comes from a relatively stable solid water storage, so its contribution to streamflow and the volume of glacier storage influences the total streamflow, and consequently influences the sustainability of water resources in a warming future. Considering the large contribution of glacier melt in the Nuxia-Pasighat section, I think a validation toward glacier data is also necessary.
2. The analysis on the WEE nexus under hydropower development and climate change is not clear for me. The authors considered four climate forcing scenarios, together with a scenario called “Only Climate Change”. It’s not clear how hydropower development is considered in this analysis. Given the four SSP scenarios are “climate forcing scenarios”, aren’t they “only climate change” conditions?
3. This study produces many results, in the aspects of WEE nexus, the influence of reservoir operation, the replenishment flow, climate change, and the potential for transboundary cooperation, making it difficult to remember the key findings. I suggest the authors to further summarize some take home message in the abstract and conclusion section, rather than simply reporting some numbers or listing some general conclusion.

Specific comments:
  Please keep terms consistent through the manuscript. For example, the Flood control capacity (FCC) and flood peak clipping rate (Fp) actually describe one characteristic; The index EI is defined but the word “ecosystem disturbance” is used somewhere.
  L389-400: This paragraph is about the reservoir on streamflow seasonality, which is not about the WEE nexus as in 4.2 section title, although it is also important.
  Figure 6 seems to contain many results, but is difficult to follow. 1) Mantel test is not a very commonly used analysis method as pearson’s r, so readers are likely not familiar with it. For example, I can’t understand the meaning of the red line between word “HP” and the top left corner in Figure b. The meaning of the lines in different colors need to be explained in more plain languages. 2) In my understanding, in correlation analysis, we need two series of data to calculate metrics like r. What specific data do you use to represent variables like Dam, Climate Scenario, and Period? 3) This figure is about the influences of hydropower and climate. However, this figure shows many results about the relations among EI, Fp and Flow.

Are such results relevant to what you want to discuss in this section?

Reviewer #2 (Remarks to the Author):

The revised manuscript has effectively addressed my previous suggestions and comments. However, I would like to reiterate a recommendation regarding the minimum discharge used in Formula 10 of the manuscript. The current minimum discharge is set at 17% of the annual average flow, why 17% ? and it is crucial to consider its potential overlap with ecological flow discharge. Furthermore, if the ecological flow could be determined based on local biodiversity survey data, it would significantly enhance the scientific validity and rationality of this research. It is important to note that the establishment of hard constraints will have a direct impact on the evaluation outcomes of positive benefits.

Version 2:

Decision Letter:

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Dear Professor Hu,

Your manuscript titled "A large-scale Cascade Hydropower System in the Yarlung-Tsangpo Grand Canyon under Climate Change: The Future Water-Energy-Ecosystem Nexus" has now been seen by our reviewers, whose comments appear below. In light of their advice we are delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment.

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewers. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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Please review our specific editorial comments and requests regarding your manuscript in the attached "Editorial Requests Table".

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If you have any questions or concerns about any of our requests, please do not hesitate to contact me.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Alienor Lavergne, PhD
Senior Editor
ORCID: 0000-0002-4591-1217
Communications Earth & Environment

REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

My concerns have been mostly addressed in this round of revision. The model validation on glacier data and the clarification of the results presentation have been improved. One minor issue is about the title of 4.2 section. My original comment does not mean that the title needs to be changed to the current one. This section is mostly related to the WEE Nexus under Reservoir Replenishment, while only one paragraph is about the influence on streamflow seasonality. Maybe consider changing the title to "The WEE Nexus and runoff seasonality under Reservoir Replenishment"

Reviewer #2 (Remarks to the Author):

This revised manuscript presents a timely and ambitious analysis of the WEE nexus for a proposed mega-hydropower cascade in the Yarlung-Tsangpo Canyon. The integration of hydrological modeling, multi-objective optimization, and climate resilience planning is commendable. Below are suggestions to strengthen the manuscript's rigor and impact.
1.Include a concise comparative discussion of your findings with existing WEF (Water-Energy-Food) nexus studies.
2.Specify the spatial resolution of WEP-L model inputs and outputs.
This work has significant potential to inform sustainable hydropower planning in contested basins. By addressing the above points, you will enhance its scientific rigor and policy relevance.

Comment Response

Firstly, many thanks to the Reviewers for their insightful comments. We have considered their feedback and implemented significant revisions to the article. The credibility of the hydrological model was improved by **the validation of the Snow Cover. A new optimization (NSGA-III) model** was considered in the revised version**.** The revised version no longer discusses **ENVIRONMENTAL FLOW** and instead focuses on **FUTURE CLIMATE SCENARIOS**. These scenarios examine the response of hydropower development to climate change. The point-by-point responses to the reviewers' comments are shown below.

Reviewer #1：

General comments

1. Snow and Glacier Simulation: Snow and glacier meltwater significantly influence runoff in the Yarlung-Tsangpo river basin, particularly in the Nuxia-Pasighat section where many glaciers are located. Although the authors claim that the simulated runoff composition aligns with similar studies, there is a lack of detailed descriptions on how snow and glacier processes are modeled. A simple comparison with other studies does not suffice to validate the model, especially given the significant uncertainties in existing studies, with glacier runoff contributions ranging from 5.7% to 45.3%. The results cannot be considered reliable solely because 22.7% falls within this wide range. I suggest adding detailed descriptions of the snow/glacier module and performing validation using snow/glacier datasets.

Answer:

The validation using snow/glacier datasets is presented in Figure 3b, and the results are presented in lines 475-478 'In addition to discharge, the snow cover fraction obtained from the WEP-L model was validated using observed snow cover data, in which the CC is 0.84 and RMSE is 9.12% (Figure 3b).'

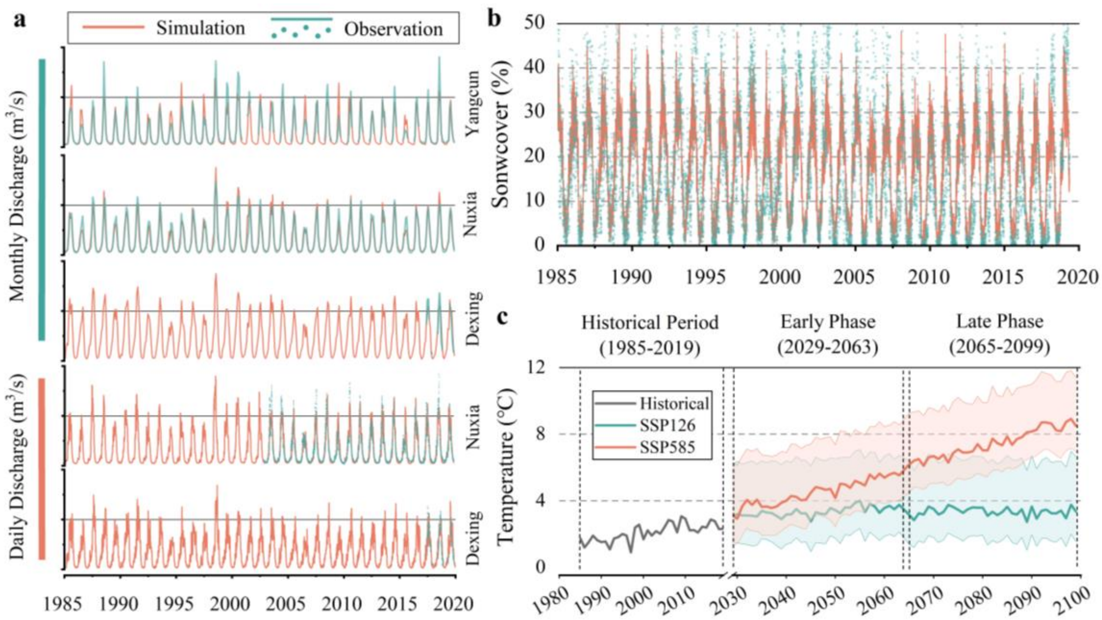


Figure 3 Hydrological model calibration and validation, and the temperature change under the future climate forcing scenarios. a) Calibration and validation of the discharge from the model. The first three figures show the simulated and observed monthly discharge at Yangcun, Nuxia, and Dexing stations. The pink solid lines represent the simulation, and the blue solid lines represent the observation. The last two figures show the daily discharge at the Nuxia and the Dexing. The pink solid lines represent the simulation, while the blue dots show the observation. **b)** Calibration and validation of the snow cover from the model. The simulated (pink solid lines) and observed (blue dots) daily data for the fraction of the snow cover in the YT river basin (proportion from 0 to 100%). **c)** Temperature variability under the climate scenarios**.** The grey line represents the annual average temperature in the historical period (1985-2019). The pink solid line represents the temperature in five selected GCMs under SSP585 in the early (2029-2063) and late (2065-2099) phases. The upper pink line represents the maximum temperature, while the lower pink line shows the minimum temperature. The blue solid line depicts the temperature under SSP126. The upper blue line represents the maximum values, and the lower line shows the minimum values.

The data source of snow cover is presented in lines 266-267 'Daily snow cover data are downloaded from the National Tibetan Plateau Data Center (https://dx.doi.org/10.11888/Snow.tpdc.271381).'

Since the details of the ice and snow melt simulations, we used are consistent with those in the literature of Sun et al. (2023). The modelling details are not included in the supplementary information but are quoted directly from that literature.

Sun, H. et al. 2023. Regional difference in runoff regimes and changes in the Yarlung Zangbo river basin. Hydro. Earth Syst. Sci. 1-53.

