Response to Reviewer 1

We very much appreciate the valuable suggestions to our manuscript. We have carefully considered the comments and have revised the manuscript accordingly. The comments and detailed responses can be summarized as follows.

1 **Comment:** Lines 3-16 in Page 3 depict the ecosystem degradation caused by hydropower portfolio management. While in my opinion, the authors confuse the degradation caused by hydropower portfolio management with that caused by hydropower generation process. As the optimization framework in this paper aims at protecting the river ecosystem in the portfolio determination stage, the authors had better differentiate between these two stages and also the damages caused by these two stages.

Response:

The degradation of riverine ecosystem was caused by hydropower generation rather than the hydropower portfolio management. In this paper we have not clearly state it, leading to the misleading that some ecological damages are caused by portfolio determination.

The determined portfolios could give two important results: 1) the optimal electricity volume that should be generated for each period (day, week, month, etc.); 2) the optimal allocation of the generated hydropower among different electricity sub-markets. The electricity volume determines the water volume that should be released to the downstream rivers, and in turn determines the degree of flow regime alteration. Portfolio determination is a task that occurs before hydropower generation. Even if the reservoir operating rules are refined, their ecological protection effects may not be as effective as expected under the conditions of improperly designed portfolios. Due to the difference of electricity price among different sub-markets, the electricity allocation among different sub-markets as well as the total generated electricity volume determines the revenue of hydropower producers. Thus, the determination of hydropower portfolio before hydropower generation is essential for both riverine ecosystem protection and producer needs.

In order to avoid the misleading by the reviewer and readers, the following sentences are added in the revised manuscript.

The determined portfolios could give two important results: 1) the optimal electricity volume that should be generated for each period (day, week, month, etc.); 2) the optimal allocation of the generated hydropower among different electricity sub-markets. The electricity volume determines the water volume that should be released to the downstream rivers, and in turn determines the degree of flow regime alteration. Due to the difference of electricity price among different sub-markets, the electricity allocation among different sub-markets as well as the total generated electricity volume determines the revenue of hydropower producers. Thus, the determination of hydropower portfolio before hydropower generation is essential for both riverine ecosystem protection and producer needs.

2 **Comment:** What does the sentence "the designed hydropower portfolio is a key factor influencing reservoir operation parameters"(Lines 21-23 in Page 3) mean? The authors should give description in details.

Response:

This sentence is not clear, to some extent leading to the misleading mentioned in the first comment of the reviewer. The sentence is replaced by the following one:

The designed hydropower portfolio can significantly influence reservoir operation through the influence of planned electricity volume and in turn the water volume released to the downstream rivers.

In addition, similar as the response to the first comment given above, the following sentences are used to given more information.

The determined portfolios could give two important results: 1) the optimal electricity *volume that should be generated for each period (day, week, month, etc.); 2) the optimal allocation of the generated hydropower among different electricity sub-markets. The electricity volume determines the water volume that should be released to the downstream rivers, and in turn determines the degree of flow regime alteration.*

3 **Comment:** Lines17-27in Page 3 prove that it is really necessary to consider ecological needs in the portfolio management stage. However, according to the passages above-mentioned, hydropower portfolio design is based on risk management of future inflow and future price. Is the portfolio optimization method more effective to protect river system than the hydropower operation optimization method given that portfolio design has to deal with uncertainty problem while hydropower operation makes real-time regulation?

Response: The optimization of portfolio is not more effective to protect river systems than the hydropower operation. The effects of portfolio optimization on river protection need to be displayed by hydropower operation. The following sentence is added to avoid misleading

The effects of portfolio optimization on river protection are displayed by the influence on hydropower operation.

4 **Comment:** Line 4 in Page 8 shows the e-flow constraint equation "Rkj EFkj".As the EFkj means the minimum e-flows, I think that Rkj should be no less than EFkj. So why should this equation not be "Rkj EFkj" ?

Response:

Yes, it was a slip of the pen, and we have corrected it.

5 **Comment:** The equation "If AEkj-CLkj>0, DLkj=min [kkj(AEkj-CLkj)PDkj , ME-CLkj]" in Line 22 Page 8 is very important for the optimization framework. The authors consider that the bidding volume is in positive correlation with the available electricity volume and also in positive correlation with the day-ahead power price,

and they assume that the effect weights of these two factors are the same. Under these premises, the equation is reasonable. Why should the equation not be other forms? A discussion or explanation is required.

Response:

As mentioned by the reviewer, the assumption in equation (6) is that the bidding volume is in positive correlation with the available electricity volume and the day-ahead power price. Besides the equation given in this paper, lots of other equation forms are also possible. To date there are no widely accepted equations for the relationship between bidding volume and the two factors of available electricity volume and the day-ahead power price. As suggested by the reviewers, the following sentences are used to briefly discuss this question.

