

## ***Interactive comment on “Future changes in Mekong River hydrology: impact of climate change and reservoir operation on discharge” by H. Lauri et al.***

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We appreciate a lot the careful work of the anonymous Reviewer #2 and her/his thoughtful comments on the manuscript. The manuscript has been revised following the comments and suggestions, as detailed below. We believe that these revisions have led to a significant improvement of our manuscript.

REVIEWER#2 This manuscript presents coupled hydrological and reservoir operation modelling of the downscaled output from multiple GCMs. An overall aim is to identify how discharge is influenced by projected climate change and expanded hydropower

C3872

production. The analysis methods are rigorous and generally well described. In particular, I appreciate the efforts of using multiple GCMs, which greatly contributes to the understanding of inherent uncertainties. The topic is of general interest and important in many aspects. However, the scientific contributions and some aspects of the results interpretation would need to be clarified. Therefore I recommend that the following main issues are addressed before publication.

RESPONSE: We appreciate a lot reviewer's excellent comments and we have addressed those as follows below.

REVIEWER#2: 1. In order to clarify the scientific contribution of this work, it would need to be related to the state-of-the art knowledge; currently, the contribution is almost only explained in the light of investigations closely related to the Mekong River. This is also reflected in the reference list. However, there are many journal papers – considering other parts of the world - on the topics of combined impacts of different reservoir operation schemes and climate change, or reservoir management under the uncertainties of climate change (none of which are mentioned in the manuscript, as far as I can see). Key questions are: a – What has been concluded previously from studies of other river systems, regarding this paper's focus question of discharge effects? b - Do findings from other river systems support some of your conclusions? Hence, can part of this study's results be more generally valid, or are they likely to be constrained, e.g. to systems under influence of monsoon dynamics? c – Did the optimal solutions for reservoir operation differ in some way (e.g., regarding water levels or stored volumes), with and without climate change? If so, are there some further implications? For instance, are there implications for levee heights (an issue of discussion in many regulated river systems)?

RESPONSE: The approach used in this paper provides a basin wide methodology to assess future impacts of both climate and hydropower development in large river basins, which are still relatively undeveloped in terms of water related infrastructure. The methodology as such has not been widely used before for basin scale future as-

C3873

assessments of large river basins. However, similar multi-model approaches have been commonly used to assess the climate change impacts on river basin hydrology and on existing water resources infrastructure such as hydropower dams and their operation in the future climate conditions.

For example Christensen and Lettenmaier (2007) studied the impacts of climate change on water resources of Colorado River Basin. They used 11 GCMs to drive macro scale hydrological model VIC which in turn forced the Colorado reservoir model and found that climate change affected precipitation, which then led to a decline in hydropower production. A similar multi-model approach to the approach of Christensen and Lettenmaier (2007) has been used at least by Hamlet et al. (2010) in the Columbia River Basin.

Thus, whilst other studies have used similar approaches, our study is to the best of our knowledge unique in its scale and the fact that we are assessing the impacts of future hydropower development under future climate change on hydrology, while existing studies concentrate mainly on existing hydropower dams under future climate conditions (e.g. Christensen and Lettenmaier, 2007; Hamlet et al., 2010) or climate variability and hydropower operation in the past (e.g. Zhang and Lu, 2009). Particularly in Asia, where there is large boom on hydropower due to rapid economic development, our approach is very relevant for other large basins.

a – As we did not find similar study set ups, we are not able to compare our findings to other studies from other basins.

b – As replied above, we cannot give a definitive answer to this question. But we would assume that the findings are case specific, i.e. depending on the climate, projected climate change impacts on hydrometeorology, and the size and locations of the hydropower dams. Basins such as the Yangtze or Brahmaputra, with large hydropower development plans, would be very interesting cases in this regard.

c – We did optimise the reservoir operation separately for each climate change scenario

C3874

and each GCM run. Thus, the impact of climate change is taken into account in the operation rules. We did not, however, analyse how the operation rules changed in detail as this is outside the scope of our study. It remains thus for further studies.

References: Christensen, N.S. and Lettenmaier, D.P., 2007. A multimodel ensemble approach to assessment of climate change impacts on the hydrology and water resources of the Colorado River Basin. *Hydrol. Earth Syst. Sci.*, 11: 1417-1434.

Hamlet, A.F., Lee, S.-Y., Mickelson, K.E.B. and Elsner, M.M., 2010. Effects of projected climate change on energy supply and demand in the Pacific Northwest and Washington State. *Climatic Change*, 102: 103-128.

Hoanh, C.T., Jirayoot, K., Lacombe, G. and Srinetr, V., 2010. Impacts of climate change and development on Mekong flow regimes. First assessment - 2009. MRC Technical Paper No. 29. Mekong River Commission, Vientiane, Lao PDR. <http://www.mrcmekong.org/assets/Publications/technical/tech-No29-impact-of-climate-change.pdf> Accessed March 2012.

Zhang, S. R., and Lu, X. X.: Hydrological responses to precipitation variation and diverse human activities in a mountainous tributary of the lower Xijiang, China, *Catena*, 77, 130-142, 10.1016/j.catena.2008.09.001, 2009.

