Response to reviewer 1 comments

We appreciate the comments by the reviewer and the general positive assessment of the manuscript. Below we respond (in blue text) to the individual comments (in black text).The comments will help us to clarify the manuscript. In some cases the reviewer asks for information/discussion that we already provide in the manuscript. In these cases, our response explains where we provided this information/discussion, but of course we can extend these parts if the reviewer/editor thinks that additional text is needed.

General comments

This article presents an interesting thought experiment about how riverine network length can influence the mean travel time distribution in catchments. The authors present a set of feasible river network extents across a range of wetness conditions, assume surface and subsurface flow velocities, and then estimate plausible distributions of travel times to the catchment outlet within these wetness scenarios. As this study is an initial exploration of how network extent can influence travel time distributions and modeling solute transport, I believe this study would be more powerful if the authors emphasized how future studies can build off of this initial exploration. For instance, emphasizing what the limitations of this study design are, and how others can use these concepts and apply real datasets and hydrologic measurements to confirm the results and interpretations of this study, would be greatly beneficial.

> We describe the limitations of the study (particularly the uniform and constant velocities and the 'steady state assumption' for each stream network) on P5L24-31 (first part of the discussion). Our main goal was to show that the geometry of the flowing stream network affects the distribution of the hillslope travel distances to the flowing streams (and to a much smaller extent the travel distances in the stream) and thus the travel time distribution. We describe in the discussion what these results mean for interpreting travel time distributions obtained from tracer data and highlight that these results should be considered in solute transport models that - so far - tend to use a fixed (rather than dynamic) stream network.

Since this study estimates subsurface and surface velocities, it seems appropriate to provide results from a sensitivity analysis or provide ranges in the mean travel times. While the authors state they tested surface to subsurface velocity ratios (from 10 to 10000; P 4 L 14), they do not appear to present the results of that analysis. A powerful addition to this paper would be to show possible ranges in mean transit time distributions, given minimum and maximum velocities.

> We actually provide the results for different velocities in Figure 6 and describe them in the last paragraph of section 3. In short, the chosen velocities greatly affect the mean travel times and the range of travel times but have a minor effect on the shape of the travel time distribution or the differences in the travel time distributions for the different stream networks. Thus the main result of this study (namely, that the geometry of the flowing stream network affects the shape of the travel time distributions) does not depend on our chosen velocities. See also the response to specific comment 6 below.

Specific comments

1. P 3 L 26: How substantial of a rainfall event? Is the rainfall occurring in "wet" conditions? I suspect not as it occurs right before the "dry" conditions survey.

> There were 27 mm of precipitation on October 25th and another 31 mm fell on October 26th. There was no other rain after this, even until November 2nd (total rainfall between October 15th and November 2nd was 83 mm). Streamflow in the catchment responds quickly to precipitation (within minutes to hours) and baseflow is generally reached within one to two days after an event. Thus, by November 2nd, streamflow had returned to baseflow conditions, although the lowest flows during this fall period were increasing slightly (see Figure R1 below).

