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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Towards a tracer-based conceptualization of meltwater dynamics and streamflow response in a glacierized catchment" *by* Daniele Penna et al.

Anonymous Referee #2

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General comments:

The manuscript of Penna et al. presents an extensive data set of EC and d2H from a glacierized catchment over a three-year period, which was used to study the spatial variability of the streamflow components and to develop a conceptual model of streamflow generation. The authors apply well established methods to identify the points in time and the locations in the catchments that control the contributions of snowmelt, glacier melt and groundwater to streamflow. Based on grab samples collected between May and October 2013 along the main river channel, the relative contributions of snowmelt and glacier melt to streamflow were calculated. An uncertainty analysis was carried out by establishing four different scenarios that reflect the spatial variability

of the different end-members.

I find the study very interesting as it considers the temporal and spatial variability of melt input into a high-altitude stream. It further presents a straight-forward approach to investigate such catchments by using environmental tracers. Although I am not a specialist in glacial catchment hydrology I am convinced that this study will be valuable for researchers working at high-altitude systems. However, I would like to point out some issues that could help to improve the quality of the manuscript.

The study is based on two earlier papers that presented the data set and identified the different tracer signatures in snowmelt and glacier melt (Penna et al., 2014), as well as performed mixing analysis on seven snowmelt-induced runoff events that were sampled at hourly frequency in 2013 (Engel et al., 2016). The aim of the current study was to investigate the spatial variability of the streamflow components and to develop a conceptual model of streamflow generation. Although this intention was expressed in the introduction of the manuscript, in the Results and Discussion sections it is often not clear what the new findings of the current manuscript are and what results are based on previous publications. Thus, I suggest to clearly indicate that the focus of this paper lies on the spatial variability of the streamflow components and to give proper credit to earlier work of the authors.

I found it very difficult to remember the different sampling times and which years are used for the calculations. For instance, in the Abstract you talk about analyzing data from three years, although end-member mixing analysis was carried out for 2013 data only. Further, in most tables, where statistics of the data are presented, no sampling year is given and I often wondered if only data from 2013 were used or the entire sampling period (2011-2013)? This should be made more clear throughout the manuscript and the captions. Also, an additional figure that shows the time series of all samples from 2011-2013 would be helpful or a table that lists the times of sampling and locations.

Specific comments:

1. L133-135: Does this mean that only in 2013 samples were collected at the same times and not in 2011 and 2012? 2. Section 3.4: This section explains the reasoning behind the 4 different scenarios used for HS. However, I had difficulties to grasp all the details presented here, i.e. what data is used for what. I would start the section by pointing out that it is challenging to quantify the (spatial and temporal) uncertainties of the tracer end-members, which contribute to the uncertainty of the HS results (e.g., L 232: What does "critical impact" mean?). Then, as no measurements exist that would capture the largest spatial and temporal variability (i.e., uncertainty), different scenarios are assumed to represent this variability. Then, the detailed description of the four scenarios can follow.

Further, it is not clear what years were used to calculate the end members of groundwater. E.g., in L237 and L241 no sampling year is provided, while in L240 the authors say that all 3 years were used for averaging (It would help to provide the years of sampling in Table 2 instead of only writing "fall"). Can you explain why you use three years to calculate the average although HS was only carried out for the data of 2013?

I am confused by the numbers of samples used for each scenario in Table 3 and Table 4. In Table 3 it seems that there is a switch of n=5 and n=7 for Scenarios A and C. In Table 4 I don't understand why there are only 4 isotope measurements and 13 EC measurements. Can you explain?

3. L272: Here you talk about groundwater as a third component independent of streamwater or tributary water, although you define earlier in L242 that groundwater IS streamwater (and spring water) during baseflow. I would not use spring water and groundwater synonymously (as in L278, L279, L288, L291, L297, L392) to not confuse the reader.

Why do you not show data from 2013 in Fig. 2 and 3? Regarding to Table 1 samples were collected also in 2013 at the locations shown in these 2 figures.

L286-287: I do not agree with the authors, that the average EC of the tributaries is higher than the EC of all other samples. T5 and T2-SG are well within the EC ranges of the other water sources. A high average EC is mainly due to T4, which is pointed out as exceptional by the authors.