2. Trade-off Among WEE Nexus: The results concerning the trade-off among hydropower (HP), flood protection (FP), and ecosystem impact (EI) are a little confusing for me. Trade-off analysis should address questions like "how will an increase/decrease in HP influence FP and EI?" It appears the paper uses a given parameter set to simulate the natural hydrograph and various scenarios to simulate runoff influenced by the hydropower system, then calculates the indexes using a series of equations. Thus, the relationship among the three indexes is not actually analyzed. For the same reason, the statements about statistical significance (e.g., L296) and Figures 4 and 7 are also unclear for me. What are the samples in the significance analysis, and what does each point in Figures 4 and 7 represent? Please correct me if I am wrong, but I guess each point represents the index in a certain year, since from the method, you didn't analyze how changes in HP/Fp/EI will influence another two indexes. Consequently, I think these results are only discussing the interannual variability of each index rather than the tradeoff among them.

Answer:

The meaning and significance of the indicators within the WEE nexus are depicted in lines 292-295 'The term "Water-Energy-Ecosystem nexus" signifies the interplay between Hydropower generation (Energy), Ecosystem disturbance (Ecosystem), and Flood control capacity (Water). This nexus is characterised by three indicators: Hydropower Production (HP), Eco-Index (EI), and Flood peak clipping Rate (Fp).'

Three-dimensional Pareto-seeking optimal distributions of indexes HP/Fp/EI at the replenishment discharges from 600 to 1400 m^3/s are shown in Figure 4a. The changes in HP/Fp/EI will influence another two indexes are shown in Figure 4b (Three-dimensional Pareto-seeking optimal distribution at the discharge of 1000 m^3/s.). Figures 4c and 4d present the Interannual variances of HP, EI, and Fp indices (each point represents a value of one year) in the ML-BXK river basin. The same meanings are shown in Figure 5.

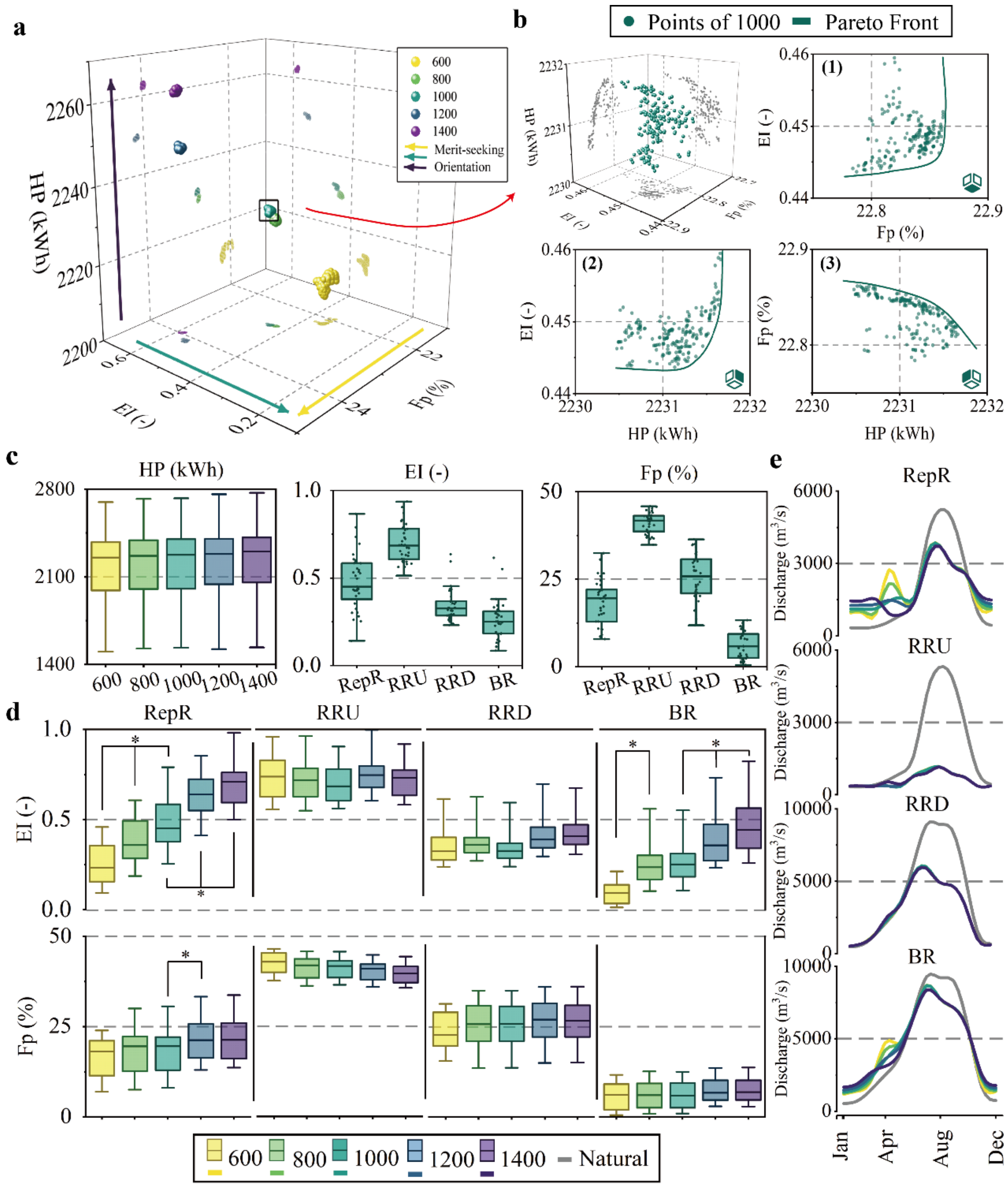


Figure 4 The WEE Nexus under varying flow sizes of reservoir replenishment. a) Three-dimensional Pareto-seeking optimal distribution of values of WEE nexus (HP-EI-Fp) for the ML-BXK river basin at the replenishment discharges from 600 to 1400 m^3/s. Arrows are merit-seeking orientations, except the red arrow. **b)** Three-dimensional Pareto-seeking optimal distribution at the discharge of 1000 m^3/s. Figure (b1) plots the Pareto-optimal distributions and boundaries of the EI and Fp indices. Figure (b2) shows the distributions and boundaries of EI and HP indices. Figure (b3) represents the relationship between the Fp and HP indices. Note that the icons in the lower right corner of the 2D figures show the positions in the 3D figure. **c)** Interannual variances of HP, EI, and Fp indices (each point represents a value of one year) in the ML-BXK river basin. The left figure represents the multi-year HP values at the discharges from 600 to 1400 m^3/s. The middle figure shows the multi-year EI values in four runoff segments (RepR, RRU, RRD and BR) at the discharge of 1000 m^3/s. The right figure explores the multi-year Fp values in the runoff segments at 1000 m^3/s.

Note that the selected points are in the middle of the Pareto bounds of the different reservoir replenishment flows, where all three indices are better. **d)** Distribution of multi-year EI (above) and Fp (below) values in the RepR, RRU, RRD and BR at the discharge from 600 to 1400 m^3/s. Note that the selected points are in the middle of the Pareto bounds. The asterisks indicate the significant difference between the data ($p<0.05$). **e)** The monthly inflow hydrographs in the runoff segments (RepR, RRU, RRD and BR) at the replenishment discharge from 600 to 1400 m^3/s and natural conditions (grey lines).

3. Change of Natural Condition: The impact of the hydropower project on WEE evolution is analyzed based on simulated runoff during historical period, but the project will be completed many years later. The Tibetan Plateau is experiencing significant climate warming, which will affect runoff in the Yarlung-Tsangpo river basin. How will climate and runoff changes influence the WEE, and will the main conclusions hold under future climate conditions when the project is completed? This is a question worth investigating.

Answer:

The description and source of the future climate data are shown in Section 3.3 in L268-278 'According to the sixth phase of the Coupled Model Intercomparison Project (CMIP6), five global climate models (GCMs) are selected for the performance evaluation of the WEE nexus under climate change in the ML-BXK basin, namely GCM1 (GFDL-ESM4), GCM2 (HadGEM3-GC31-LL), GCM3 (IPSL-CM6A-LR), GCM4 (MIROC6), GCM5 (NorESM2-LM) (https://esgf-node.llnl.gov/search/cmip6). Daily climate data from 2029 to 2099 are derived from these GCMs. Moreover, two shared socio-economic pathways (SSPs) are considered, i.e., SSP126 is a reimagining of the optimistic scenario RCP2.6, designed to simulate a development path that is compatible with the 2 °C target. SSP585 is an update of the CMIP5 scenario RCP8.5, combined with socioeconomic considerations.'

The results of the hydropower development under climate change are displayed in Section 4.3 in L626-666.

'Climate change and hydropower development profoundly changed the WEE relationship in the ML-BXK basin, especially in the late phase under the high forcing scenario (SSP558-LP), where EI and HP are significantly larger than others (Figure 5a). Zooming into each runoff segment, ecosystem disturbances in SSP558-LP are strongly expressed ($p<0.05$), as depicted in Figure 5c.

Under four climate forcing scenarios (SSP126-EP; SSP558-EP; SSP126-LP; SSP558-LP) in the figure 5a, ecosystem disturbances under SSP126 remain steady ($EI_{mean\text{-}EP}$=0.50; $EI_{mean\text{-}LP}$=0.50), while enhancing under SSP558 ($EI_{mean\text{-}EP}$=0.53; $EI_{mean\text{-}LP}$=1.06), compared with the values in the historical period all increased (EI_{mean}=0.45). Meanwhile, the tendency of the HPs is like the EIs, flatting under SSP126 ($HP_{mean\text{-}EP}=2406.2 \times 10^8$kWh; $HP_{mean\text{-}LP}=2413.1 \times 10^8$kWh), and notably improving under SSP558 ($HP_{mean\text{-}EP}=2502.3\times10^8$kWh; $HP_{mean\text{-}LP}=2736.3\times10^8$kWh, $p<0.05$), with lower values in the historical period ($HP_{mean}=2231.4\times10^8$kWh), as shown in Figure 5d. Furthermore, the FCCs continually diminished in all climate scenarios ($Fp_{mean126\text{-}EP}$=29.18%; $Fp_{mean126\text{-}LP}$=22.26%; $Fp_{mean558\text{-}EP}$=13.53%; $Fp_{mean558\text{-}LP}$=11.00%), and only the value under SSP126-EP is higher than that in the historical period (Fp_{mean}=22.82%). The specific distributions of the climate scenarios from figure 5a are amplified and displayed in Figure 5b, and the results are distributed in the Pareto fronts nicely.

