Dear Dr. Stamm,

Thank you for the helpful comments and suggestions on our manuscript entitled "How does daily groundwater table drawdown affect the diel rhythm of hyporheic exchange?" [MS No.: hess-2020-288]. Below we provided a point-by-point reply to reviewer #3's comments. To summarize, the following major changes were made:

1. To clarify the model assumption on groundwater boundary conditions, we reworded the research objectives in Introduction section (line 69) and clarified the selection of groundwater scenarios in Method section (line 165).

2. Additional information is provided for model parameterizations.

We look forward to your further reply!

Kind regards,

Liwen Wu

c.c.: Jesus D. Gomez-Velez, Stefan Krause, Anders Wörman, Tanu Singh, Gunnar Nützmann, and Jörg Lewandowski

# Response to Comments from Reviewer #3

## General Comments

The authors have investigated an interesting aspect of hyporheic exchange that has yet to receive much attention. Although the results are compelling, I found that there is a large discrepancy between what was simulated and its conceptual interpretation. The issue with the conceptual interpretation of the model results is that the prescribed flux boundary along the bottom of the model domain does not directly represent groundwater table drawdown at some distance away from the river. My comments below should clarify this discrepancy.

> Response: The authors thank this reviewer's comments regarding the selection of groundwater boundary conditions and model parameterizations. The point-by-point reply to the comments is given below. Changes in the manuscript are indicated by ***underlined text in italic***. Line numbers in this response refer to the numbers in the track-changed manuscript. By responding to the following comments, we clarified the model assumptions and included more information on the model parameterization.

## Detailed Comments:

1. The modelling does not actually simulate the effects of daily groundwater table drawdown. The boundary condition that conceptually represents a daily fluctuation in groundwater table is a prescribed flux on the bottom boundary of a 2D model. The title should instead read: "How does dynamic losing and gaining river conditions affect the diel rhythm of hyporheic exchange?"

   There is a disconnect between the way the authors describe the groundwater table and the conditions at the river. Only in lines 428 to 433 do the authors explain this conceptually. It is possible that pumping can lower groundwater tables, thus effecting the hydrogeologic gradients and fluxes to a river. However, this depends on the hydraulic properties between the pumping well and the stream (transmissivity, storativity), as well as the distance between the pumping well and the stream (Barlow and Leake, 2012). Unless the well is directly connected and next to the river, there will be a delay between the start of pumping and its influence on hydrogeologic conditions at the river (i.e., magnitude of river gaining/losing).

How realistic is the prescribed flux boundary that represents daily groundwater withdrawals? I believe that this boundary condition is not realistic in cases where the pumping well is far away from or is not well connected to the river. Hence, I would remove from the manuscript any mention of groundwater table dynamics and simply discuss changing in river losing/gaining conditions, which is what was simulated. Alternatively, more should be stated at the beginning of the manuscript about the assumptions the authors have made about hydraulic connection between the dewatering well and river, as well as the distance between said well and river (i.e., they need to be relatively close to one another). I have referenced specific lines below with where I think these changes should be made. There are many more places in the manuscript where this wording should be changed, I have only listed a few.

> Response: The reviewer has raised concerns on how the distance between well and river affects the groundwater level fluctuations. However, this is not directly relevant in this study with the proposed model settings and research scope.
>
> The model uses groundwater fluxes with daily fluctuations to study how groundwater dynamics caused by evapotranspiration or pumping impact the hyporheic exchange and how they interfere with the effects caused by daily temperature fluctuations in a river. A superimposed groundwater flux on the lower boundary offers an efficient way to investigate these complex interactions among river stage, river temperature and groundwater table fluctuations, and their impacts on hyporheic exchange. As discussed in line 429 to 433 in the study limitation, although the superimposed groundwater flux was not a perfect representation of the real groundwater response, this simplification allowed us to investigate hyporheic exchange dynamics under complicated multifactorial interactions efficiently. The hyporheic dynamics that cannot be captured by using superimposed groundwater fluxes were listed and discussed in line 433-442.

