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Discussions

Interactive comment on "How does daily groundwater table drawdown affect the diel rhythm of hyporheic exchange?" *by* Liwen Wu et al.

Anonymous Referee #2

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The authors present an extensive modelling study on the interplay between diurnal temperature effects and groundwater gradients on the dynamic evolution of the hyporheic zone in a river with a defined bedform topography. The hyporheic zone is a highly relevant transition zone controlling biogeochemical processes such as denitrification in streams (e.g., Gomez et al. (2015)). Therefore, the topic of the manuscript fits well with the scope of HESS.

The processes affecting the exchange between river water, the hyporheic zone and groundwater are highly non-linear and can lead to seemingly counter-intuitive effects. The authors build on previous work (e.g., Wu et al., (2020, 2018)) and a model to investigate the questions specific to this manuscript. In particular, they study how daily temperature fluctuations in a stream impact the hyporheic exchange and how it interfers

with effects caused by dial fluctuations of groundwater fluxes caused by evapotranspiration or pumping.

The authors provide a broad range of data and results on the hyporheic water fluxes, temperature gradients and potential impacts on biochemical process rates such as denitrification.

The manuscript is interesting. But before it can be published I suggest major revisions for clarifying open issues and for improving the structure to enhance readability.

Major issues:

Improve readability The structure of the text is not always very reader-friendly. This means that it is not always easy to immediately understand and follow the logic of the arguments and results. This observation holds true for single paragraphs as well as for entire sections (e.g., the Result section). Often the starting point of an argument is not what is directly evident to the non-specialists but the necessary explanations follow only afterwards.

The text on L. 55 - 58 may serve as an illustrative example: The starting point is that there are diel fluctuations of hyporheic exchange and that they may interact with diurnal changes of groundwater fluxes. However, for the non-specialist regarding the hyporheic zone, the diel fluctions may not be evident. Hence, upon reading one stops and reflects why this should be the case. In the current manuscript, the explanation comes only afterwards. I suggest a different structure:

1. Daily temperature fluctuations in stream (every reader will know and agree)
2. This affects viscosity and hence hydraulic conductivity (the readers will follow)

3. This induces diurnal changes in hyporheic exchange as demonstrated in Wu et al. (2020) (the reader will believe this)
4. There are also diel fluctuations in groundwater fluxes for several reasons (readers will know and agree)
5. Therefore, there are two dynamic processes affecting the hyporheic zone and they may potentially interact in rather non-linear ways.

This is just an example but I suggest to pay due attention to this aspect because the authors claim (with good reasons) that hyporheic processes have wider implications. This means their paper should also be read by a wider audience in the hydrology and water resources management community. Accordingly, they should write the paper for such an audience and consider what to expect from such readers as starting points for presenting the arguments and results.

Model description There are several aspects of the model and its set-up that are not fully satisfactory:

1. *Model dimensions*. Given that the authors have used a 2-D model (L. 81), the model domain has to have dimensions along the x- and z-axes. Please provide this information (e.g., in terms of λ). Please demonstrate as well that this model set-up is a meaningful representation for the case study that represents a given real situation.
2. *Fig. 2*. At that point, the panels *b* and *c* are rather confusing. Panel *a* is very generic, but on the lower panels real dates are given and it is not clear to the reader what these values on the x-axes mean and why the are chosen. It is also obscure what the temperature represents. It takes a lot of reading until one can make the link to the case study and the respective observations.
3. *Mass balance*. From Fig. 2 (a), it follows that the water balance for the model domain is given by $Q_{river-out}(t) = Q_{river-in}(t) + q_b(t)$. Based on

how the boundary conditions are defined however, the water flow in the river is independent on the groundwater fluxes imposed (the flow simply follows from the prescribed $H_s(t)$ (Eq. 2, 3). Also the head distribution at the water-sediment interface is flux-independent. However, this distribution was derived from empirical observations Elliott & Brooks (1997) without considering gaining or losing situations. This seems to be adequate as long as $U_s(t)\, H_s(t) >> q_b(t)\, L_{domain}$ with L_{domain} being the length of model domain. Please i) provide the evidence that this holds true for the case study and the dimension of the model domain, and ii) make these aspect also clear in the discussion. Actually, this aspect seems to emphasis the importance of the findings: even small groundwater fluxes may have a pronounced influence on the hyporheic zone. This may be evident to the authors, but I missed that point in the context of the entire paper.
4. *Eq. 6a*. I could not find an explanation for a_0. It is tedious to go to previous publications and guess that $a_0 = 1$.
5. *Model implementation*. Please provide some information on the model implementation (grid set-up, model version, run time etc.).
6. *Defining the hyporheic zone*. It is unclear how the procedure described on L. 130 - 136 is actually implemented. First, because the hyporheic zone changes over time, the proposed procedure needs to be repeated, I assume. Can you comment on that? Second, for neutral and losing conditions, it seems that the threshold $C \geq 0.9C_s$ will eventually exceeded across the entire domain. Can you clarify?

Description of the case study This description is very superficial and has to be improved substantially.