The ecosystem disturbances and FCCs exhibited variations across four runoff segments (RepR, RRU, RRD and BR), influenced by hydropower development and climate change as depicted in Figure 5c. The BR demonstrated the least ecological disturbances, whereas the RRU showcased the highest FCC. The RepR saw the most dramatic fluctuation, including FCCs and EIs. In all runoff segments, the ecosystem disturbances under the SSP558-LP were indisputably the most significant, with obviously higher than the values only considering climate change ($EI_{Only\ CC}$=0.47). It is worth noting that FCCs saw a notable reduction in the RepR from 27.91% to -4.98%, and a slight decrease in the RR and BR. In comparison to Only CC conditions (Only considering Climate Change), there was a slight increase in ecosystem disturbances in the upstream section (RepR and RRU), which remained relatively unchanged in RRD. Conversely, there was a minor decrease in ecosystem disturbances in the BR. FCCs are most enhanced in the RRU, with the weakest variations observed in the BR.

The monthly normal flow from three regimes (Fig. 5e) shows that Climate Change increases inflow during the flood period and Hydropower Development flattens the inflow hydrograph. The inflow rates under SSP558 from June to October surpass those under SSP126. The largest increase in inflow rates occurred in the BR. However, inflow rates under climate change have always been lower than those under natural conditions in the historical period during the flood period, except for the inflows under SSP558-LP.'

The discussions of the hydropower development under climate change are displayed in Section 5.1 in L749-807.

'Hydropower production, flood control performance, and ecosystem disturbances all displayed relatively favourable outcomes under medium flow (1000 m^3/s) replenishment during the dry period for hydropower development based on Pareto optimisation.

The variations of shared socio-economic pathways (SSP) have played an important role in changing the WEE relationship in the ML-BXK basin. The aquatic ecosystems operated relatively stably under SSP126, with a slight raised disturbance compared to the historical period. Additionally, hydropower generation remained consistent, and FCCs showed some weakness. The ecosystem shifted considerably under SSP558. Its disturbance increased significantly, and FCCs notably dropped in the late phase. Conversely, there was a remarkable improvement in hydropower generation.

From an ecological perspective, the superimposed effects of climate change and hydropower development do not result in more drastic ecosystem disturbances, except under SSP558. The disturbance is maintained to some extent, and even slightly suppressed in BR, compared to under Only CC conditions. There is a certain critical threshold for the intervention of hydropower development, and the ecosystem disturbance increases exponentially under SSP558-LP. Additionally, the inflow hydrograph (Figure 5e) illustrates that the inflow rises significantly during the flood period, and the inflows in BR under SSP558-LP are higher than the natural inflows in the historical period. It is also worth noting that the ecosystem disturbances remain relatively stable over an extended period in the low-forcing scenario. This indicates that the long-term stability of the climate system (precipitation, temperature, and snow cover, as illustrated in Figure 6a) plays a role in maintaining the stability of aquatic ecosystems (Chang et al, 2020). As elucidated in the correlation heatmap (Figure 6b), the impact of ecosystem disturbance is shaped by a complex interplay between climate change and hydropower development, with no single factor emerging as a significant correlation. However, the ecosystem disturbances were found to be negatively correlated with the precipitation factor and positively correlated with the temperature and snow cover, indicating that increased precipitation and restoration of the snow cover contribute to the optimal functioning of aquatic ecosystems (Poff, Brinson and Day, 2002). A closer examination of the runoff segments (Fig. 6b) reveals that the ecosystem disturbance in the RRU is predominantly shaped by dam construction and replenishment flow ($p < 0.05$). However, other runoff segments are significantly influenced by precipitation, temperature, and snow cover due to climate change ($p < 0.05$). Furthermore, the disturbance intensifications in runoff segments beyond the RRU are profoundly affected by the discharge increase in the RepR. In contrast, the flow restoration in the RR positively impacts the aquatic ecosystem, implying that the glacial meltwater in the Grand Canyon region contributes to the ecosystem restoration (Milner, Brown and Hannah, 2009).

Regarding hydropower production, Hydropower production does not increase significantly at replenishment flow change. However, the flows during the flood period rise due to climate change (Fig. 5e), leading to a steady growth in hydropower production, which becomes particularly significant under SSP558. Notably, the correlation between hydropower generation and both EI and FCC in the RRU is particularly strong ($p < 0.05$), and it also demonstrates a significant positive correlation with the discharge in the RR ($p < 0.05$). This suggests that the increased hydropower generation results in a more unstable aquatic ecosystem and a stronger FCC (Kuriqi et al., 2021).

In terms of flood control performance, the RRU exhibits the highest FCC, which decreases as water resources revert to the natural river (BR). Furthermore, drastic climate change has been observed to result in a reduction in the FCCs. This is primarily attributable to the rise in temperature, melting of ice and snow, and increase in natural flood volume, which have resulted in alterations to the Fps (see Figures 5e and 6c). The correlation analysis indicates a significant positive correlation between FCC and the inflow in the RR. The FCC in RepR notably correlates negatively with climate change and positively with hydropower development. This implies that hydropower development can mitigate the flood disasters in the ML-BXK basin caused by climate change (Yun et al, 2022).'

Specific comments

- Title: I suggest using the full name of "e-flow" in the title.

Answer:

This part has already been deleted.

- L33-38: There are three phases, but it's unclear which phase is described in L34-38. Besides, consider changing "phase" to "segment" for consistency with the main text.

Answer:

L37-39: 'The simulations revealed distinct alterations in the runoff regime within the Milin-Pasighat basin, categorised into three **SEGMENTS** based on variations in total runoff volume and processes.'

- L117: What is meant by "expansive basin area"? If it refers to the drainage area, the number "8 million km^2" is incorrect.

Answer:

L155-156: 'It has a natural headfall of 2921 m and an average riverbed aspect ratio of 3.85‰, within **THE DRAINAGE AREA** of approximately **80,000 km^2**(Figure 1d).'

- Method: The methods section lists many parts but lacks clear connections among them, despite the framework diagram. Adding a few sentences or adjusting the diagram to clarify the overall framework and connections between different methods (e.g., how the hydrological model outputs are used in the operation model) is recommended.

Answer:

L225-234: The framework diagram is shown in Figure 2 and the description of each Step is shown in Figure's subtitle.

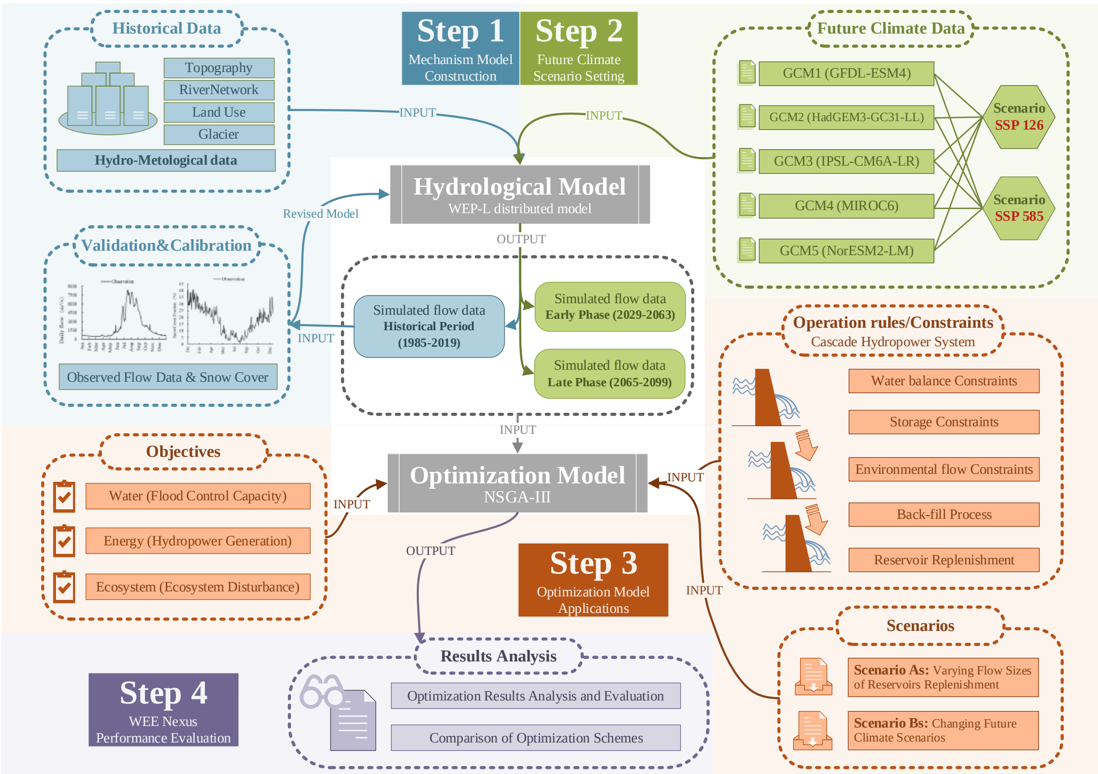


Figure 2 A modelling framework of the Water-Energy-Ecosystem nexus. Step 1: Topography and meteorological data are input into the WEP-L model to simulate the hydrological process of the YT river basin. The model parameters are then calibrated based on the observed discharge and snow cover data. **Step 2:** Meteorological data under future climate scenarios are input into the WEP-L model to simulate future hydrological processes in the basin. **Step 3:** Under the constraints of the cascade reservoir scheduling rules and the "Water-Energy-Ecosystem" objectives, the NSGA-III model runs to reveal the changes in the WEE nexus under different climate-forcing scenarios. **Step 4:** The performance and changing patterns of the three objectives under various scenarios are analyzed.

