Reply to Referee #2

Z. Yin on behalf of all co-authors

1 **"The study 'Irrigation, damming, and streamflow fluctuations of the Yellow River' by Yin et al. provides an overview of the water budget in the Yellow River basin, by considering irrigation and dam regulations. In this study, the authors developed a simple dam model coupled with ORCHIDEE to represent the major flow regulations in the river basin. The topic fits the scope of HESS, However, as a scientific manuscript, a clearly defined science question is missing in this study. What is your major contribution to the hydrology community as the concept of modeling dam regulation is not new?"**
A: Thank you very much for your comments. There are two objectives of this study. First, with newly developed crop and irrigation module, the land surface model ORCHIDEE must be evaluated whether it is able to simulate the discharge of complex rivers with a generic parameterization and to explain the mismatch of simulated discharge of the Yellow River in our previous study (Xi et al., 2018). Moreover, the dam operation model should be evaluated before integrated into ORCHIDEE.
Second, we aim to quantify the impacts of irrigation and dam operations on the monthly discharge fluctuations of the Yellow River, which is not well demonstrated in previous studies. In the revised manuscript, we underlined, "This study aims to 1) demonstrate whether the global land surface model ORCHIDEE is able to simulate the streamflows of complex rivers with human activities using a generic parameterization, and 2) quantify the respective roles of irrigation and artificial reservoirs in monthly streamflow fluctuations of the Yellow River from 1982 to 2014 by using ORCHIDEE with a newly developed irrigation module, and an offline dam operation model." In comparison to previous studies, there are several advantages in our work. Details are discussed in our reply to comment 1 of Referee #1.

2 **"Page 1, line 5, line 10: new → newly"**
A: Corrected.

3 **"Page 4, lines 7-8: Although it's true that many dam model algorithms in recent GHMs and LSMs are inherited from Hanasaki et al. (2006), it is worth mentioning there are other types of dam/reservoir models such as agent-based models (e.g. Riverwave), or basin-specific models (e.g. USBR Colorado River Simulation System)."**
A: Thanks. We've added them in the short review of dam model development.

4 **"Page 4, line 23: Remove 'real' before observations. Are there 'unreal' observations?"**
A: Sorry for the confusion. It has been removed.

5 **"Page 4, lines 29-30: I'm not convinced that the new dam model 'does not require any prior information from observation'. In my opinion, observed information include the data or parameters measured/collected from the real world. In this case, the location, storage capacity, geometry of the dam and reservoir, etc. They are all 'observations'. So, I feel this sentence (and the one in the abstract) is a bit overselling the model and needs to be further clarified."**
A: True. The dam model does require information like regulation capacity, location, and the year when regulation started. This part has been removed in the revision.

6 **"Section 2.1.1: Could you add some more background about ORCHIDEE before introducing ORCHIDEE-CROP? What's the relationship between these two? Is ORCHIDEE-CROP an offline crop model taking ORCHIDEE output as input, or it's an updated ORCHIDEE with an online crop model, or it's a regional model only focuses on China?"**
A: ORCHIDEE-CROP is a special branch of ORCHIDEE with an online crop model, which will be merged with the trunk version after extensive evaluation. It has been applied widely in current research. To avoid this confusion, we removed ORCHIDEE-CROP in the revision. A short introduction of ORCHIDEE and this special version has been added in the revision as: "ORCHIDEE is a physical process-based land surface model that integrates hydrological cycle, surface energy balances, carbon cycle, and vegetation dynamics by two main modules. The SECHIBA (surface-vegetation-atmosphere transfer scheme) module simulates the dynamics of water cycle, energy fluxes, and photosynthesis at half-hourly time interval, which are used by the STOMATE (Saclay Toulouse Orsay Model for the Analysis of Terrestrial Ecosystems) to estimate vegetation and soil carbon cycle at daily time step. The ORCHIDEE used in this study is a special version with newly developed crop and irrigation module (Wang et al., 2017; Wu et al., 2016; Yin et al., 2020). The novel crop module includes specific parameterizations for three main staple crops: wheat, maize, and rice, which are calibrated over China by observations (Wang, 2016; Wang et al., 2017). It is able to simulate crop carbon allocation, different phenological stages as well as related managements (e.g., planting date, rotation, multi-cropping, irrigation, etc)."

7 **"Section 2.1.2: This scheme concept is quite similar to Voisin et al. (2013). Considering citing the work."**
A: Thanks. It has been cited in the introduction of the dam model framework.