The groundwater fluxes time series are conceptualized as sinusoidal. In other words, the groundwater fluxes were not observed but synthetic datasets. There is hence no actual well that was measured. To state this point clearer, the research objective at the end of introduction was reworded as below (line 69):

*With these objectives in mind, a series of synthetic groundwater scenarios corresponding to different timings of groundwater table drawdown under gaining and losing conditions is applied in a physically based hyporheic flow and heat transport model.*

Additionally, the reviewer suggested to change the title with only mentioning "losing and gaining river conditions". However, the groundwater scenarios used in the study not only include different groundwater flow directions (gaining or losing), but also include the timing of drawdown (in-phase or out-of-phase) and the fluctuation amplitudes (low, medium and high). Therefore, only use "losing and gaining" cannot accurately describe the groundwater scenarios explored in this study. Therefore, we have kept the original title.

Line 68 – The aim to quantify the impact of "groundwater table drawdown" on hyporheic exchange processes. Replace "groundwater table drawdown" with "the degree of gaining/losing conditions".

Response: Please refer to the response to the first comment above.

Fig 3 – "Effect of diel river temperature fluctuations and daily groundwater table drawdowns on hyporheic fluxes…". Again daily groundwater table drawdown was not simulated, but daily fluctuations in gaining/losing conditions of the river.

Response: Please refer to the response to the first detailed comment above. Additionally, simulating groundwater table drawdown is not within the research scope. The research objective is to simulate hyporheic responses to daily groundwater drawdown. Therefore, groundwater flux time series representing daily groundwater table drawdown were used directly.

Line 300 – "The timing of groundwater table drawdown also affects hyporheic exchange rates." Upward and downward fluxes representing gaining/losing conditions affects hyporheic exchange rates. There is a conceptual disconnect here.

Response: Here we particularly refer to the timing of the lowest groundwater table. "Gaining and losing" can only represents the direction of the groundwater flow but not the temporal pattern of the groundwater fluctuation.

Line 310 – "Therefore, the timing of the aquifer pumping can potentially amplify or reduce the dispersal of pollutants in the aquifer". It would be better to state that the 'timing of river gaining/losing magnitude can potentially amplify or reduce…"

Response: Here we specifically refer to the timing of the lowest groundwater fluxes in a hypothetical wastewater discharge event. "Timing of river gaining/losing magnitude" cannot accurately describe the timing of the lowest groundwater fluxes. Together with the response made above to the first detailed comment, we decided to keep the "time of aquifer pumping". Also, this paragraph is part of the results implication. Although aquifer pumping is not simulated but groundwater flux is directly used, the results have important implications on selecting pumping scheme with necessary considerations of river hydrologic conditions.

Lines 313 to 317 - Sure, but it also depends on the level of hydraulic connection between the river and the well (Barlow and Leake, 2012).

Response: As explained above the hydraulic connection is beyond the research scope.

Line 380 – Scheduling pumping activities to protect thermal heterogeneity across multiple spatial scales again depends on the well-stream connection, if any.

> Response: Yes, it depends on the well-stream connection. However, the objective is not simulating groundwater fluctuations but rather the hyporheic response to various groundwater fluctuation scenarios. With the current model setting, the well-stream connection is irrelevant.

Line 392 – "hyporheic denitrification potential can be regulated by adjusting the timing of daily groundwater table drawdown." It would be better to state the "timing of hydraulic gradients towards the river or groundwater in/out flow to the river" and not "timing of daily groundwater table drawdown". The influence of groundwater table drawdown on the state of the river depends on its hydraulic connection and distance between the well and the river. It's possible to have a delayed response in the rivers condition or no response at all if there is little to no connection or if the well is very far from the river.

> Response: Please refer to the response to the first comment above.

Line 456 – "Groundwater table dynamics" replace with "Groundwater discharge/recharge to/from rivers substantially…"

> Response: Here the groundwater table dynamics not only include the direction of the groundwater flow (gaining or losing), but also the phase and amplitude of the groundwater table fluctuations. Using "groundwater discharge/recharge to/from rivers" is not accurate.

