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Discussions

Interactive comment on "Characterizing hillslope-stream connectivity with a joint event analysis of stream and groundwater levels" *by* Daniel Beiter et al.

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Reviewer 1:

General comment

This manuscript focuses on the characterization of hillslope-stream connectivity by using a novel joint event analysis of the response of stream and shallow groundwater levels. The authors examined the response timing of 18 groundwater sites located in five different footslopes in Luxembourg for 706 runoff events. The applied methodology included event detection, the quantification of response timing of groundwater compared

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to stream water level, the analysis of the relations between pre-event groundwater level with pre-event stream water level and runoff coefficient. The authors concluded that the joint analysis of groundwater and stream water levels provided information on the presence or absence, and on the degree of subsurface hillslope-stream connectivity. The found threshold relations between groundwater and stream water levels were interpreted as transmissivity feedback in the marls study sites, and fill-and-spill in the schist areas. The topic of this manuscript is of interest for the readers of the journal, and overall the paper is well written and structured. The presented analysis for such a large time series of groundwater levels is quite rare, and therefore is particularly important to advance our comprehension of hillslope-stream subsurface connectivity. Nonetheless, I have some specific questions/comments for the authors, and I would like to see integrated in the manuscript some more methodological details.

Answer: We thank the reviewer for taking the time to review our manuscript and are happy to see this positive assessment.

Specific comments

1. I suggest to the authors to clearly provide in the introduction the definition of subsurface hydrologic connectivity, that they considered (currently such a definition can only be guessed by the readers).

Answer: We agree and will add the following definition to the introduction: Ali and Roy (2009) and Bracken et al. (2013) collected various definitions of hydrologic connectivity used in previous studies, which differ in spatial scale (hillslope vs watershed) and observed features (e.g. water cycle or landscape). The most appropriate definition in the context of our investigation is via flow processes on the hillslope scale, where disparate regions on a hillslope are linked via lateral subsurface water flow (Hornberger et al., 1994, Creed and Band, 1998).

2. The authors mentioned in the abstract that they performed their joint analysis for rainfall-runoff events, but throughout the manuscript there is no description of the rain-

fall characteristics (e.g., total rainfall, intensities and duration of the selected events)and where they were monitored (are the weather stations located in the study catchments?). I suggest to report such details in the text. Furthermore, I would like to see a table presenting the main summary statistics for rainfall, runoff and groundwater characteristics of the considered events.

Answer: More details about precipitation will be added to the revised manuscript in the form of gauge locations (map), summary statistics (table) and description in the text.

3. Since the analysis was carried out for the whole time series (winters and early spring included), I am wondering whether there were snowfalls, and if the authors considered snowmelt-induced runoff events and rain-on-snow events in the analysis. If such events were discarded, I suggest to integrate the description of the methodological approach for event detection. Otherwise, the authors should clearly state that they focused only on rainfall-runoff events.

Answer: We agree that events influenced by snow fall or snow melt could impact this analysis. However, snow fall events are generally quite rare in Luxembourg, so the number of events affected is assumed to be low. Furthermore, as the analysis is based on streamflow response, snow fall events themselves will not appear in our analysis. A major snow melt event or rain on snow event would be captured by its runoff response, but in this case erroneous estimate of rainfall input would only impact the analysis of runoff coefficients as we otherwise focus our analyses on the relationship between streamflow and groundwater responses. We will add a sentence explaining this to the revised manuscript.

4. In Table 1 (or in a new table), I suggest to provide the topographic characteristics of the groundwater sites together with their depth. These details could help to understand whether the topography is very similar (or very different) among the monitored locations, and to support the discussion at page 17, lines 15-19. Moreover, what is the extension of the riparian zone compared to the hillslopes in the study sites?

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Answer: We agree that this information would be helpful. Unfortunately, the available topographic data only has a resolution of 10m, which does not give any additional information on the sites as the piezometer distances are around 10m. However, we will provide average slopes for the measurement locations in addition to the average slopes of the subcatchments. The spatial extent of the riparian zone varies between the five sites but was estimated to be around 2-10m, depending on topography. The adjacent hillslopes derived from the DEM were at least 250m long, except M_D with around 50m.