In Eq. (6), $k_{kj}(AE_{kj} - CL_{kj})PD_{kj}$ *means that the higher the available electricity volume, the higher the day-ahead power price, and the higher the bidding volume for power. There may be some alternative and more sophisticated equations to replace* $k_{kj}(AE_{kj} - CL_{kj})P_{kj}$*. The equation forms may also influence the revenue of hydropower producers and the effects of riverine ecosystem protection. Further research would be valuable to analyse the influence of equation forms and the optimal forms.*

6 **Comment:** Lines 25-28 in Page 10 shows that the contract load under the second e-flow strategy is higher than that under the first e-flow strategy because of the high flow pulses provision. It's certain that many factors influence the contract load, such as future inflow and future price, but how the high flow events influence the contract load? Why do not the high flow events make the bidding volume high on certain days? Is the authors' conclusion suitable for other study cases?

Response:

We agree that future inflows and price as well as the e-flow management strategy can influence the contract load. However, for the present study case, the future inflow and price are the same under the two e-flow strategies, and thus the major factors influencing the contract load is the parameters in e-flow management strategy. In addition, we are not sure whether the conclusion is suitable for other study cases. It needs to be tested by additional research based on sufficient data.

7 **Comment:** The authors infer that as the electricity in spot market has higher prices than the contract market, the mean annual revenue under the second e-flow strategy is lower than that under the first e-flow strategy, which has more electricity designed in the spot market. This is plausible, but the authors need to inform what causes the spot market price to be higher to make it more understandable. I wonder what if the spot market price is lower than contract price.

Response:

Sorry that it is a misleading. The price in the spot market is not necessary to be higher than the price in the contract market. The price in the spot market is very unstable, and it could be higher than, lower than or equal to the price in the contract market. To avoid the misleading, the following sentence is added in the new manuscript.

The price in the spot market is uncertain, and it could be higher than, lower than or equal to the price in the contract market.

8 **Comment:** In Lines 5-14, Page 12, the authors present that the lowest degrees of alteration under the non and the first e-flow strategies are the same (0.31), while the lowest degree of alteration under the second e-flow strategy is 0.21. My question is: Why the high flow pluses could still make difference under the lowest disturbance to make the alteration degree under the second strategy lower than that under the other two strategies?

Response:

In this research, the parameters k_{kj} and CL_{kj} are two variables that need to be optimised. If the parameters k_{kj} and CL_{kj} are set the same under the three e-flow management strategies, the flow regime alteration degree under the second e-flow strategy will be no greater than that under the other two strategies due to the additional high flow pulses required to be released to the downstream rivers.

9 **Comment:** According to Lines 11-12 in Page 12, the minimum mean annual revenue that all three strategies can achieve is 3.59×10^6 RMB, which is inconsistent with 3.89×10^6 RMB in Line 17 Page 12. I consider one of them might be mistaken.

Response:

Thanks for the reminder. Here, it is right to use 3.89×10^6 RMB. 3.59×10^6 RMB is minimum revenue that can be achieved under the second e-flow management strategy. 3.89×10^6 RMB is the minimum revenue that can be achieved under the non or the first e-flow management strategy. Thus, 3.89×10^6 RMB is the minimum revenue that can be achieved by the three strategies simultaneously.

10 **Comment:** The authors have discussed the revenue unachievable scenario in Lines 13-16, Page 13. They suggest participate in other electricity markets to solve this problem, but how? What if participating in other markets can still not achieve the planned revenue?

Response:

Figure 1 shows the flow regime alteration degree and mean revenue when the hydropower producers participate in the contract and day-ahead market. If a revenue is expected within the unachievable interval in the figure, producer can participate in other sub-market with possible higher price, such as the real-time balancing market. However, the price in the real-time balancing market is more uncertain, i.e. with higher risk. The following sentence is used to clarify it.

For planned revenue within an unachievable interval, if the revenue is above the highest value for all e-flow strategies, no strategy can achieve a low degree of flow regime alteration in the contract and day-ahead market. The revenue can possibly be achieved by participating in other electricity sub-markets, such as the real-time balancing market (the price in this sub-market can be higher, but the price is more uncertain).

Response to Reviewer 2

Thank you very much for your excellent comments on our manuscript. We have carefully considered the comments and have modified the manuscript accordingly. The comments and detailed responses can be summarized as follows:

1 **Comment:** A slight disappointment is to see the Montana (Tennant) method applied to a Chinese river, to set limits for certain e-flows. How do you now that Montana water level will be relevant to this Chinese river? They should be calibrated first. I suggest that the authors reconsider the justification for using the Montana method, or at least provide some evidence that the rules are relevant.

Response:

1) The State Environment Protection Administration of China (2006) has offered official guidelines for environmental flow assessment, called “technical guidelines for environmental impact assessment for ecological water usage, low temperature water and fish habitat facilities in the hydraulics projects (in Chinese)”. In the guidelines, Montana method is recommended for the determination of seasonal environmental flows. In addition, in the Comprehensive Water Resources Planning for Hai River Basin by Hai River Water Commission, Ministry of Water Resources of China (2008), Montana method was also applied to determine the environmental flows. Our study case, the Wangkuai Reservoir, is in the Hai River Basin, and thus we also applied Montana method in this paper.