Line 471 – "…hyporheic denitrification potential is also changing following groundwater table drawdown." Replace "groundwater table drawdown" with "groundwater discharge/recharge". For the statement made be the authors about groundwater tables, one would require a 3D model that contains areas beyond the river banks. Instead, what has been simulated is a 2D section along the river with a prescribed flux boundary representing fluctuating gaining/losing conditions. There is a conceptual gap between the prescribed boundary condition simulated in this study and groundwater table drawdowns that the authors describe. Groundwater table drawdowns could be happening at some distance away from the river with varying hydraulic properties between, which would dramatically influence the degree to which aquifer pumping would effect gaining/losing conditions at the river.

Response: As we explained in the response to comment on line 380, understanding groundwater responses to pumping activities is not our research objective. To avoid misunderstanding, we added the following text in Method section line 165:

*The objective of this study is not to understand groundwater responses to pumping activities. Even though the timing of groundwater table drawdown depends on multiple factors, i.e. hydrological connectivity between wells and aquifer, aquifer properties for plant water-use, and pumping capacity and electricity tariff for anthropocentric pumping activities, the two special cases, namely in-phase and out-of-phase groundwater conditions, can capture the representative dynamic hyporheic responses to different timing of daily groundwater withdrawal under corresponding river temperature conditions*

2. Model parameters

I am trying to gauge the realism of the model parameters but am having a hard time finding certain values. I have listed the specific line numbers for parameter values that were not stated or difficult to find. Clearly stating the parameter values would help future researchers to extend or repeat these numerical experiments.

Response: In the revised manuscript, we added the missing information. Please also find it below.

Line 91 – What were the values selected for permeability and porosity?

Response: This sentence is revised as below (line 91):

*$\theta$ is porosity 0.3[-], $\kappa$ is permeability [$L^2$] 1E-10 $m^2$.*

Line 100 – Do you have references to support this aspect ratio?

Response: References are added as below (line 101)

*In the present study, an aspect ratio (the ratio between amplitude and wavelength Δ/λ) of 0.1 and slope of 0.01 are used to describe the geomorphological setting as dunes (Dingman, 2009; Bridge, 2009).*

Line 108 – What is the hydrodynamic thermal dispersion tensor value chosen?

Response: The detailed calculation steps of thermal dispersion tensor can be found in Wu et al. (2020). The reference was added (line 109):

*$D_T$ is the hydrodynamic thermal dispersion tensor $[L^2T^{-1}]$ calculated following Wu et al. (2020).*

Line 288 – "mainly due to the change of hydraulic conductivity which is a function of diel temperature fluctuations." Again what was the permeability value chosen? How much does hydraulic conductivity vary in your simulations due to temperature? Line 341 states that there is a 220% change in K due to a 30 degree change in temperature, but I'm not sure if this is a realistic magnitude of daily temperature change or K change. Thomas (2014) shows temperature fluctuations over a year in Sauk River, Washington. There is a 18 degree C range over the year, but at the daily scale there is rarely more than a 10 degree fluctuation throughout the day. Perhaps the daily temperature range should be decreased by 3x, unless the authors have references that support a daily 30 degree temperature change in river water.

Response: A permeability value was added in the revised manuscript and in the response to the comment on line 91 above. 30-degree change is the seasonal variation. As the reviewer wrote, the daily variation is much smaller. The calculation is based on 5-year river discharge datasets. It is not a result based on daily river temperature variations.

3. Other comments

Line 28 – Chow et al. (2019) conducted a sensitivity analysis on the effects of river bathymetry (i.e., geomorphological settings) on meander-scale hyporheic exchange.

Response: We have added the reference in the revised manuscript (line 29).

Line 30 – Chow et al. (2020) evaluated sediment heterogeneity and its effects on meander-scale hyporheic exchange.

Response: We have added the reference in the revised manuscript (line 32).