1. *Site identification and description* Please provide more information on the site including the location and name. It is not necessary that every inter-

ested reader has to check the USGS website. Describe some key characteristics of the climate and hydrology of the catchment and the measuring site (altitude, mean discharge etc.). This is important to put the findings in a proper context.

It is also essential to know which observation period was used for the simulations. One learns only at a later stage (e.g., from Fig. 3a) that three hydrological years seem to have been used.

On L. 160, the amplitude of groundwater flux changes are linked to a range of the groundwater table fluctuations. Although a reference is provided, this is not sufficient. Boano et al. (2008) presents a general framework for linking stream-groundwater interactions and the influence on the hyporheic zone, but not any site-specific information for this case study. Describe the approach including the equations used and the model assumptions. In this context, it would be also useful to provide evidence that this assumed water table fluctuation is also reasonable for a hypothetical groundwater pumping operation.

The paragraph on L. 144 - 155 describes the *in-phase* and *out-of-phase* conditions. It might enhance the intuitive understanding for a general reader if the authors indicate more explicitly that the *out-of-phase* conditions represent the natural state with high stream temperatures and lower water table in the aquifer due to transpiration by the vegetation.

Result section: This section contains a lot of material (which is positive) but the way of presenting needs improvement. The more so because not all of the necessary results seem to be shown so far.

1. *Structure* One of the key messages of the manuscript is that there is an intricate interplay between the temperature regime, the flow regime of the stream and the water table fluctuations in the aquifer that needs to be un-

derstood. To be able to understand this, one has to get an overview about the general conditions prevaling at the study site during the period of interest. Therefore, I suggest to start with a short description of the key features of the three hydrological years.

   Subsequently, it helps the reader if the complexity is increased in a stepwise fashion. Therefore, I would first describe the results for the neutral conditions, then the losing conditions and finally the gaining conditions. Furthermore, I suggest to use explanations such as on L. 277 - 279 to frame the result section in a way that is intuitive also to the non-specialist reader.

2. *Nomenclature* One of the confusing things is the terminology used for describing the hyporheic fluxes. Nowhere it is explained what actually meant by the infiltrating and exfiltrating hyporheic fluxes. For the neutral case, the two fluxes are identical, which makes sense. Under gaining conditions, the infiltrating flux is consistently larger than the exfiltrating flux. How is this explained and why is the same true for the losing conditions when there is a net flux from the river to the aquifer? Please clearly define the terms and explain the apparent contradictions mentioned.

3. *Residence times* The method sections describe how to estimate time-variable residence times in the hyporheic zone. Despite of using an average value for calculating the reaction significance factor RSF, no data on residence times are provided. This is essential if one would like to be able to evaluate the relevance of the results for any biological or bio(geo)chemical processes. Provide the results on the time-variant residence times and how they change upon the different boundary conditions.

4. *RSF* First of all, this approach has not been introduced so far. It should be mentioned in the Introduction when introducing the denitrification topic and described in the method section. Apart from that I am not sure whether the chosen form is an adequate implementation of the concept. I have three

question marks:

(a) The first relates to q_{HZ} because I could not follow what this term actually represents (see above: how does it relate to infiltrating and exfiltrating fluxes?).
(b) Why is the mean residence time used for calculating a time-variant quantity such as RSF when residence times were derived as a function of time? Depending on the temporal correlation functions between the relevant hyporheic flux q_{HZ} and the residence times τ_{HZ}, there might be substantial deviations from the current version.
(c) The time scales of denitrification. First, the description of how τ_{HZ} was parameterised is insufficient. Which quantiles in Gomez et al. (2015) do you refer to? Second, denitrification depends very much on temperature (e.g., Boulêtreau et al. (2012)). This implies that τ_{dn} is not constant. Given that the manuscript deals with temperature as a key influencing factor, it would seem logic to consider such a temperature dependence also for τ_{dn}. At least one could test the sensitivity of RSF against the temperature dependence of denitrification.

5. *Plausibility check against empirical data* One of the values of such a model study is the possibility to study processes and their interactions under well defined conditions and to explore system behaviours that are otherwise impossible to obtain. This comes at the costs of the difficulty to relate the model findings and insights back to the real world. To improve on that the authors should provide more context on the case study (see above). On the other hand, they should also add some comparisons of model results with empirical observations to provide some plausibility checks. Possibilities for doing so would for example be the extent of the hyporheic zone, residence times (both not even shown for the model results, see above) or RSF values as depicted in Fig. 8. Such values could for example be compared to estimates provided by Gomez et al. (2015).

Detailed comments:

L. 18 - 19: Why is this understanding *key to water resources management*? There are many aspects relevant for water management (land use management, hydropower generation schemes etc.). Please be more specific for aspects this understanding is key and why.

L. 23, 26 and elsewhere: Articles or pronouns are missing sometimes. Please have a linguistic check.s

Fig. 4: Explain the time axes and give a reason why only that part of the entire study period is displayed? It seems to be rather arbitrary. Are the results from the *in-phase* or *out-of-phase* simulations?

Fig. 6: Unfortunately, one can hardly see the differences between *a* and *b* or *c* and *d*, respectively. One option could be to show the respective difference plots and to add difference plots for the fluxes.

Fig. 8: Add the year to the time axes and explain why this specific period was selected.

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