5. Have the authors considered their analysis of subsurface connectivity in light of recent findings by Klaus and Jackson (2018) and Gabrielli and McDonnell (2020)? Are there bedrock permeability data for the selected study sites?

Answer: Unfortunately, we do not have information on bedrock permeability. Klaus and Jackson (2018) found that according to the Downslope Travel Distances (DTD) only lower regions of a hillslope contribute to the streamflow via interflow, while in upper regions water percolates into the deeper groundwater. We do agree that the presence of a perched groundwater table at the footslope is no proof for a connected hillslope. However, we can observe a threshold behaviour in the hillslope-stream-system that depends on initial groundwater levels. This indicates that soil characteristics (flow path system, layering) start playing a role in how water parcels travel along the hillslope. It is very likely that these heterogeneities allow a hillslope or at least the footslope to connect to the stream via interflow for a short period of time. Gabrielli and McDonnell (2020) built upon the DTD and developed a (gridded) Index which describes the general tendency of a catchment to either shed water laterally to the stream channel or infiltrate water to depth. They found high correlations between their Anisotropy Index (AI) and the assessed Mean Transit Time (MTT) for several catchments. As we are focussing on the hillslope-stream connectivity we did not make any statement towards the water age. We will add a brief discussion of these papers to the revised manuscript.

5. In the section "2.4 Event detection" and Fig. 4, it is not clear which response timings

were considered for complex events with multiple peaks (both in stream and groundwater level). Furthermore, which peak in stream water level is considered if there is only one peak for the groundwater level?

Answer: Thank you for pointing this out. This will be clarified in the text. After merging overlapping event timings, the highest peak is determined as the event maximum. From there on it is handled as a simple event according to Figure 3. This also accounts for the situation where multiple overlapping streams events correspond with a single groundwater level event.

6. Page 11, line 5: Please provide a reference for the method used for the stormflow calculation.

Answer: The approach to separate baseflow from discharge was developed in the style of the constant slope method (Dingman, 2002).

7. Page 20, line 5: "No pronounced differences...": could the authors report the results of the applied statistical test?

Answer: This statement is related to the timing patterns in Figure 8. It illustrates several dimensions of information such as rising and maximum time of a groundwater event, normalised by the according stream event, where each piezometer has a different number of events. This makes it difficult to apply statistical tests to see whether two groups of samples are significantly different from each other. Furthermore, a p-value below a common significance level of alpha = 0.05 would not tell how pronounced differences would be.

8. Page 21, lines 3-4: Please provide more details about the investigated relations between rainfall characteristics and event responses.

Answer: The relationship between rainfall characteristics and event responses is not a major focus of this study and we therefore touched on it only briefly here. However, we agree that this brief glimpse of the analyses might be unsatisfactory and we will add the results of the correlation analyses in the supplementary data.

9. Page 22, lines 8-10: Please remove these details from the available literature, and report them in a table. Please consider that other recent studies examined almost or more than 100 events (e.g., Rinderer et al., 2016; Zuecco et al., 2019).

Answer: Thank you for pointing these studies out. We will revise the illustration of numbers of events.

10. Page 23, line 13-16: The example of considering just two events in the data analysis is a very extreme case, and so far I have never seen it. Therefore, please revise the sentence. The main question is how many events and piezometers do we need to capture the temporal and spatial variability of subsurface connectivity?

Answer: We agree that considering only two events is a very extreme case. We will remove this statement and will make it clearer, that the question is not so much about how many events are necessary (in absolute numbers) as more about the necessary time period to cover the temporal variability generated by different hydrological processes. It is therefore necessary to accumulate a large number of events across all seasons. In terms of extreme events (droughts/floods) the covered time period and number of events will need to be even higher, on the one hand to capture these events, and on the other hand to put them into context.

Technical corrections 1. Page 2, line 25: “assess”. 2. Page 3, line 1: “hillslope” instead of “slope”. 3. Page 4, line 2: “July”. 4. Page 23, line 4: “these” instead of “this”. 5. Figure 11: Based on the caption, the label of the y axis should be “Normalised pre-event groundwater level”.

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