- Section 3.3: There are many methods to simulate operation of hydropower station, such as Simple Linear conceptual Model (SLM) and Standard Operation Policy (SOP). Is the conclusion only applicable to the operation rule used in this study, or does the operation rule have little impact on the WEE system? Consider discussing this in the discussion section.

Answer:

The explanations of operation rule methods are shown in L328-334 'To explore the influence of the cascade reservoirs regulation within the ML-BXK basin, we adopted the Standard Operation Policy (SOP) model (Morris and Fan, 1998) that includes the effects of environmental flow, flood discharge and others. R1 is the controlling reservoir and has a significant impact on hydrological alternation. Its constraints include water balance, maximum storage, minimum storage, environmental flow, backfill process, and river replenishment.'

The limitations study of the reservoirs' operations are discussed in L999-1001 '(3) The operation rules employed in this study come from actual reservoir operation documents, and the impacts of different operation policies on the WEE nexus are not considered. Further research could be developed in this area.'

- Section 3.5: Please refer to supplementary section 3 in the main text. Could you explain "representative indicators for operational purposes" in simpler language?

Answer:

The meaning and significance of the indicators within the WEE nexus are depicted in lines 292-295 'The term "Water-Energy-Ecosystem nexus" signifies the interplay between Hydropower generation (Energy), Ecosystem disturbance (Ecosystem), and Flood control capacity (Water). This nexus is characterised by three indicators: Hydropower Production (HP), Eco-Index (EI), and Flood peak clipping Rate (Fp).'

- Section 3.7: Given the scenario settings are divided into two parts, what is the flow size when investigating the influence of QNOR or Qe-flow, and is the discharge flow set as QNOR or Qe-flow when investigating the influence of flow size?

Answer:

This part has already been deleted.

- L344-345: I think only when all indexes in a scenario are better than another scenario, we can say it is an optimal tradeoff. Based on Table 4, only in the 800 scenario, all indexes obtained are worse than the 1000 scenario, while in other scenarios, at least one index is better than 1000 scenario. So I think we cannot simply say which one is the optimal. This depends on which objective the decision-maker values more.

Answer:

You're correct. Hence, we modified descriptions, which indicates that our results were derived by balancing these three indices, ultimately opting for outcomes under relatively optimal conditions.

L52-55:'Moreover, the relatively favourable trade-off within the WEE nexus during reservoir replenishment for rivers with medium flows (1000 m^3/s) during dry periods was identified.'

L503-506:'Considering the three objectives in a balanced manner, the study identifies the relatively favourable trade-offs within the WEE relationship when recharging the river with the medium flow (1000 m^3/s) during the dry period (refer to Figures 4a and Table S3).'

L1024-1028:'Hydropower production, flood control performance, and ecosystem disturbances all displayed relatively favourable outcomes under medium flow (1000 m^3/s) replenishment during the dry period for hydropower development based on Pareto optimisation.'

- L487-517: The impact of hydropower system construction on downstream countries is indeed a critical issue, in addition to its influence on the WEE system. Therefore, this section is essential. However, I find that this part primarily provides a general description based on other studies, without directly relating to the results of this study. Could the authors discuss or further analyze transboundary cooperation and downstream impacts based on the findings of this study?

Answer:

Based on our research findings, we've considered the impact of hydropower development under climate change on ecosystem disturbances and downstream flood prevention, which is reflected both in the abstract and the conclusions.

L939-957: 'The advantages of hydropower development become more apparent in the context of climate change. Under the low forcing scenario, the disturbances to ecosystems resulting from hydropower development appear to maintain those caused by climate change. Moreover, there is evidence of a slight suppression of ecosystem disturbances caused by climate change in the Pasighat outlet (Fig. 5c). Concurrently, hydropower development can yield electricity benefits in China while also considering the flood control function for the downstream region. Even under SSP558-LP, it has consistently provided a certain degree of flood control for the downstream region, thereby safeguarding the lives and properties of the downstream countries (Fig. 5c).

In conclusion, the Chinese government has been implementing scientifically grounded water resource development and management initiatives. These efforts have successfully minimised ecological disturbances in the RR and BR while facilitating downstream agricultural irrigation and navigation through flow replenishment during dry seasons. Additionally, hydropower development provides flood protection downstream without increasing ecosystem disturbance under climate change. These endeavours have played a pivotal role in promoting mutual benefits among nations sharing cross-border rivers and fostering harmonious coexistence between humans and nature.'

Reviewer #2:

Specific comments

- In lines 29-32 This sentence, "Using the WEP-L distributed hydrological model, the research simulated reservoir operations to forecast hydrological changes, flood mitigation, hydropower generation, and impacts on aquatic ecosystems." has a Chinese style of expression. Please optimise this kind of expression, also elsewhere in the manuscript.

Answer:

Thank you for your suggestion, we strive to express our viewpoints in genuine English. L34-37: 'The research simulated reservoir operations to forecast hydrological changes, flood mitigation, hydropower generation, and impacts on aquatic ecosystems by the hydrological (WEP-L) and Optimization (NSGA-III) model.'

- In lines 74-76, the eco-index should be presented for its general applicability rather than its use in the region in the introduction. It is suggested that you remove this phrase-"In the YT River Basin "

Answer:

L104-121: 'Various studies have investigated the impacts of reservoir operations on ecological goals (Jager and Smith, 2008; Li et al., 2018; Qi et al., 2023). In these studies, integrating ecological considerations with Integrated Habitat Assessment (IHA) parameters is widely utilized. The eco-index (EI), derived from IHA metrics, quantifies the extent of natural flow restoration and represents the distinctive features of runoff processes (Olden and Poff, 2003; Gao et al, 2009). This index serves as a metric for assessing the response of the aquatic ecosystem in the YT Grand Canyon (Li et al., 2018).'

- In lines 86-87, please provide evidence (add some references) for this sentence" Cascade hydropower development plays a crucial role in flood control and mitigating river downcutting in the YT Grand Canyon."

Answer:

L122-123: 'Hydropower development plays a crucial role in flood control and mitigating river downcutting (Webb and Leake, 2006).'

Webb, R. H., & Leake, S. A., 2006. Ground-water surface-water interactions and long-term change in riverine riparian vegetation in the southwestern United States. J. Hydrol. 320(3-4), 302-323.

- In lines 153-154, "hydrological station" changes into "hydrological stations" in the title of Figure 1

Answer:

L200-202: '**Figure 1 Location of the study area (a&d), the constructed hydropower plants and HYDROLOGICAL STATIONS (b) as well as the conceptual diagram of the large-scale cascade hydropower system under climate change (c)**'

- In lines 159-162, good explanation about your hydrological model in supplementary information. However, it isn't easy to visually verify this model in the manuscript. Please provide a few papers to demonstrate the reliability of this model.

Answer:

L207-215: 'The WEE nexus modelling framework relies on the WEP-L model (Modeling Water and Energy Transfer Processes in large river basins) (Jia et al., 2001; Wang H. et al., 2023; Wang P. et al., 2023) and the NSGA-III (Optimization model) (He et al, 2022b; Ren, Li, and Zhou,2024), integrated with the future climate scenarios and scheme analysis of operating rules for the cascade hydropower system (Figure 2).Section 4.2 aims to establish criteria for reservoir replenishment during non-flood seasons following trade-offs within the WEE nexus. In Section 4.3, the hydropower system's operations are examined under different climate scenarios to assess their impact on the WEE nexus within the ML-BXK basin.'

Jia, Y. et al. 2001. Development of WEP model and its application to an urban watershed. Hydrol. Proce. 15(11): 2175-94.

Wang, H. et al. 2023. Study on Interaction between Surface Water and Groundwater in Typical Reach of Xiaoqing River Based on WEP-L Model. Water, 15(3), 492.

Wang, P. et al. 2023. Application of an improved distributed hydrological model based on the soil-gravel structure in the Niyang River basin, Qinghai-Tibet Plateau. Hydro. Earth Syst. Sci. 27(14), 2681-2701.

He, S. et al, 2022b. Multi-objective operation of cascade reservoirs based on short-term ensemble streamflow prediction. J. Hydrol. 610, 127936.

Ren, L., Li, Y., & Zhou, S.,2024. An Improved NSGA-III Algorithm for Scheduling Ships Arrival and Departure the Main Channel of Tianjin Port. IEEE Access.

- In line 259, it should be added a reference or explanation to explain the reason why the indicator represents the flood control operations.

Answer:

L318-320: 'The flood peak clipping rate (*Fp*) of the runoff regimes serves as an indicator for assessing the flood control operations performed by the cascade hydropower system, effectively representing FCC (He et al, 2014).'

He, Y. et al, 2014. Reservoir flood control operation based on chaotic particle swarm optimization algorithm. Appl. Math. Mod. 38(17-18), 4480-4492.

- In line 230, getting rid of Monsoon or flood season is better, otherwise it is easier to misunderstand "dry &Normal season" in line 232.