Line 40 – "Large groundwater upwelling and downwelling may compress 'or extend' hyporheic…"

Response: According to our definition of hyporheic zone following Triska et al. (1989) and Gooseff (2010), and the flow reverse technique that is commonly used in simulating losing conditions (line 139), large groundwater upwelling and downwelling will always compress hyporheic zons. For strong gaining conditions, less surface water can penetrate the subsurface; for strong losing conditions, more surface water will flow downwards without returning to the surface. Therefore, less hyporheic exchange occurs under larger gaining or losing conditions.

Fig 1b and c – The hyporheic exchange should be compressed in Fig 1b and extended in Fig 1c. Instead it looks the same between Fig. 1b and c.

Response: The size of the hyporheic zone depends on the hydraulic gradient at the sediment-water interface and not only on the direction of the groundwater flow. Hyporheic zones under gaining conditions are not necessarily larger than that under losing conditions. Figure 1 is only a conceptual description and not supposed to be used to compare the hyporheic zone extension. Determining accurate size of hyporheic zone extension requires numerical modeling.

Lines 324 to 330 – I find this sentence confusing. So what plays a dominant role in the winter? Pumping? Please clarify.

> Response: The following sentence was added to better describe the effect of river temperature (line 331):
>
> *In other words, higher river temperature has larger impacts on the temporal variations of hyporheic exchange.*

Line 380 – Remove s from 'cares'

> Response: Done as suggested (line 381).

Line 387-389 – Wouldn't losing conditions have longer residence times since the flow paths would be extended and stretched?

> Response: Under gaining condition, there is mixing between surface water and groundwater which has significantly longer residence time than surface water. Therefore, the overall residence time under gaining condition is generally longer than under losing condition where there is no groundwater mixing.

Line 467 to 468 "The timing of aquifer pumping should be adjusted to avoid…". Can you be more specific here. I.e., "The pumping should decrease or stop during flood events in order to ensure minimal contaminant uptake".

> Response: This sentence was reworded as below (line 467):
>
> *Pumping activities should be avoided during flood events in order to ensure minimal contaminant uptake.*

Lastly, a general comment about the two scenarios of in-phase and out-of-phase compared throughout the manuscript. It would be nice to get from the authors their ideas on how likely these two scenarios are and what kinds of assumptions must be met in order for them to be realistic. I can imagine that in-phase is a more likely scenario because ET tends to increase as temperatures increase during the day. Also, in cases where there is hydraulic connection and a short distance between the well and river, I would expect that groundwater usage would increase following daytime activity. Out-of-phase may be less likely, but this could depend on the well-stream connection.

> Response: Groundwater uptake by vegetations is higher with higher air/river temperature during the day. Additionally, because of the large storage capacity of the modern reservoir, pumping activities can be scheduled independent of the human need. Therefore, pumping can happen at any time during the day including the timing of the two special scenarios explored in this study.

## References

Barlow, P.M. and Leake, S.A., 2012. Streamflow depletion by wells: understanding and managing the effects of groundwater pumping on streamflow (p. 84). Reston, VA: US Geological Survey.

Bridge, J. S.: Rivers and floodplains: forms, processes, and sedimentary record, John Wiley & Sons, 2009.

Chow, R., Bennett, J., Dugge, J., Wöhling, T. and Nowak, W., 2020. Evaluating subsurface parameterization to simulate hyporheic exchange: The Steinlach River Test Site. Groundwater, 58(1), pp.93-109.

Chow, R., Wu, H., Bennett, J.P., Dugge, J., Wöhling, T. and Nowak, W., 2019. Sensitivity of simulated hyporheic exchange to river bathymetry: The Steinlach River test site. Groundwater, 57(3), pp.378- 391.

Dingman, S. L.: Fluvial Hydraulics, Oxford University Press, USA, Oxford ; New York, 2009.

Thomas, L., 2014. Stream Temperature Variability: Why It Matters to Salmon. Science Findings, United States Department of Agriculture Forest Service. https://www.fs.fed.us/pnw/sciencef/scifi163.pdf

Wu, L., Gomez-Velez, J. D., Krause, S., Singh, T., Wörman, A., and Lewandowski, J.: Impact of flow alteration and temperature variability on hyporheic exchange, Water Resources Research, 2020.