4. L317-L328: It is confusing that here you describe mixing model results based on hourly data from 7 events in 2011-2013, although in L166 you state that mixing model analysis was carried out only for monthly data from 2013. Thus, you should mention in the text that the high-resolution data set is based on the analysis in Engel et al. (2016).

5. L387: The "similar temporal variability in EC" between streamwater and tributaries is not at all visible in Fig. 2 that only visualizes spatial variability. Also in Figure 3 no similar EC patterns are visible. What is your conclusion based on?

6. What months define the summer and Fall-winter periods? For instance, in Table 6 an indication of the months used to calculate the statistics summer and fall-winter periods would help the reader to link the numbers to other figures and tables where data of specific days and months are presented. 7. L353-357: Results based on Engel et al. (2016) are used here, and thus should be cited this way. The same might be true for Figure 8.

8. L378-388: I find the discussion about the meltwater contributions to the Saldur stream and its tributaries rather speculative as it is mainly based on the statistics presented in Table 6 – particularly, when there is a more detailed mixing-model analysis presented in the Results section that clearly shows the different contributions of meltwater to the stream over time. Some other issues I found puzzling in this section: In L378-L379 you say that more negative d2H values in the streamwater and the tributaries are caused by inflow of meltwater. However, glacier melt has a very similar d2H signature to streamwater and tributary water (Table 5) and thus, your conclusion would only be true for snowmelt. L380-383: "more negative values" of d2H? Is d2H in the stream really "more negative" than in the tributaries when you take the standard devi-

ations into account? The same question arises for the EC values. L386-L388: Do you compare averages from the whole years or again only certain seasons? The “similar temporal variability in EC” is not visible in Fig. 2. L388 presents the same observation as L386.

9. L390-402: This section discusses the tracer signature of the springs/groundwater and draws conclusion very similar to those already presented in Penna et al., 2014 – thus, at least the reference to the previous work of the authors should be included. L394: Do you mean Figs. 2-4 instead of 3-5?

10. L412-417: I do not follow your claim that the tracer signal (both, EC and d2H) at S3-LSG is influenced by T4. What is the evidence for this? Further, I’d like to see some hypotheses that may explain the offset behavior of T4 and SPR4. Could it be related to different geology or permeability? SPR4 is located at the highest elevations and thus might be more influenced by snowmelt-driven recharge than the other springs further downstream?

11. L433: I do not see any plot that shows the hysteretic behavior between streamflow and EC – either provide a reference to previous work or describe the hysteresis in the Results section. L438-440: I like that a link to future climate change is made here, however, I would also put it into context to the shrinking glacier (mentioned by the authors earlier in L99).

12. L461-L465: Can you, for the sake of completeness, provide the relative glacierized areas of all references you cite here? I am not a specialist in the field of glacierized catchments, however, I was wondering whether the relative contribution of glacier melt to streamflow is somewhat dependent on the areal fraction that is covered by glaciers?

13. Section 5.4: As far as I understood did you establish four different scenarios for the end-member mixing analysis in order to quantify the effects of spatio-temporal variability of the tracer signature on the model uncertainty. However, in this section these results were not included. What scenario(-s) causes the highest uncertainty and why?

Further, can you say anything (qualitatively) about how neglecting of rainwater may affect your uncertainty?

14. Section 5.6: For a clearer understanding it might be useful to add vertical (shaded) boxes to the time series in Fig. 9 that represent the respective time intervals, e.g. mid-summer. Further, please add panel letters and refer to them in the text when you describe the individual processes.

Technical corrections:

L26: add s to “signature”

L31: “These results” – The previous sentence is about uncertainty and sampling design, thus starting the sentence with “These results” is confusing.

L54: Add “the” before “snowpack”

L58: “especially in remote locations” – I don’t understand why this important only for remote locations?

L63: What is “groundwater glacier melt”?

L68: “Finally,. . .” – I would start a new paragraph here as you talk about the Saldur catchment now.

L69: Add “glacierized” before “Saldur River catchment”

L71: Add “s” to “signature”, “sampled” instead of “samples”, remove “however”

L77: Add “s” to “reaction”

L86: remove “s” from “sources”

L99: Add the relative area of the glacier, i.e. 3.7% of total catchment area.