Answer:

L345-354: 'In addition to the above constraints, an additional maximum storage constraint was added for the drainage of sand during the flood season in the D1 and R2,

FLOOD SEASON:

$S_{max,t}=S_{dead}, t=6\sim10$

Dry&Normal season:

$S_{max,t}=S_{total}, t=1\sim5, 11\sim12$

Where S_{dead} denotes the dead water storage (m^3); S_{max} denotes the maximum water storage (m^3) and S_{total} denotes the reservoir storage capacity (m^3). The storage processes of P1, P2 and P3 reservoirs were not considered due to the limited water storage capacity.'

- In line 279, please mention the specific serial number of supplementary figures or tables from supplementary information. Please do the same elsewhere in the manuscript.

Answer:

We are already done, thank you for the mention.

- In lines 284-286, it would be more readable to indicate the values (NSE&RE) of model performance for Nuxia and Dexing stations.

Answer:

The model performances are presented in Table S2.

Supplementary Table S2 The performance of runoff simulation at the representative hydrological stations

Hydrological stations	Time Scale	Calibration period		Validation period		Full period	
		Monthly: 1985-2003		Monthly: 2003-2019 Daily: 2003-2019 2017-2019 (Dexing)		Monthly: 1985-2019 Daily: 2003-2019 2017-2019 (Dexing)	
		NSE	PBIAS	NSE	PBIAS	NSE	PBIAS
Yuncun	Monthly	0.79	-0.2%	0.77	1.5%	0.79	0.3%
Nuxia		0.88	3.0%	0.91	-0.4%	0.89	1.8%
Dexing		/		0.86	1.8%	0.86	1.8%
Nuxia	Daily	/		0.88	-0.4%	0.88	-0.4%
Dexing				0.75	4.7%	0.75	4.7%

- In Figure 3, it should be removed "Annual" to reduce misunderstanding.

Answer:

The figure is shown in L486-500

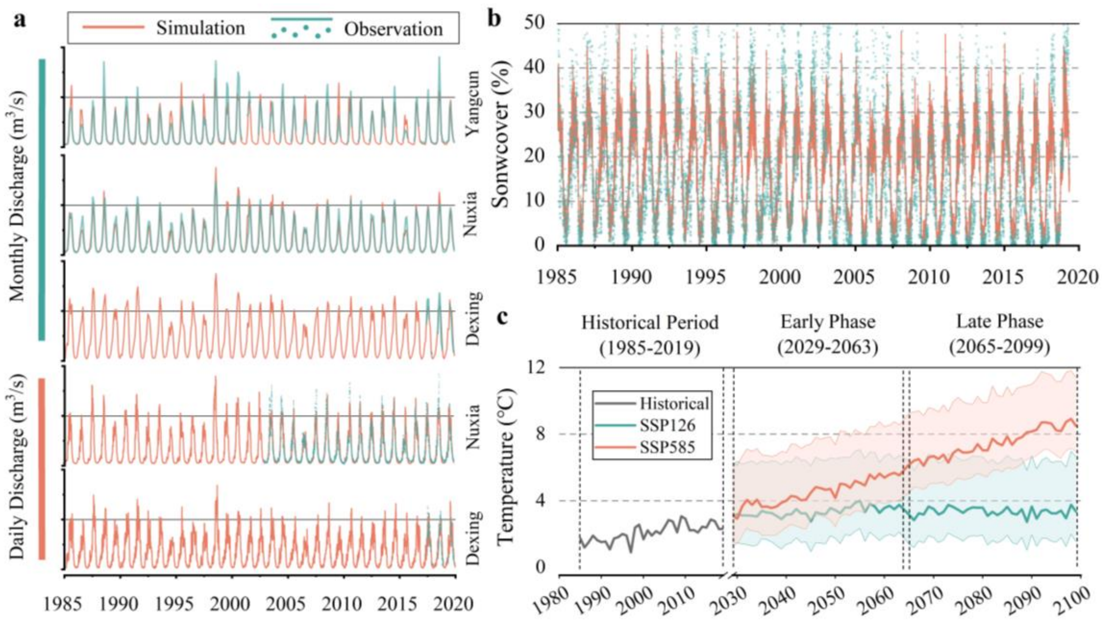


Figure 3 Hydrological model calibration and validation, and the temperature change under the future climate forcing scenarios. a) Calibration and validation of the discharge from the model. The first three figures show the simulated and observed monthly discharge at Yangcun, Nuxia, and Dexing stations. The pink solid lines represent the simulation, and the blue solid lines represent the observation. The last two figures show the daily discharge at the Nuxia and the Dexing. The pink solid lines represent the simulation, while the blue dots show the observation. **b)** Calibration and validation of the snow cover from the model. The simulated (pink solid lines) and observed (blue dots) daily data for the fraction of the snow cover in the YT river basin (proportion from 0 to 100%). **c)** Temperature variability under the climate scenarios**.** The grey line represents the annual average temperature in the historical period (1985-2019). The pink solid line represents the temperature in five selected GCMs under SSP585 in the early (2029-2063) and late (2065-2099) phases. The upper pink line represents the maximum temperature, while the lower pink line shows the minimum temperature. The blue solid line depicts the temperature under SSP126. The upper blue line represents the maximum values, and the lower line shows the minimum values.

- Please add the figures for daily discharge calibration and validation after Figure 3.

Answer:

Please check the Figure in the above answer.

- Statistical analysis: Please make clear what significance analysis and correlation analysis method are used.

Answer:

L450-454: 'The study employed ANOVA analysis to identify the intrinsic differences in the objective index. The relationship between the response of climate factors or reservoir scheduling parameters to the objective indices was revealed using the Pearson correlation and Mantel test (Goslee and Urban, 2007). The significance of each correlation was evaluated using 10,000 permutations.

’

- In Figure 5 and Figure 8, it should be more harmonized that p values are changed to asterisks “*” and mention the significance level in titles.

Answer:

We have already changed the p values to asterisks “*” in all the figures.

- In lines 298&317, Please standardize the subscripts, either “e-flow” or “eflow”.

Answer:

This part has already been deleted.

- In lines 426-427, For this sentence “From a hydropower generation standpoint, e-flow restrictions significantly reduced generation by 228×108 kWh (9.1%).”, I did not see a significant drop in hydropower generation in the results, please check the results to restate the discussion.

Answer:

This part has already been deleted.

- In lines 583-584, Also for this sentence “However, there was a significant reduction in hydropower generation.”, please check the results to restate the conclusion.

Answer:

This part has already been changed. L1023-1027: ‘(2) Considering the three objectives in a balanced manner, the relatively favourable trade-off in the WEE relationship was observed under reservoir replenishment with the medium flow (1000 m^3/s) during the dry period, showcasing a hydropower production of 2231 × 10^8 kWh, an EI for the entire river at 0.45, and an FCC at 22.8%.’

Comment Response

Firstly, many thanks to the Reviewers for their insightful comments again, and we put our thanks comments in the Acknowledgements.

‘Thanks to the anonymous reviewer for the very pertinent and sound advice!’

We have considered their feedback and implemented revisions to the article. The credibility of the hydrological model was improved by **the validation of the glacier mass balance.** The abstract and conclusions are rewritten from four perspectives: **Optimal Reservoir Operations, Climate Resilience, Ecosystem Synergy, and Transboundary Benefits.** The **inadvertently miswritten** of the environmental flow was corrected.

Reviewer #1：

General comments

1. The Glacier validation: The authors have added the validation of snow simulation, without validating glacier simulation. The roles of snow and glacier melt in sustaining water resources are different. Snowmelt mainly comes from the snowfall occurring in the current year, so the partitioning between snowfall and rainfall mainly influences the streamflow seasonality. On the contrary, the glacier melt comes from a relatively stable solid water storage, so its contribution to streamflow and the volume of glacier storage influences the total streamflow, and consequently influences the sustainability of water resources in a warming future. Considering the large contribution of glacier melt in the Nuxia-Pasighat section, I think a validation toward glacier data is also necessary.

Answer:

There is less data on glacial freeze-thaw processes in this area, and we tried to collect as much data as possible for validation. Compared to the other paper, we provide longer time series data on glacial mass balance and more stations. Also, we used real data rather than the normalization.

The glacier data sources were presented in Lines 219-224 “The glacier data were obtained from the First and Second Chinese Glacier Inventory (Liu et al., 2012, 2015, 2017), and the validations toward the glacial freeze-thaw were the observed glacier mass balances of Parlung NO.94, GURENHEKOU and ZHONGXI Glaciers acquired from World Glacier Monitoring Service (https://wgms.ch/). The reconstructed glacier mass balance of the Parlung NO.94 glacier was also used to enhance model reliability (Mu et al., 2019)."