8 **"Section 2.1.2: Essentially the dam model is trying to flatten the hydrograph. Any support from the observation that all dams follow this generic rule? I understand sometimes it's hard to obtain the actual operation rules from the dam operators, but given this is a basin scale analysis (not global),**

some level of 'fact-checking' needs to be included to reflect the local reality."
A: The functions of main artificial reservoirs in the YRB has been collected from the Yellow River Conservancy Commission of the Ministry of Water Resources (`http://www.yrcc.gov.cn/hhyl/sngc/`), and has been added in Table 1 in the revised manuscript. The information confirms that flood control ('C' in Table 1), irrigation ('I'), and water supply ('W') are primary targets of these reservoirs, which, in principle, would flatten the hydrograph (seems impossible to release water for water supply and irrigation during flooding season, or reduce the discharge during the dry season).

9 **"Page 8, line 22: Since NI and IR are major simulation experiments performed in this study, it is necessary to include more descriptions about the irrigation scheme in Section 2.1.1. For example, how does the irrigation demand be evaluated, at what time step? How does the irrigation water be applied, at what time step? I'm assuming different PFTs are associated with different irrigation methods (e.g. drip, sprinkler, or flood)? How does the return flow be treated in the model? How does the groundwater be represented in the model? If no groundwater pumping is represented in the model, the level of uncertainty needs to be evaluated and discussed for the study basin."**
A: We've improved the introductions of the irrigation module in Section 2.1.1 as: "The water resources in ORCHIDEE account for three water reservoirs: 1) the stream reservoir indicates streamflows; 2) the fast reservoir indicates surface runoff; and 3) the slow reservoir indicates total deep drainage, the order of which indicates the priorities of water reservoirs considered for irrigation. As long-distance water transfer is not taken into account, streams only supply water to the crops growing in the grid-cell they cross, according to the river routing scheme of the ORCHIDEE model (Ngo-Duc et al., 2007)." and the simulation protocol in Section 2.4 as: "In IR, only surface irrigation is considered in this study (irrigated water is applied on the cropland surface without interception by canopies), which only works during the crop growth period. The soil water stress, a function of profiles of soil moisture and crop root density (up to 2 m depth, (Yin et al., 2020)), is checked every half an hour. When it is less than a target threshold (=1), irrigation will be triggered with amount equal to the deficit of saturated and current soil moisture. To precisely estimate irrigation water consumption (direct water loss from the surface water pool excluding return flow), the deep drainage of the three crop soil columns is turned off in the IR simulation."
The irrigation demand is checked every half an hour. If water stress excesses predefined threshold, irrigation will be triggered. Due to lack of information about irrigation techniques for specific crops, only surface irrigation is applied. If irrigated rate is larger than the infiltration rate, surface runoff will occur, which however is almost forbidden by constraining the irrigation rate. To give a precisely estimation of irrigation consumption, the deep drainage of crop soil columns is turned off. Therefore, the irrigated water can only be used for evapotranspiration. Note that soil water in natural vegetation soil columns still can be lost by deep drainage, which forms the slow reservoir (shallow ground water) that can be withdrawn for irrigation as well. The fossil ground water pumping is not

taken into account in our model. Firstly, the interactive mechanisms between shallow and fossil ground water is now well known (Scanlon et al., 2018). Secondly, there is rare data about the accessibility of deep fossil ground water. Nevertheless, in our previous study (Yin et al., 2020), by using ORCHIDEE-estimated irrigation water withdrawal and a proportion of surface water withdrawal versus ground water withdrawal derived from census data, we successfully explained the trend of total water storage in the YRB (simulated trend is -5.4 $\mathrm{mm.yr^{-1}}$; GRACE based trend is -5.36 $\mathrm{mm.yr^{-1}}$).

10 **"Page 10, line 5: I don't understand why $\mathrm{ET_{NI}}$ and $\mathrm{ET_{IR}}$ had no significant differences as I can see the discharge had significant decreases at some gauges (Figure 3). I assume the reduced Q is due to the irrigation water withdrawal, and then become additional ET through the irrigation, or it's not the case here?"**
A: Here we compared the magnitudes of simulated ET and observed (or satellite-based) ET, the differences between which is not significant (differences are smaller than the variation of observed ET among different products). In fact, simulated ET coincides well with the observations (Table S1). True. The $\mathrm{ET_{IR}}$ is always higher than $\mathrm{ET_{NI}}$ due to the irrigation withdrawal, which also results in $Q_{\mathrm{IR}} < Q_{\mathrm{NI}}$.

11 **"Page 10, line 9: In this equation, A_i is the total drainage area between two gauges. Will it make more sense to use irrigated area instead of total area? This way you can compare the relative level of irrigation for different sub-regions?"**
A: Thanks for your suggestion. The equation here corresponds to the Equation 8. Here we provided sub-section-based water balance diagnosis. Although it is a good idea to show irrigation intensity (by changing A_i to irrigated area), we should consider the water balances in sub-sections, where precipitation and evapotranspiration – that are not only occur on irrigated area – are taken into account as well. The spatial distribution of irrigation intensity has been illustrated in our previous study (Yin et al., 2020).

