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Reply on RC1

Amanda Triplett and Laura E. Condon

Author comment on "Climate-warming-driven changes in the cryosphere and their impact on groundwater–surface-water interactions in the Heihe River basin" by Amanda Triplett and Laura E. Condon, Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2022-160-AC1, 2022

Thank you for taking the time to provide us with meaningful feedback about our manuscript. We have provided detailed responses to each of your concerns below. We hope that the explanations and suggested revisions to address concerns are satisfactory.

1. About the PF-CLM model simulation. Because the interaction between the surface and subsurface flow is important, the flow in the river channel in the study region need to be accurately simulated. So, what method is used for the river routing in the study region?

ParFlow is a fully integrated ground and surface water model, it links surface and subsurface flow with an overland flow boundary condition. When ponded water occurs on the surface, ParFlow uses the kinematic wave approximation to solve for overland flow. With this approach there is no need to determine a priori if a cell is a river cell or not, or to have a separate river routing model. In ParFlow, streams can form and disappear over the course of the simulation as areas become ponded or dry out. A full description of this coupled approach is available in a publication by Kollet and Maxwell from 2006, “Integrated surface-groundwater flow modeling: a free-surface overland flow boundary condition in a parallel groundwater flow model.” This is referenced and described in Section 2.2 Hydrologic Modeling Approach on Line 118. We will move the reference from Line 118 to Line 117 to make it clear that a reader should look here specifically for details on the overland flow formulation. In addition, we will expand our methods summary in Section 2.2 to more directly explain the way that streams are simulated per this comment.

2. The pumping of groundwater for irrigation may have significant impact on groundwater simulation in the study region. How is this considered in the model simulation.

Pumping groundwater assuredly has an impact on both ground and surface water in the Heihe River Basin. However, we chose to model a natural flow state in order to isolate the impacts of a warmer climate on streamflow and groundwater storage. Our goal is to quantify how much warming could change the overall water supply of the basin (i.e. the water that managers would have available to them). If we had included management operations simultaneously, they could overwhelm the signal we are trying to see. We agree that that groundwater pumping is important to the region though and needs to be treated carefully. In Section 3.1 we discuss the impacts of modeling a natural flow state and comparing to streamflow and water table depth measurements which have been subject to operations. We also note that future work could build on our current findings to consider how operations might respond (Lines 600-602). In response to this comment, and comment five, we will add a paragraph to Section 2.2 Hydrologic Modeling Approach which more clearly explains the decision to model a natural flow state and the possible impacts of that decision.

3. For the glacier scenario, a 15% percent of flow is considered as the contribution of glacier melt. Is this fraction provided by previous observations or other studies?

We reference several studies which use a variety of methods to estimate glacial contribution to streamflow on lines 244-246. A brief explanation of why 15% was selected is on lines 246-248. To expand, we decided to reduce the glacial fraction by the largest amount we considered possible, higher than the largest literature estimates for the Heihe River of around 10% (Chen, 2014; He et al., 2008; Yang, 1991) for three reasons. First, estimates in the literature of glacial contribution to streamflow are based on historic melt rates and cryosphere interactions and, as such, cannot account for unforeseen nonlinearity under future climate change. Second, it is challenging to gather fine resolution data in mountainous environments such as the Qilian mountains, adding uncertainty to assessment of the glacial fraction. Finally, many studies are for the mainstem of the Heihe River, and while it is the largest contributor of water to the downstream basin, other tributaries do contribute to the total basin water balance and may have smaller or larger fractions of glacial contribution, such as 32% as predicted by Li et al., 2014.
We preferred to err on the side of overestimating the overall glacial fraction so that our findings can be used as an outer bound of what might be expected. Again, because the goal of the study was to look at possible directions and rough magnitudes of trends driven by a warming cryosphere (as opposed to giving exact predictions of what the basin will look like in 2050 for example), we decided that using an upper bound for this value would give the most information while maintaining a low total number of runs. In response to this comment, we will add an additional paragraph explaining this choice in more detail.

