Reply on RC2

Tom Müller et al.

Author comment on "Towards a hydrogeomorphological understanding of proglacial catchments: an assessment of groundwater storage and release in an Alpine catchment" by Tom Müller et al., Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2022-110-AC2, 2022

Comment on hess-2022-110 - Anonymous Referee #2

General comments

Comment 1:

The manuscript presents two interrelated but separate pieces of work in one large package: (1) literature review of proglacial landforms and (2) case study of storage assessments in an Alpine catchment. As such, the manuscript has an unusually large volume, approximately double the size of standard journal papers. The literature review is informative, but it does not offer much new insights. Therefore, I suggest that Section 1 (Introduction) be reduced to 10-15% of the current volume.

Answer 1:

We thank the referee for his/her careful review of our paper and his/her detailed and constructive comments. We admit that the review part is rather long but our intention was to bridge the gap between existing hydrological and geomorphological reviews. The hydrological part certainly overlaps strongly with the work of Hayashi (see also Reviewer comment 1). We believe the review is useful to provide a comprehensive overview of proglacial geomorphological and hydrological processes for non-expert readers, but may be too long for others. We agree that the review can be more strongly synthesized (i.e. largely reduced in length), by removing the subsection and keeping only key information about the proglacial landforms and their hydrological dynamics. Some part of the review was also repeated in the discussion, which we will improve. We will provide a much shorter introduction in the revised document.

- *Suggested changes: shorten introduction, remove/move repetitions from/to discussion*

Comment 2:

That will still leave a much larger volume of texts compared to standard research papers, meaning that the rest of the manuscript will have to be condensed substantially to make it more concise and useful to the intended readership.

Answer 2:

After a careful assessment of both reviewers' comments, we agree that some parts of the documents are not well organized, some parts need to be rearranged in the right section and some text can be reduced to be more concise.

- *Suggested changes: We will reduce the introduction, reorganize the methods and be more concise in the result section. From the current manuscript containing 13043 words, we will reduce it to about 8000-9000.*

Comment 3:

The case-study part of the manuscript presents unique and interesting information, which will be of great interest to the reader of this journal.

Answer 3:

We thank the referee for this appreciation. Although the paper is long, we believe that the core messages contained in the case-study will remain unchanged in the new version of the manuscript and will be useful to readers of the journal.

Comment 4:

However, it has some fundamental issues that need to be addressed before the manuscript can be considered for publication. Overall, the case study needs to re-examine some of the assumptions that are central to the results. I will elaborate more in my specific comments below. Particularly important issues are indicated in my comments on Line 420, 660, 696, 698, and 718

Answer 4:

We thank the referee for his/her helpful specific comments. Generally, we think that parts of the results were not entirely clear, especially regarding the modelling parts. We also realized that we introduced some confusion by refereeing to "proglacial" landforms, while we were actually refereeing to the entire glaciated catchment.

- *Suggested changes: carefully check all instances of "proglacial landforms" and replace with more specific terminology*

We will discuss the main issues in the next part of the answer, but as a general comment on our approach, we copy here our comment #10 of this answer (see below):

"While our approach is clearly simple, we believe that it is valid to represent the individual storage-release response of specific superficial landforms, and especially to compare their relative significance in terms of response time scales and overall volumes. In addition, the estimated volumes and timescales agree well with other more specific studies as presented in the discussion. Our goal here is to provide the reader with a simple approach, easily reproducible at other locations, to acquire a general understanding of the key processes of glaciated catchments, which can then be used to develop more complex models or approaches with a better representation of the groundwater processes."

Comment 5:

I would recommend that the manuscript be rejected at this time, and the authors be encouraged to submit a completely new manuscript written concisely and clearly, presenting reanalysis of the data addressing the fundamental issues.

Answer 5:

Although the manuscript needs to be rearranged, we believe that it mostly suffers from lack of clarity and conciseness, which can be greatly improved with the help of the referee's comments but will not lead to a complete reshaping of the manuscript. We believe that the results and main outcomes will still convey the same message so that we would prefer to promptly submit a new manuscript under major revision.

Specific comments

We thank again the referee for the detailed comments. We discuss below all the points that require an answer. The points that simply require implementation (e.g. language issues, figure captions, etc.) will be all addressed in the revised version and formal rebuttal.

Below, we also regrouped comments that belong to the same topic.

Comment 6:   Comments on ERT

Line 312. Please present more detailed information on the ERT methodology, for example, electrode spacing, configuration, and data inversion methods.

Line 402-406. Please present this information in the section of field methods (see my comment on Line 312). In general, the manuscript suffers from a lack of organization, meaning that methods are not presented in where the reader expects them to be.