The results were shown in Figure 3, Figure S1 and Lines 367-371 " In addition to discharge, the snow cover fraction obtained from the WEP-L model was validated using observed snow cover data, in which the CC is 0.84 and RMSE is 9.12% (Figure 3b), and the glacier mass balance was validated using observed and reconstructed data from the Parlung NO.94 Glacier in which the CC is 0.67 and PBIAS is -14.2% (Figure 3c). The validations of the other two glaciers, which reported good simulation results (CC=0.95;0.97), are presented in Figure S1. Figure S2 "

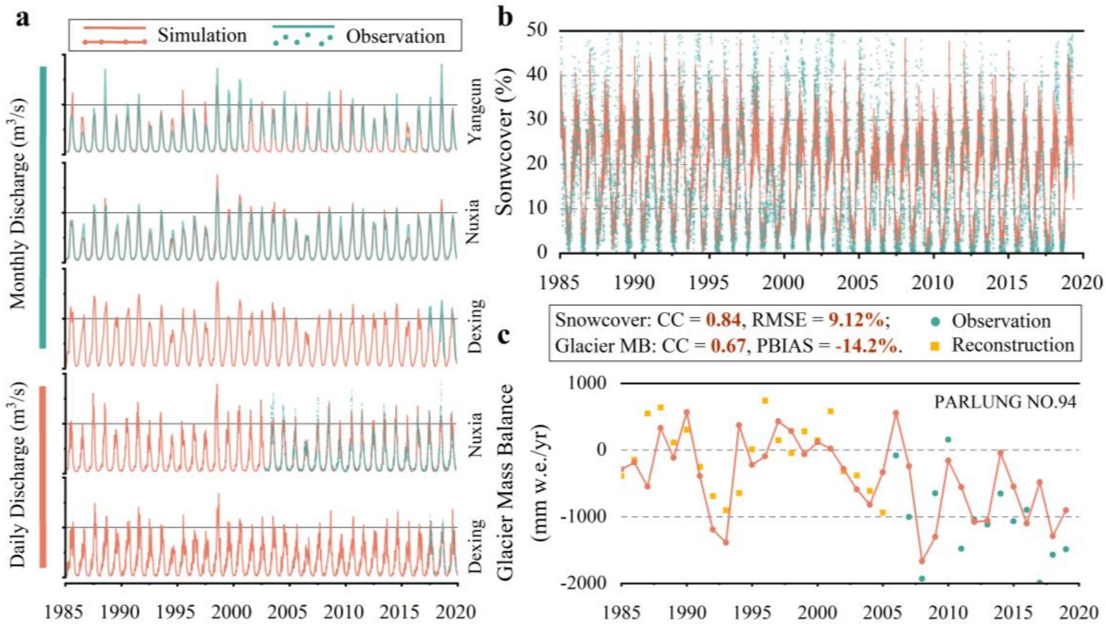
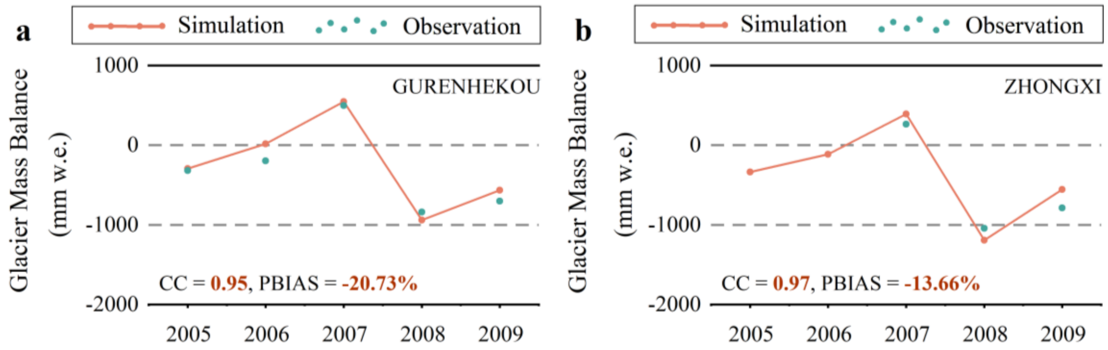


Figure 3 Hydrological model calibration and validation. a) Calibration and validation of the discharge from the model. The first three figures show the simulated and observed monthly discharge at Yangcun, Nuxia, and Dexing stations. The pink solid lines represent the simulation, and the blue solid lines represent the observation. The last two figures show the daily discharge at the Nuxia and the Dexing. The pink solid lines represent the simulation, while the blue dots show the observation. **b)** Calibration and validation of the snow cover from the model. The simulated (pink solid lines) and observed (blue dots) daily data for the fraction of the snow cover in the YT river basin (proportion from 0 to 100%). **c)** Validation of the glacier mass balance from the model. The simulated (pink-dotted dot solid lines), reconstructed (yellow squares) and observed (blue dots) annual data for the glacier mass balance in the PARLUNG NO.94 Glacier.



Supplementary Figure S1 Validations of the glacier mass balance by the GURENHEKOU(a) and the ZHONGXI(b) Glaciers. The simulated (pink-dotted dot solid lines) and observed (blue dots) annual data for the glacier mass balances in the GURENHEKOU and the ZHONGXI glaciers.

2. Not clear enough about WEE Nexus under climate change: The analysis on the WEE nexus under hydropower development and climate change is not clear for me. The authors considered four climate forcing scenarios, together with a scenario called "Only Climate Change". It's not clear how hydropower development is considered in this analysis. Given the four SSP scenarios are "climate forcing scenarios", aren't they "only climate change" conditions?

Answer:

It's our lack of clarity in interpreting the charts. Therefore, we make a distinction between these patterns in the Methods section and also reveal it in the figure notes.

Lines 325-331 " For elucidating the regulatory effects of hydropower development on river systems under climate change in Scenario Bs, the simulation that exclusively considers climatic variations while disregarding the impacts of water infrastructure operations is defined as the "Only considering Climate Change (Only CC)" mode, thereby isolating the individual impacts of climate change on the runoff processes. Other Scenario Bs all consider hydropower development."

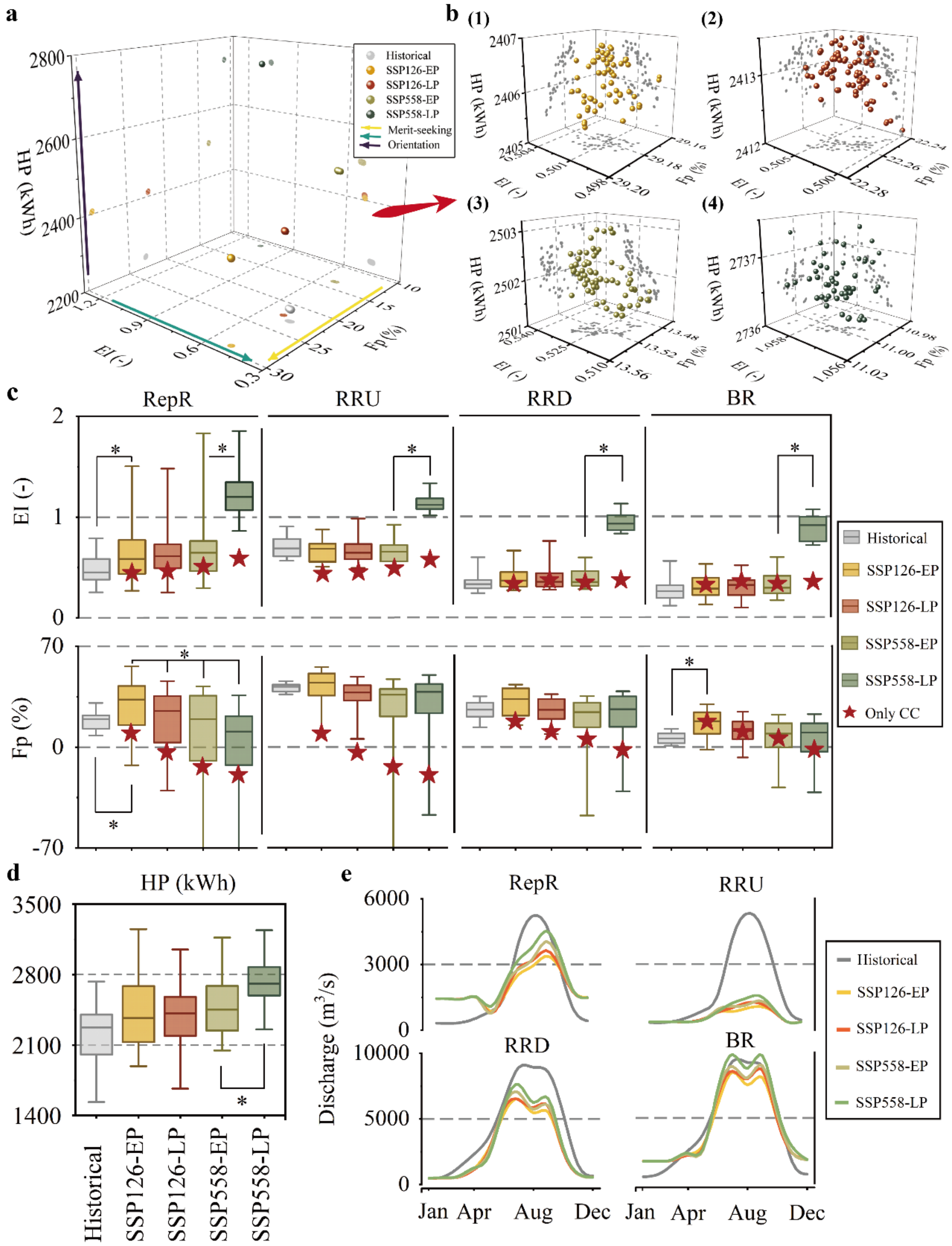


Figure 5 The WEE Nexus under hydropower development and climate change. a) Three-dimensional Pareto-seeking optimal distributions of WEE nexus (HP/EI/Fp) for the ML-BXK river basin at the replenishment discharges of 1000 m^3/s in the historical period (historical; 1985-2019), as well as the early phase (EP; 2029-2063) and the late phase (LP; 2065-2099) under two climate forcing scenarios (SSP126-low forcing scenario &SSP585-high forcing scenario). The 'Historical' indicates the optimal distributed values in the historical period. The 'SSP126-EP' indicates the optimal distributed values in the early phase under the low forcing scenario. The 'SSP126-LP' shows the values in the late phase under the low forcing scenario. The 'SSP558-EP' shows the

values in the early phase under the high forcing scenario. The 'SSP558-LP' shows the values in the late phase under the high forcing scenario. Arrows are merit-seeking orientations, except the red arrow. **b)** Each specific distribution from the figure 5a is amplified and displayed. Figure b1 shows the 'SSP126-EP'. Figure b2 shows the 'SSP126-LP'. Figure b3 shows the 'SSP558-EP'. Figure b4 shows the 'SSP558-LP'. **c)** Distribution of multi-year EI (above) and Fp (below) values in the RepR, RRU, RRD, and BR in the historical period, as well as the early and late phases under the climate forcing scenarios. The red stars represent the average values of multi-year EI (above) and Fp (below), only influenced by climate change (Only CC: the simulation that exclusively considers climatic variations while disregarding the impacts of water infrastructure operations). Note that the selected points are in the middle of the Pareto bounds. The asterisks indicate the significant difference between the data ($p<0.05$). **d)** The multi-year HP values in the historical period, as well as the early and late phases under the climate forcing scenarios. Note that the selected points are in the middle of the Pareto bounds. The asterisks indicate the significant difference between the data ($p<0.05$). **e)** The monthly inflow hydrographs in the runoff segments (RepR, RRU, RRD and BR) in the early phase and the late phase under two climate forcing scenarios, as well as the natural conditions in the historical period (grey lines).