REVIEWER #2: 2. Regarding the results interpretation, a main conclusion is that the impact of reservoir operation is larger on the Mekong river hydrology/ hydrograph than climate change impacts. However, the conclusion seems to be drawn based on relative changes in monthly discharges only. For instance, if the total discharge over a year (the hydrograph area) is considered, would not the impact of climate change be larger than the impact of reservoir operation? Such total, annual water volumes changes must be of interest for hydropower production. Please clarify this issue and rephrase the conclusions accordingly.

Please also clarify whether or not the additional evaporation from the considered reser-

C3875

voirs is considered in the modelling of discharges (or if this effect would be negligible under prevailing climatic conditions).

RESPONSE: This is an excellent point and we have rewritten that part of the conclusions, and also added the impact of climate change on runoff to Table 5. The annual runoff under climate change would change between -13.9% and 9.7% while the impacts of reservoirs on the total discharge over a year are negligible (see below). The conclusions are now completed with this information.

The additional evaporation from the considered reservoirs is not considered in the modelling of discharges. There is no published information on how the reservoirs impact on evaporation in the Mekong. We are at the moment commissioning a study related to the changes in evaporation due to reservoir construction in case of NT2 in Lao PDR. It is still under preparation but the preliminary results indicate that the reservoir does not impact significantly on the evaporation. Moreover, during the rainy season the reservoirs 'harvest' water as direct rainfall to a reservoir. Thus, we believe that at the annual scale the reservoir's impact on the amount of discharge is negligible.

REVIEWER #2: 3. More generally, regarding the analyses, the results are of course sensitive to the actual choice of reservoir operation rules, as also acknowledged in the manuscript. It is mentioned that irrigation could expand in the basin, which would create a need for multipurpose reservoirs. Would not this create opposing needs for water storage, such that the here discussed reservoir operation effects could become less pronounced, relative to the assumed conditions? Or is it possible that the needs can coincide, creating amplifying effects during parts of the year, under considered climatic conditions? It would be interesting to add a brief discussion of this issue.

RESPONSE: The major need for irrigation in the Lower Mekong basin is in the dry season months December-May as shown also by Phengphaengsy and Okudaira (2008). The December-May months are also the months when the flows in the Mekong Region are low and the reservoirs are required to release the water stored in wet season

C3876

through turbines to maximize the energy production. Thus the hydropower generation and irrigation are competitive water uses during the dry season months. The impact of irrigation is expected to be opposite to the hydropower impacts on stream flows, which means that the irrigation may reduce the water level increase of dry season months caused by hydropower operations. However, currently there are no comprehensive assessments in the Mekong Region which have estimated the individual and combined impacts of hydropower generation and irrigation showing the significance of basin wide irrigation development and therefore further research is needed on this topic.

Reference: Phengphaengsy, F. and Okudaira, H., 2008. Assessment of irrigation efficiencies and water productivity in paddy fields in the lower Mekong River Basin. *Paddy Water Environment*, 6(1): 105-114.

REVIEWER #2: Detailed comments:

I. p. 6573, row 19: Downscaled GCM data for the period 2032-2042 was used in this study. However, in climate change quantifications, time periods of 20 to 30 years are most often considered, to avoid effects of annual to decadal anomalies. Are the results based on multiple simulations per GCM for this 10-year period, to avoid such bias? If not, please motivate the choice of such a short time period, and discuss potential bias effects.

II. p. 6579, row 22: Since evapotranspiration has a main influence on (changes in) basin scale water balances, it would be useful to include key equations used to calculate evaporation and evapotranspiration as supplementary information, including the leaf area index quantification methods.

III. p. 6581, row 11: "Delta factors were calculated compared to. . ." Please check language here.

IV. p. 6583, row 15: Figure 3A (p.6610). The figure heading reads "average annual temperature" whereas the figure caption reads "average annual daily maximum tem-

C3877

perature". Please correct. I suspect that the figure can regard the changes of maximum temperature; however, I think it would be much more useful to show the mean temperature changes. It would also be useful to see the evapotranspiration changes in a separate panel.

V. p.6583, row 16. Why does the average temperature need to be computed from the maximum and minimum temperatures, thereby probably introducing some errors?

VI. p. 6584, row 20. The text reads "a 10.4 degree decrease" referring to Table 5, showing a 10.6 degree decrease. Please correct.

VII. p. 6588, row 12. It is stated that increases in annual precipitation will lead to increases in river discharges. This is only true if (temperature-induced) ET increases does not counteract the precipitation increase.

RESPONSE:

I. Whilst many studies indeed use longer time periods (~30 years) for similar studies, we were limited in the length of our baseline period because of some major dam construction like the Manwan dam (filled up 1993). We therefore selected 1982-1992 as baseline period and wanted a similar length future time period and decided on 2032-2042. This is now clarified in the text.

II. The key equations are added to the Online Supplement (section S2 in the revised supplement) with brief explanation.

III. The section has been revised, including the unclear sentence pointed out by the reviewer (see response to a comment of reviewer 1)

IV. The figure has been changed to show average temperature, computed as the average of Tmin and Tmax. Unfortunately the Tavg was not used in the model (see also point V. below).

V. This is a feature of the computational model. Thank you for spotting the problem - the

C3878

model programmer has been informed and the computation method will be modified accordingly.

VI. This is corrected; thanks for checking the text so carefully!

VII. This is naturally the case and the misleading sentences are now rewritten

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C3879