12 **"Page 11, line 16: There are many negative spikes in $\hat{Q}_{\mathrm{IR}}$ time series in Figure 5. This is unacceptable. I don't think your model is doing the right thing."**
A: Many thanks for your comment which allows us to find and correct an issue in our dam modelling. Indeed, the water recharge of reservoirs was not constrained by inflows and that explains the negative spikes in $\hat{Q}_{\mathrm{IR}}$ time series. In the revision, we corrected corresponding equations (Eq. 6) and re-performed the simulations and results.

13 **"Figure7: Given it's a regional study, I'm expecting better results than this, especially when you mentioned some previous study reached NSE around 0.9 for natural flow in the very same basin. Theoretically speaking, the inclusion of irrigation and dam regulation would improve the performance, not the opposite. I think more discussion about this issue is required. Also, how confident are you about the numbers in the conclusion?"**
A: The inclusion of irrigation and dam regulation would dramatically reduce the RMSE,

which has been shown in our result (MSE=RMSE^2, Fig. 7a). However, it probably will not lead to a higher NSE of regulated discharge than NSE of naturalized discharge. Here is a simple proof.

Assuming that N_i is the time series of natural discharge and ΔW_i is water storage change of a reservoir. Thus, the regulated discharge R_i can be calculated as:

$$\begin{aligned} R_i &= N_i - \Delta W_i, \\ r_i &= n_i - \Delta w_i. \end{aligned} \tag{1}$$

Where i is month index. Capital letters indicate observed variables; while lower case letters indicate simulated variables. Then the NSE of regulated discharge (NSE_1) can be calculated as:

$$\begin{aligned} \text{NSE}_1 &= 1 - \frac{\sum_{i=1}^{M} (R_i - r_i)^2}{\sum_{i=1}^{M} \left(R_i - \bar{R}\right)^2} \\ &= 1 - \frac{\sum_{i=1}^{M} \left[(N_i - \Delta W_i) - (n_i - \Delta w_i)\right]^2}{\sum_{i=1}^{M} \left(R_i - \bar{R}\right)^2}, \end{aligned} \tag{2}$$

where M is the length of the time series. Let's assume that the model can give a perfect simulation of water storage change of reservoir. Thus $\Delta w_i = \Delta W_i$ and NSE_1 is,

$$\text{NSE}_1 = 1 - \frac{\sum_{i=1}^{M} (N_i - n_i)^2}{\sum_{i=1}^{M} \left(R_i - \bar{R}\right)^2}. \tag{3}$$

Note that the NSE of natural discharge (NSE_2) is,

$$\text{NSE}_2 = 1 - \frac{\sum_{i=1}^{M} (N_i - n_i)^2}{\sum_{i=1}^{M} \left(N_i - \bar{N}\right)^2}. \tag{4}$$

The difference between NSE_1 and NSE_2 is the variation of regulated and natural discharge. As assuming that dam operations always reduce the variation of discharge, the variation of N_i is smaller than R_i. Consequently, NSE_2 is always less than NSE_1. In summary, if reservoirs reduce the variation of river discharge, a model even with **a perfect dam module** will always provide a smaller NSE (with regulated discharge as reference) than that of the model without functions of dam operations (with natural discharge as reference)! The conclusion is that it is not comparable of model (study) performances with different references and that it is not adequate to evaluate dam parameterizations. This proof has been added in the online supplement. And in Sect. 4 we discussed: "These NSE decreases were interpreted due to the complexity of the YRB under the impacts of human activities and climate variation. However, the NSE of natural discharges is incomparable to the NSE of regulated discharges. Even if the model can perfectly simulate the reservoir operations, the NSE of natural discharges is certainly larger than that of regulated discharges from the same model, if you accept the assumption that reservoir operations reduce the variation of river streamflows (a simple proof is available in Sect. A in the online supplement)."

14 **"Figure 7: NSE is good for evaluating high frequency flow data but might not be a good metric for monthly time series, as it is more sensitive to the peak values (Krause et al. 2005). Maybe that's why your NSE is so bad. I would suggest removing this metric."**
A: True. NSE is more sensitive to peak flows than base flows. It is ideal for short-term flood prediction. However, for studies concentrating the resilience of human society to water resources variation, how much base discharge that reservoirs are able to guarantee will be more interesting, in the case of which NSE probably is not suitable. Moreover, we recognize that it is unfair to compare NSEs of natural discharge to that of regulated discharge (see our reply to Comment 13). In short, we agree with your suggestion and removed the NSE in the revised manuscript. The evaluation is now performed using the complementary criteria: KEG, MSE and index of agreement.

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