2) The main purpose of this paper is to develop a hydropower portfolio optimization method to sustain environmental flows. Checking the suitability of Montana method is not a key research point. Thus, we applied the simple and widely used Montana method for a preliminary estimation of the e-flows. If Montana method is testified not suitable for the environmental flow determination in some rivers, the researchers can replace the Montana method by other methods, and can also apply the

reservoir operating rules designed in this paper to sustain the environment flows.

As suggested, to clearly explain the reasons why the Montana method is applied in this paper, we used the following sentences in the new manuscript:

Tennant method was recommended for e-flow assessment in the "technical guidelines for environmental impact assessment for ecological water usage, low temperature water and fish habitat facilities in the hydraulics projects" by the State Environment Protection Administration of China (2006), and was applied by the Haihe Water Commission (2008) for the Hai River basin. Accordingly, the wet season e-flow was set at 30% of average daily flow (ADF), and the dry season e-flow was set at 10% ADF. (see lines)

2. **Comment:** The sentence in line 1 on page 3, "However, none of the previous research considered the need to protect riverine ecosystems", seems to be too absolute. Some existing literatures have already considered the constraints of environmental protection on hydroelectric dams from an economic perspective (See in reference: (1) Kotchen et al., 2006. Environmental constraints on hydropower: an ex post benefit-cost analysis of dam relicensing in Michigan. Land Economics, 82(3), 384-403.; (2) Castelletti et al., 2008. Water reservoir control under economic, social and environmental constraints. Automatica, 44(6), 1595-1607.) The authors may draw a similar conclusion from the perspective of the hydropower producers.

Response:

As suggested, the sentence has been replaced by the following one:

However, none of the previous research on hydropower portfolio optimization considered the need to protect riverine ecosystems.

3. **Comment:** The description of line 10-18 on page 4 is questionable. In line 12, the authors said that "Day-ahead and real-time balancing markets are also called spot markets", while in line 17 they said "The trading power volume and price will not change in a spot market". The spot market includes the real-time market. I don't think

the trading power volume and price in real-time market don not change.

Response:

Owning to the reminder of the reviewer, we also realize the mistake. These sentences are corrected as follows:

In a bilateral contract, the trading power volume and power price are designed by the power producers and grid companies, and will not change during the contract period.

4. **Comment:** In section 2.2.3, the D D0 is reasonable to act as the constraint. But why is it that the designed e-flow no more than the actual reservoir water releases (Rkj EFkj) is used as the constraint?

Response:

It was a slip of the pen. It should be $R_{kj} \geqslant EF_{kj}$. We have corrected it accordingly.

5. **Comment:** In section 2.2.1 Range of variability approach, the variable G is the number of hydrological indicators. Is it equal to 32? Please give a clear definition.

Response:

Yes, G is equal to 32. We have added this information in the new manuscript.

6. **Comment:** There are some errors in detail as following: 1) On page 4, line 13, the first letter of the two words “Participants In” is capitalized at the same time. 2) On page 5, line 29, the sentence “However, the two objectives are in conflict and cannot be achieved simultaneously; a typical multi-objective problem.” is not a complete sentence.

Response:

The “Participants In” is correct to “Participants in”. The sentence has been has been modified as follows:

However, the two objectives are in conflict and cannot be achieved simultaneously, which is a typical multi-objective problem.

7. **Comment:** Variables representation is not consistent in whole manuscript. 1) On page 7, line 1, the variable of “Dm” should be written in italic type; 2) On page 7, line 2 and line 4, the letter m of “mth” should be written in italic type; 3) On page 7, line 10 and line 12-13, the letter “G” and “D” in all three places should be written in italic type 4) On page 8, line 6, the variable of “PCkj” should be written in italic type.

Response:

We have corrected these errors following the comment

8. **Comment:** Line 15-18 on page 15, the format of the Acknowledgement section is not alignment on both ends.

Response:

We have corrected these errors following the comment

9. **Comment:** The reference style is not inconsistent. 1) On page 15, line 24, the reference is not complete for lack of a full stop. 2) On page 17, line 16, the “Regulated Rivers: Reaserch & Management” should be written as “Regul. Rivers: Res. Mgmt.” for short. 3) On page 17, line 7, the reference is in wrong format and should be modified as “Eichhorn, A., Heitsch, H., and Römisch, W.: Scenario tree approximation and risk aversion strategies for stochastic optimization of electricity production and trading, in: Optimization in the Energy Industry, Springer Berlin Heidelberg, 321-346, 2009.” 4) On page 17, line 16, the reference is in wrong format and should be modified as “Fleten, S. E., Wallace, S. W., and Ziemba, W. T.: Hedging electricity portfolios via stochastic programming, in: Decision making under uncertainty, Springer Verlag, New York, 71- 93, 2002.” 5) On page 18, line 4, the magazine name should be modified as “The Electricity Journal” not “Electricity Journal”.

Response:

We very much appreciate the careful review and detailed check by the reviewer. We are sure the check of the references has spent the reviewer much precious time. Thanks very much. All these detailed errors have been corrected accordingly.