3. Further summarization in the abstract and conclusions: This study produces many results, in the aspects of WEE nexus, the influence of reservoir operation, the replenishment flow, climate change, and the potential for transboundary cooperation, making it difficult to remember the key findings. I suggest the authors to further summarize some take home message in the abstract and conclusion section, rather than simply reporting some numbers or listing some general conclusions.

Answer:

We have made significant changes in the conclusion and abstract sections based on your suggestions. To highlight the readability of the ideas and summarize them in four areas (**Optimal Reservoir Operations, Climate Resilience, Ecosystem Synergy and Transboundary Benefits**).

The conclusions part is in Lines 708-735.

"This study demonstrates the viability of balancing hydropower development, ecological conservation, and climate resilience in the Yarlung-Tsangpo Grand Canyon. Key takeaways include:

(1) Optimal Reservoir Operations: Medium replenishment flow (1000 m^3/s) during dry seasons optimizes the WEE nexus, yielding 2231×10^8 kWh of hydropower annually, 22.8% flood peak reduction, and moderate ecosystem impact (EI=0.45). This strategy stabilizes runoff processes while sustaining downstream agricultural and navigational needs.

(2) Climate Resilience: Hydropower systems enhance flood control under climate change, reducing peak flows by 29.2% under SSP126. Even under high-forcing scenarios (SSP585), reservoirs mitigate flood risks, safeguarding downstream regions despite rising temperatures.

(3) Ecosystem Synergy: Low-forcing scenarios (SSP126) show aquatic ecosystems maintain stability through sustained snowpack and glacial meltwater supplies, where gradual replenishment rather than abrupt melting ensures consistent hydrological regimes. Hydropower operations suppress climate-induced disturbances in downstream segments (e.g., BR), highlighting the dual benefits of energy production and ecological preservation.

(4) Transboundary Benefits: Strategic reservoir management minimizes cross-border impacts, as evidenced by the controlled initial impoundment volume constituting less than 10% of the annual inflow volume in the downstream country. Flood control and dry-season flow stabilization foster regional cooperation, aligning China's energy goals with downstream flood security and irrigation needs.

By integrating hydrological modelling, multi-objective optimization, and climate scenario analysis, this work provides actionable insights for sustainable water-energy governance in fragile, geopolitically sensitive basins. Future efforts should focus on refining ecosystem impact thresholds and adaptive operational rules to further enhance resilience."

The abstract part is in lines 28-46.

"The world's largest diversion-type hydropower system will be created on the China-India border. The Yarlung-Tsangpo Grand Canyon, a critical region for hydropower development and ecological conservation, faces challenges under climate change. This study evaluates the water-energy-ecosystem (WEE) nexus in a proposed large-scale cascade hydropower system using the WEP-L hydrological model and NSGA-III optimization framework. Key findings reveal that reservoir operations with medium replenishment flow (1000 m^3/s) during dry periods achieve an optimal balance among hydropower generation annually (2231 × 10^8 kWh), flood mitigation (peak clipping rate 22.8%), and minimal ecosystem impact (eco-index 0.45). Hydropower development stabilizes runoff regimes, enhances flood control capacity under climate scenarios (e.g., 29.2% peak reduction under SSP126), and mitigates downstream flood risks while supporting dry-season irrigation and navigation. Notably, under low-forcing climate change scenarios (SSP126), ecosystem stability is sustained primarily through the gradual and consistent replenishment of water resources from stabilized snowpack and glacial reserves. Transboundary cooperation is strengthened through adaptive reservoir management, ensuring energy security for China and flood protection for downstream nations. This integrated approach highlights the potential for harmonizing sustainable hydropower expansion with ecological and geopolitical resilience in international river basins."

Specific comments

- Please keep terms consistent through the manuscript. For example, the Flood control capacity (FCC) and flood peak clipping rate (Fp) actually describe one characteristic; The index EI is defined but the word "ecosystem disturbance" is used somewhere.

Answer:

We revised all definitions that

Hydropower generation (Energy)-Hydropower Production (HP);

Ecosystem impact (Ecosystem)-Eco-Index (EI);

Flood control capacity (Water)-Flood peak clipping Rate (Fp).

- L389-400: This paragraph is about the reservoir on streamflow seasonality, which is not about the WEE nexus as in 4.2 section title, although it is also important.

Answer:

The title was renamed "*4.2 The Reservoirs on Streamflow Seasonality*"

- Figure 6 seems to contain many results, but is difficult to follow. 1) Mantel test is not a very commonly used analysis method as pearson's r, so readers are likely not familiar with it. For example, I can't understand the meaning of the red line between word "HP" and the top left corner in Figure b. The meaning of the lines in different colors need to be explained in more plain languages. 2) In my understanding, in correlation analysis, we need two series of data to calculate metrics like r. What specific data do you use to represent variables like Dam, Climate Scenario, and Period? 3) This figure is about the influences of hydropower and climate. However, this figure shows many results about the relations among EI, Fp and Flow. Are such results relevant to what you want to discuss in this section?

Answer:

Thank you very much for your suggestion, we ignore the fact that this method is not widely used in the field of water resources for the time being. Therefore, we have included the similarities and differences between the mantel test and pearson correlation analysis, and the advantages of the mantel test in the methods section. In addition, the reasons for using this method are explained. Also, we explain the definition of dam and other data.

Lines 332-353"The study employed ANOVA analysis to identify the intrinsic differences in the objective index. The relationship between the response of climate factors or reservoir scheduling parameters to the objective indices was revealed using the Pearson correlation and Mantel test. The Mantel test, a permutation-based nonparametric statistical method, shares a homologous algorithmic framework with Pearson correlation analysis, as both approaches quantify the strength of linear associations between variables for correlation assessment. Compared to conventional bivariate correlation analysis, the primary advantage of this methodology lies in its capability to handle multivariate data structures, specifically enabling the examination of associations between a multivariate explanatory matrix and a univariate response variable. When the explanatory matrix reduces to a single variable, the dimensionality-reduced form of its mathematical model becomes equivalent to Pearson correlation analysis, resulting in statistically indistinguishable outcomes in terms of hypothesis testing efficacy and inferential conclusions (Goslee and Urban, 2007). **Given the distinct EI and Fp across different segments (RepR, RR and BR), the EI and Fp matrices, incorporated multi-year average values for the entire river basin and individual segments, are employed for the Mantel test to evaluate their correlations with other indicators.** The significance of each correlation was evaluated using 10,000 permutations. The specific classifications for some important indicators are shown as follows. Dam Construction: 0-Without Dam, 1-Dam; Climate Scenarios Setting: 0-Historical, 1-SSP126EP, 2-SSP126LP, 3-SSP558EP, 4-SSP558LP; Period: 0-Historical, 1-Early Phase, 2-Late Phase.”

To make the image more readable, we have explained the meaning of the colour, thickness and type of lines in the notes section of Figure 6.

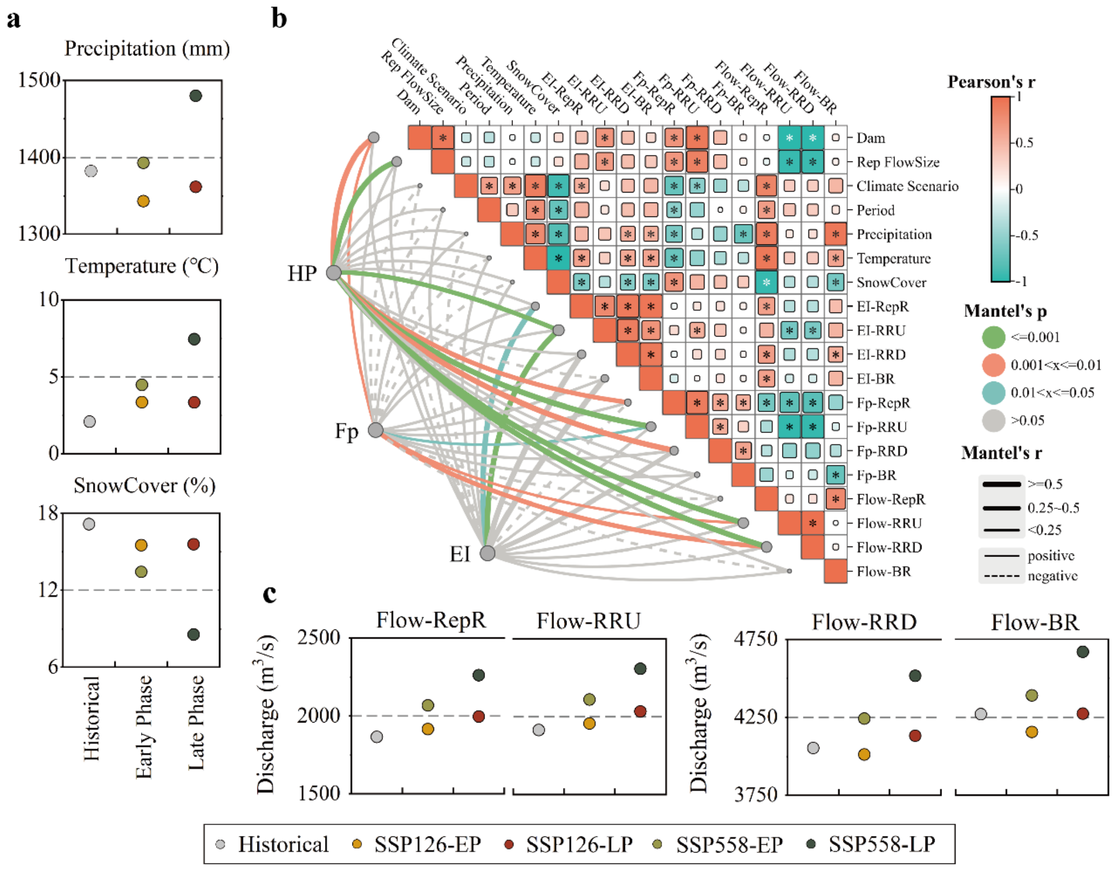


Figure 6 Influence and Correlation of Hydropower Development and Climate Change for the WEE Nexus. a) The multi-year average values of precipitation, temperature and snow cover in the historical period (historical; 1985-2019), as well as the early phase (EP; 2029-2063) and the late phase (LP; 2065-2099) under two climate forcing scenarios (SSP126-low forcing scenario