L118: Add “respectively” after “11.2km2”

L119: Add “d” to “acquire”

L124: remove “used in this study and”

L125: “from” instead of “collecting”

L177: “to derive” instead of “deriving”

L205: Add “s” to “notation”

L210: Switch “be” and “then”

L227: remove “the” before “those”

L231: “of the end-member signal”

L232: “especially in glacierized catchments” – I don’t understand why this important only for glacierized catchments?

L232: “critical” – What does this mean?

L234: Add “locations” to “stream”

L237: In fall 2013? Or fall as average from 2011-2013?

L255: Add “the” before “snowpack”

L272: “characterized” or “characterised”? This is not consistent throughout the manuscript.

L292: Add “in” before “the other springs”

L299: Use “whiskers” instead of “error bars”?

L317: Add the years of sampling and the reference Engel et al. (2016) to separate these results from the monthly samples in 2013.

L321: “clearly evident for . . .” – awkward expression, maybe rearrange the sentence?

L331: Add the years of sampling.

L332: Add “locations” to “sampling”

L347: remove “to”

L351: “associated with”

L352: “It is worth,. . .” – I would start a new paragraph here.

L374: replace “this behavior” with “spatial variability"

L383: “larger” instead of “higher”, “of” instead of “for"

L396: Add Penna et al. (2014) and Engel et al. (2016) to references?

L406 and L408: “consistent” instead of “consistently”

L413, L447: “meltwater” – glacier melt or snowmelt?

L414: “evidence” instead of “evidences”

L457: “dependent” instead of “depended”

L479: “model applications”

L498: “addressed by sampling”, remove “a” after “observed”

L516: Add “it” before “represents”

L547-549: This sentence is confusing: Temporal or spatial variability? Isn’t meltwater dynamics the same as contribution of snowmelt? It would be helpful to make two sentences out of it.

L558: “under changing climatic condiitons” – I don’t understand why this important only for such conditions? I would remove this term.

L565: “components”

A heading of Section 3.4 more like “Different scenarios to quantify uncertainty of the mixing-model end-members” seems more suitable.

Tables 2-5: Provide the year 2013 in the respective column or in the captions.

Table 3: The column “Sampling day” is missing or wrong.

Table 6: Do the rows “Summer” and “Fall-Winter” refer to the period 2011-2013 as well?

Table 7, caption: “two time series”

Figure 1a: There is a red diamond plotted outside of Figure 1a below the legend. Figure 1b: Why is the catchment cut off at the northern side? It is hard to see whether T5 is the long or short tributary. The light blue color of the springs is not suitable to read the letters properly.

Figure 2: Why don’t you add the signatures of snowmelt and glacier melt here? This would make a visual comparison much easier.

Figure 3: Why don’t you switch the x- and the y-axis to be more consistent with Figure 2. This makes it easier for the reader to grasp the temporal variability expressed by the whiskers in Figure 2 in comparison to Figure 3. Further, in Figure 2 the order of SPR1-SPR4 is opposite as in Figure 3.

Figure 4: Just a suggestion: Would it be useful to plot 2011 and 2012 data separately? It seems that, for instance, SPR4 behaves very different for both years. I would further suggest to use open symbols for the spring data in Fig. 4 to visually separate them more from the tributary data, as well as use the same color code as in Figure 2. I found that in Figure 3 SPR4 shows no values above 200 microS/cm, although Figure 4 shows the opposite. Please explain.

Figure 4 caption: What year were T1 and T3 sampled only?

Figure 5: Could you also provide the error bars here? This would help to make your point clearer that there is only a weak relationship for the times when glacier melt occurs. Figure 8: What data from which years were used for this plot? Weren’t there only seven melt-induced runoff events mentioned in the paper?

References:

Engel, M., Penna, D., Bertoldi, G., Dell’Agnese, A., Soulsby, C., and Comiti, F.: Identifying run-off contributions during melt-induced run-off events in a glacierized alpine catchment, Hydrol. Process., 30, 343-364, 10.1002/hyp.10577, 2016.

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