Answer 6:

We agree that the ERT methodology was not well organized and described. The description of the data was published on Zenodo (https://doi.org/10.5281/zenodo.6342766) but this was not clearly indicated in the document (only in the Data availability section). We will bring the description of the ERT methodology together and provide the main useful information to the reader.

In a nutshell, lines had between 2 to 5 m spacing with 48 electrodes, we used both Dipole-Dipole and Wenner-Schlumberger methods and data inversion was performed using a robust inversion scheme from the Open-Source pyGIMLi python library with a set of regularization parameters to test the results sensitivity.

- *Suggested changes: Rearrange ERT data in one section. Provide detailed useful description of the setup and methodology. Properly refer to Zenodo.*

Comment 7:   Comments on ERT

Line 313. How was the presence of buried ice blocks identified?

Line 396. How was B determined based on ERT results? Considering the quality of ERT data and spatial heterogeneity, the determination may not be straight forward. Please explain this more carefully.

Answer 7:

The presence of ice is clearly visible as very high resistive area. However, this is not really the topic of this work and we will consider to remove this sentence.

Likewise, the depth of the bedrock is relatively clearly visible with a sharp change in

resistivity. This was described in the Zenodo repository but we will provide more detailed information on that topic in the result section.

- *Suggested changes: Add information and inversion results on bedrock depth in Result section.*

Comment 8:   Comments on classification method

Line 420 and Figure 2. I do not think that the classification approach solely based on slopes adequately captures the spatial extents and distribution of the landforms for the purpose of this study. For example, a quick examination of satellite images on Google Earth indicates that much of '22-42 deg (talus slopes)' on the north side of the instrumented area are likely bedrock slopes covered by a thin layer of soil and vegetation. They are clearly not talus slopes and hence, will have completely different hydrological storage functions. This applies to other landforms as well, putting the entire exercise of data analysis on a shaky foundation. I strongly recommend that the authors use an approach combining digital elevation models and satellite images to come up with more appropriate landform classification, and reanalyse the data set.

Answer 8:

Thanks for pointing this out. The classification used for the analysis was purposely chosen to be simple, in order to present a method that is easily reproducible by others.Our approach aims to provide general trends using a simplified representation of the different landforms, in order to estimate the time-scales of the hydrological response. We agree that some parts of the catchment could be better classified and will attempt to use a somewhat more complex method to classify the landforms, but still keeping it easily reproducible elsewhere.

- *Suggested changes: Improved classification method*

Comment 9:   Comments on mass-balance model

Line 437. 'Fitted by matching the snowline limit'. How was it done? Please explain the methodology. It may not be a straightforward task in a mountain environment with frequent cloud covers obscuring satellite images.

Line 438. If the elevation of the weather station is lower than the average elevation of the catchment, the data may substantially underestimate winter precipitation. How was this issue addressed? Please explain.

Answer 9:

The snowline mapping was performed automatically using a k-means algorithm from daily 2m resolution Planet images. Only the days with <5% cloud cover were used and manually verified, leaving usually at least 1 to 2 clear image per week.

Indeed, the weather station is located at about 2500m asl, while the catchment has a mean elevation of about 3000m. The snow mass-balance model was calibrated for temperature and precipitation lapse rate by matching observed SWE measured during peak snow accumulation in spring. We will review this part to make it clearer.

Finally, we want to stress again that the precision of the analysis was not the key focus, we wanted to produce a realistic rain/snowmelt for our simplified model. Since we do not aim to simulate the measured discharge of a specific year, but rather show the general seasonal trends, we do not need a particularly well calibrated hydrological model.

- *Suggested changes: Add a clearer and concise description of the mass-balance methodology.*

Comment 10:   Comments on simple model

Line 447. Simple model. I feel that the model may be too simple for the purpose of determining aquifer storages with sufficient rigor. Please improve the presentation of scientific rigor in various parts of Section 3.

Answer 10:

We agree that our model uses a rather simple approach. Again, this is also on purpose in order to be easily reproducible in other catchments, without the need to set up a complex hydrological model. We agree that the method and result sections can be improved. In particular, we introduced some confusion using the term "proglacial" while we were sometimes refereeing to the whole glaciated catchment.

While our approach is clearly simple, we believe that it is valid to represent the individual storage-release response of specific superficial landforms, and especially to compare their relative significance in terms of response time scales and overall volumes. In addition, the estimated volumes and timescales agree well with other more specific studies as presented in the discussion. Our goal here is to provide the reader with a simple approach, easily reproducible at other locations, to acquire a general understanding of the key processes of glaciated catchments, which can then be used to develop more complex models or approaches with a better representation of the groundwater processes.

- *Suggested changes: We will better present the methodology, clearly highlight the limitation, improve the landform classification and improve the clarity of this section.*

Comment 11:

Line 506. This is an unusually large value for rain (EC for rain is 31.6 µS/cm). Please examine the possibility of contamination by sampling devices or sample handling. Rain sample values are expected to be similar to snow sample values.