&SSP585-high forcing scenario). The 'Historical' indicates the multi-year average value in the historical period. The 'SSP126-EP' indicates the average value in the early phase under the low forcing scenario. The 'SSP126-LP' shows the value in the late phase under the low forcing scenario. The 'SSP558-EP' shows the value in the early phase under the high forcing scenario. The 'SSP558-LP' shows the value in the late phase under high forcing scenario. **b)** The Pearson correlation coefficients and mantel test of the WEE nexus (HP-EI-Fp) with the relative factors, including the hydropower development (Dam Construction-Dam; Reservoir Replenishment-Rep FlowSize), the Climate Change (Climate Scenarios Setting-Climate Scenarios; Multi-year average precipitation-Precipitation; Multi-year average temperature-Temperature; Multi-year average snow cover-SonwCover), and the multi-year average EIs, Fps, flows in the runoff segments (RepR, RRU, RRD and BR). The asterisks indicate the significant correlations ($p<0.05$). The colours of the lines represent the mantel's significance (p), and the thicknesses represent the mantel's correlation (r). The dashed lines indicate the negative influence, while another means the positive impact. The figure was drawn on a website (https://www.chiplot.online/). **c)** The multi-year average discharges in the RepR, RRU, RRD and BR in the historical period, the early and late phases under the climate forcing scenarios without hydropower development.

We give many results in the correlation analysis section. The main purpose is to demonstrate the correlation between hydrological processes, climate change, rainfall, and ice and snow melt with these three indicators from the mathematical and statistical aspects. Not only this subsection is discussed, but there are also echoes of the results section.

Reviewer #2：

Specific comments

- The revised manuscript has effectively addressed my previous suggestions and comments. However, I would like to reiterate a recommendation regarding the minimum discharge used in Formula 10 of the manuscript. The current minimum discharge is set at 17% of the annual average flow, why 17% ? and it is crucial to consider its potential overlap with ecological flow discharge. Furthermore, if the ecological flow could be determined based on local biodiversity survey data, it would significantly enhance the scientific validity and rationality of this research. It is important to note that the establishment of hard constraints will have a direct impact on the evaluation outcomes of positive benefits.

Answer:

I'm really, really sorry, it was a writing error. The percentage of environmental flow is always 10%, which is consistent with the results in version 1. Meanwhile, in order to show the reliability of this data, we also cite the relevant regulations of the Ministry of Water Resources of China. At the same time, I apologize that I can't give more biological data based on this data. Because this data originates from the project report itself.

Supplementary information in section “3.4 Environmental flow constraint”.

“where $Q_{out,t}$ denotes the outflow of the reservoir in the tth month (m^3/s). As per “*Guidelines for Water Resources Assessment of Water Resources and Hydropower Construction Projects*” (WMR, 2011) and the scheduled reservoir operating protocols, the Environmental flow ($Q_{e\text{-}flow}$) is set at 10% of the natural runoff (Eq.10).”

Reference

“Ministry of Water Resources of the People's Republic of China (MWR). 2011. Guidelines for Water Resources Assessment of Water Resources and Hydropower Construction Projects. SL 525-2011. Beijing: China Water & Power Press.”

Comment Response

The substantial improvements in this article are largely attributed to the invaluable suggestions from the two reviewers. We look forward to potential opportunities for collaborative research in the future.

By the reviewers' recommendations, we have implemented further revisions, including **a comparative discussion** with existing Water-Energy-Food (WEF) nexus studies and have specified **the spatial resolution** of the model.

Reviewer #1：

- My concerns have been mostly addressed in this round of revision. The model validation on glacier data and the clarification of the results presentation have been improved. One minor issue is about the title of 4.2 section. My original comment does not mean that the title needs to be changed to the current one. This section is mostly related to the WEE Nexus under Reservoir Replenishment, while only one paragraph is about the influence on streamflow seasonality. Maybe consider changing the title to "The WEE Nexus and runoff seasonality under Reservoir Replenishment".

Answer:

Sorry for my misunderstanding. It is kind that you gave me the title directly and we replaced it in the paper.

It is in Lines 378-379 "*3.2 The WEE Nexus and runoff seasonality under Reservoir Replenishment*"

Reviewer #2：

This revised manuscript presents a timely and ambitious analysis of the WEE nexus for a proposed mega-hydropower cascade in the Yarlung-Tsangpo Canyon. The integration of hydrological modeling, multi-objective optimization, and climate resilience planning is commendable. Below are suggestions to strengthen the manuscript’s rigor and impact.

1.Include a concise comparative discussion of your findings with existing WEF (Water-Energy-Food) nexus studies.

2.Specify the spatial resolution of WEP-L model inputs and outputs.

This work has significant potential to inform sustainable hydropower planning in contested basins. By addressing the above points, you will enhance its scientific rigor and policy relevance.

General comments

1.Include a concise comparative discussion of your findings with existing WEF (Water-Energy-Food) nexus studies.

Answer:

We have expanded the Discussion section with a dedicated subsection comparing our findings with existing Water-Energy-Food (WEF) nexus studies. However, due to space constraints, we have condensed this discussion to approximately 200 words. We hope this revision strikes an appropriate balance between comprehensiveness and conciseness, maintaining the essential comparative insights while adhering to paper-length requirements.

It is in Lines 609-629 “ *4.2 Comparative Discussion with Existing WEF (Water-Energy-Food) Nexus Studies*

Existing WEF studies in the YT River Basin (e.g., Lyu et al., 2023) emphasize hydropower's role in balancing energy, agriculture, and flood control, demonstrating enhanced dry-season flows for navigation (increase navigable to four months per year in Bangladesh) and irrigation assurance (be able to reach 100% in Bangladesh). While these findings align with our conclusions on reservoir-driven runoff stabilization (Section 4.2), prior work largely neglects climate-ecosystem dynamics. Our study advances this field by integrating climate scenarios (SSP126/585) and glacial/snowpack processes into a coupled WEE framework, explicitly quantifying ecosystem impacts via eco-index (EI) metrics-a critical gap in transboundary analyses. For instance, Lyu et al. (2023) reported flood reduction of up to 32.6% in India and 14.8% in Bangladesh through reservoir storage but did not address climate-amplified flood risks or ecological trade-offs. Our results reveal that hydropower operations under SSP126 reduce flood peaks by 29.2% while maintaining EI < 0.45, achieving synergies unattainable in static WEF models. Furthermore, NSGA-III optimization identifies medium replenishment flows (1,000 m^3 s^{-1}) as optimal for balancing energy output, ecological stability, and flood resilience nuanced resolution beyond conventional sectoral trade-off analyses. This dynamic, climate-integrated approach provides a more actionable foundation for transboundary cooperation, addressing both hydrological variability and ecosystem integrity in international river management."

2.Specify the spatial resolution of WEP-L model inputs and outputs.

Answer:

We sincerely apologize for the insufficient clarity in describing the model's input-output configuration in Section 3.2. To enhance methodological transparency, we have added a comprehensive tabular summary of datasets in the Supplementary information (Table S1), providing details of data sources, spatial resolution, and temporal resolution for each model component.

It is in lines 791-792 " More details of the input and output datasets are displayed in Table S4."

Table S1 is in the Supplementary information.

Supplementary Table S4 The input and output datasets of the WEP-L model

Variable	Dataset	Temporal Resolution	Spatial Resolution

Gauged meteorological data (precipitation, temperature, relative humidity, wind speed and solar radiation)	China Meteorological Administration and Corrected ERA5: only for precipitation (Sun et al 2022)	Daily	Site, 0.1°
DEM	Geospatial Data Cloud (http://www.gscloud.cn)	-	1000m
Soil type	Resource and Environment Cloud Platform of the Chinese Academy of Sciences (CAS)	-	1000m
Landuse	Chinese Academy of Sciences	per 5 years	1000m
Glacier	1st & 2nd Chinese Glacier Inventory (Liu et al., 2012, 2015, 2017)	-	Polygons
Snow Cover (fraction)	National Tibetan Plateau Data Center (https://dx.doi.org/10.11888/Snow.tpdc.271381)	Daily	0.05°
Observed and Reconstructed glacier mass balance	World Glacier Monitoring Service (https://wgms.ch/) and (Mu et al., 2019)	Annual	Site
Observed streamflow	Hydrological Bureau, Ministry of Water Resources, P.R. China	Monthly, Daily	Site