4. The groundwater storage increases in all the scenarios, this may be related to the precipitation changes. So, the results of all the scenarios are also related to the precipitation. Then the conclusions are also need to be revised and analyze the precipitation conditions is need. I suggest to add some scenarios, such as a scenario without the increase in precipitation.

It is likely that precipitation changes as a result of climate change are occurring in the basin and some studies do indicate there is an increasing precipitation trend in the region (Shi et al., 2006; Zhang et al., 2016, lines 47-48). However, we decided explicitly to exclude modeling precipitation changes because of greater uncertainty and variability in future precipitation trends, especially in high mountain regions as stated in lines 48-49. Additionally, by adding more processes to track, it becomes more difficult to isolate the impact of a few changes, namely cryosphere melt and temperature, which this study was focused on.
We would also like to note that our results are not strongly impacted by this trend because all the scenarios were subject to the same precipitation forcing data. All of our major results are also taken with reference to the Baseline, eliminating the influence of precipitation on storage trends. In response to this comment, we will add to Section 3.3 Subsurface Storage to explain that increasing storage could be due to increasing precipitation trends and explain why we think that is not impactful in this study.

5. Figure 3. It seems that the model overestimated the observed flow, why?

Yes, the model overestimates flow, particularly peak flows. This is primarily to do with the fact we are modeling a natural flow state, while the observed data we must compare to is subject to operations (this is discussed on lines 283 and 284). This means that in spring and summer months, when water is diverted to reservoirs and for irrigation, our model does not capture that diversion. Additionally, groundwater pumping is not included. Excluding these processes impact how our modeled flow compares to observed. We adjusted the observed streamflow timeseries according to Zhang et al., 2015a to account for surface diversion, which improved our match. However, we should note that this adjustment doesn't account for groundwater pumping or long-term differences in water table and how they could influence peak flow trends. Our winter month baseflow, when minimal operations occur, was a good match to observations though and we determined that the model is behaving reasonably for our intended natural flow conditions. As we are modeling a natural flow state, we simply have more water than observed data and should expect our flows to be higher. The authors will review Section 3.1 Baseline Model Performance to assure that the reasoning as outlined above is clearly stated and expand on our justifications.

6. For the permafrost degradation, it may reduce the summer peaks, is this effect considered in the study?

We did not reduce peak flows to explicitly account for possible impacts by permafrost degradation. We did this for several reasons. First, we based our perturbations on previous research in the basin. Gao et al. (2018) found the impact of permafrost degradation in the upper Heihe on streamflow to be a 50% increase in baseflow, which was assessed in winter months due to minimal other contributions to streamflow (Gao et al., 2018). While there are likely reductions to peak flows in higher flow spring and summer months due to permafrost degradation, there are many more contributing sources to streamflow at that time, so it is difficult to attribute what changes are due to permafrost degradation and which are due to other processes, specifically precipitation. Any selection of a reduction of peak flows would be arbitrary on our part since we did not explicitly model these processes in the upper basin and there is no previous research to support the estimates we would need. Attributing changes in peak flows to changes in permafrost coverage would be best answered by a physically based model of the upper basin and is unfortunately outside of the scope of our middle basin model.

In addition to the uncertainty noted above, we would like to point out that due to the steep elevation gradient between the upper and middle basin there is significant groundwater recharge from the mountain front happening upstream of our model boundary. Thus, we expect that some of the changes the reviewer notes here may already be accounted for in the baseflow adjustment, which may have been greater without reduced peak flows upstream.

Finally, we would like to highlight that similar to the glacial reductions to streamflow, we are attempting to set outer boundaries to the water supply of the naturalized basin. By not reducing the upper basin peaks, we get the maximum amount of water that may be available in this permafrost scenario, while the glacier scenario provides us with the least amount of water that may be available.

We do discuss possible impacts of permafrost degradation to both peak and baseflow in the introduction (lines 58-63), but we agree this is an important consideration and will be sure to explain why we do not explicitly reduce peaks in Section 2.5 Cryosphere Melt Scenarios as per the answer to this comment.