Answer 11:

Thanks for this point, which might indeed puzzle some readers. We can exclude contamination since the samples were cleaned with DI water. From the literature, we do not think this is a particularly high value. From a the composition of major ions in rain, it seems that rain contained more Calcium and Sulphate than snow. We can only make the hypothesis that snow underwent some biological processes leading to a loss of ions or a different precipitation composition in winter.

- *Suggested changes: mention explicitly that the EC value of rain is compatible with published data and mention why EC of snow could be different*

Comment 12:   Comments on hydraulic gradient

Line 539. This statement ("the river stage is always 10 to 40 cm higher than the groundwater level close to the river") contradicts with the caption of Figure 8, which states that the lateral gradients are directed towards the main river. Which is the correct observation?

Line 545. Water contribution from the hillslopes. This is a losing stream. How is it possible for it to be gaining groundwater from hillslopes? Please clarify.

Answer 12:

This will be better explained in the revised documents and detailed in the discussion section as follows:

The main longitudinal gradient is sustained by stream water infiltration into the groundwater. This is supported by the clear delayed response between stream discharge (i.e. stream level) and the slope of the hydraulic gradient. Moreover measurements show that the stream stage is 10 to 40 cm higher than groundwater, meaning that groundwater drains faster downslope than the rate of water infiltration through the streambed, where hydraulic conductivity may be limited by streambed colmation. Higher infiltration occurs when river stage is higher, which in turn increases the longitudinal gradient. There is therefore an equilibrium state between the rate of stream infiltration and the capacity of the aquifer to move the water downstream.

In addition to this process, surface and subsurface runoffs from the hillslopes locally infiltrate into the outwash plain, leading to a small increase of the lateral gradient from the hillslopes towards the stream network, but which does not increase the groundwater level close to the river channel so that the stream remains a losing stream.

- *Suggested changes: improve clarity of the text*

Comment 13:   Comments on storage volumes

Line 660. These landforms cover the entire catchment, not just the proglacial zone. Given that glacier outflow is sustained during winter months (Figure 8), the storage capacity of these landforms in the entire catchment during winter months needs to be evaluated. I see this as a fundamental issue in this study.

Answer 13:

There is here a confusion with the term "proglacial zone" which we sometimes used while refereeing to entire glaciated catchment (that is also above/around the glacier). The storage capacity estimated in the result section (figure 9) are already provided at the entire catchment scale by dividing the total storage volume by the surface of the entire catchment and not just the proglacial zone. This confusion will need to be corrected in the future version.

Comment 14:   Comments on storage volumes

Line 696-697. Can you quantify the total storage provided by these landforms in the entire catchment (see my comment on Line 660)? How does it compare to the total amount (mm) of winter flow measured at GS3? This information will provide an important 'reality check' for the perceptual model.

Line 718-719. Please consider the areal extent of the landforms in the catchment-scale storage calculation (please see my comment on Line 660).

Answer 14:

This is linked to the previous comment (#13). We already assess the total storage in the entire catchment and not just the proglacial zone. We are actually already doing exactly what the referee is suggesting; it was just not clearly detailed. We will also compare with the discharge at GS3 during winter (which is in the order of 0.5 to 0.2 mm/day).

- *Suggested changes: Make a clear distinction between proglacial and catchment-scale*

analysis. Better compare estimated storage volumes with baseflow discharge.

Comment 15: Comments on recession analysis

Line 698. This value (40 mm) is solely based on mathematical reservoir models, which in turn are based on several assumptions, which may or may not have the physical basis validated by field data. While this approach is useful, its limitation needs to be clearly acknowledged.

Answer 15:

We completely agree that the limitation of such approach can be further discussed and compared with discharge data for instance.

Comment 16: Comments on storage volumes

Line 732. Having seen the results from an objective set of eyes, I do not believe that they 'indicate clearly' that winter baseflow is governed by non-superficial reservoirs. Please re-evaluate the assumptions and calculation methods, and re-examine this statement.

Answer 16:

Based on our previous comments, we think that there was a confusion between the proglacial-scale and the catchment-scale. While we were referring to "proglacial" storage, this was actually estimated at the catchment-scale. It is clear that if we only had estimated storage in the proglacial zone, we could not provide the statement that baseflow in not sustain by superficial reservoirs. But the numbers we have estimated are actually provided at the catchment scale which provide stronger evidence.

- *Suggested changes : We will make an effort to clear any possible confusion in the new manuscript.*

Comment 17:

Figurer 11. This is a confusing diagram. Fluxes (snowmelt, rain, etc.) are mixed up with storage volumes. Please use a different scheme to represent the perceptual model.

Answer 17:

We will provide an improved perceptual model version by better distinguishing between fluxes and storage in the new version.