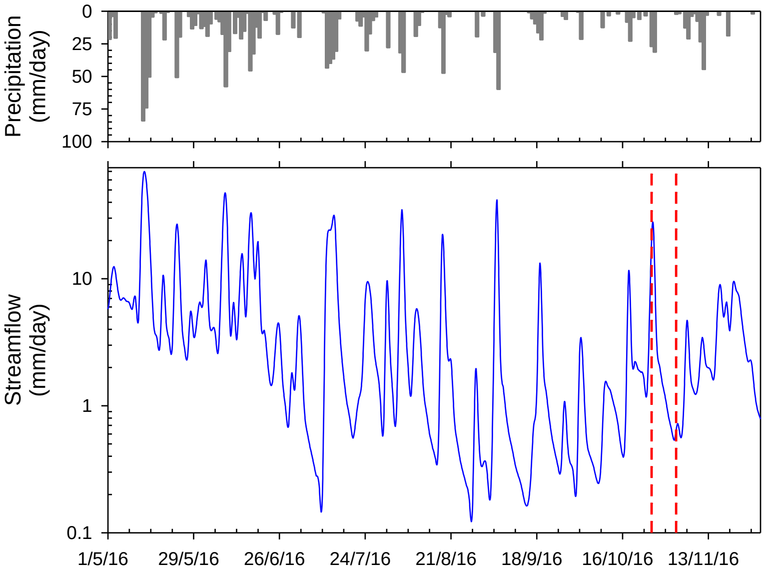

Figure R1. Daily precipitation and streamflow at the Erlenbach gauging station during spring to-fall 2016. The red lines indicate the times of the two stream surveys in fall 2016. Note the log-scale for streamflow. The flow during the extremely dry conditions in summer 2018 was 0.18 mm/d. The data were obtained from Stähli (2018), Long-term hydrological observatory Alptal (central Switzerland); https://www.envidat.ch/dataset/longterm-hydrological-observatory-alptal-central-switzerland.

2. P 3 L 20: The authors say that the field mapping is too slow during rainfall events to capture the entire extent of the stream work during rainfall events due to how dynamic it is. However, it appears the authors use a survey taken during a rainfall event in this analysis. Thus, it would be helpful to the reader if more information was provided on these surveys, e.g. how long did the surveys take, did the researchers start at the channel heads and walk down (to ensure they capture the most dynamic extents), was the network actively expanding during the survey, etc?

> We didn't survey the stream starting at the channel heads but rather walked along the contours and then up the different streams (thus the surveys were done in more of a zigzag pattern across the catchment). Each survey took at least half a day to complete. Since the peak of the event is very short, we cannot survey the entire stream network at the peak of the event. We will make it clearer in the text of the manuscript that the mapping is too slow to capture the peak flow conditions during an event.
>
> The October 2016 stream network was mapped in the afternoon of October 25th during an event with low intensity rainfall (see Figure R2 below). Total rainfall was 10 mm by noon (when the mapping started), 16 mm by 3 pm, and 20 mm at 5 pm when the mapping was completed.

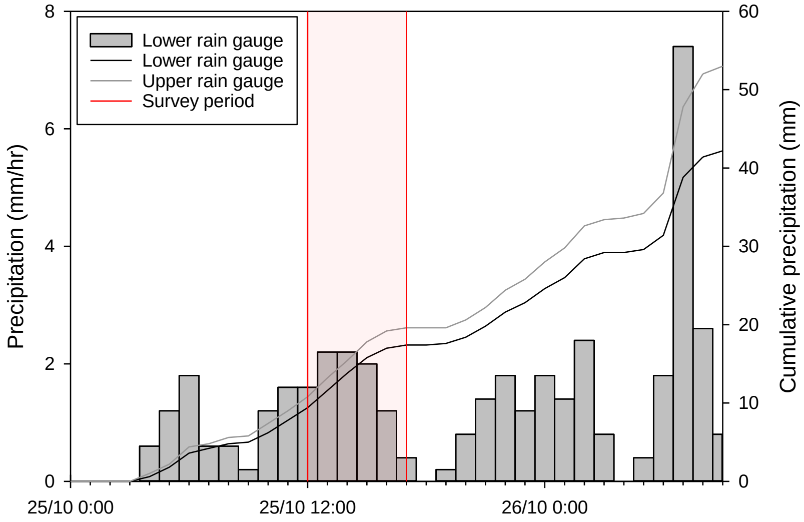

Figure R2. Hourly and cumulative precipitation recorded at the lower and upper rain gauge in the Studibach before and during the stream survey on October 25, 2016.

3. P 3 L 27: It may be more clear to the reader how survey #4 was accomplished (every other survey is described in parentheses, but this one).

> The stream network was surveyed on multiple occasions to ensure that we had mapped all streams. The complete network is assumed to represent the fully extended network during extremely wet or peak flow conditions. We did not observe flow in all streams at the same time; instead, #4 represents a hypothetical scenario in which all channels are flowing during extremely wet conditions. We explained this in the text but will try to make it clearer. We will move this clarifying text to the parentheses and make sure that in the figure and table caption it is clear that the complete network is assumed to represent the flowing stream network during extremely wet conditions.

4. There have been several recent studies that sought to predict river network extent, which can be used to model transit time distributions as suggested by the authors on
P33. Some suggestions below for two recent studies that can be used:
P 7 L 1: Add another example of predictive modelling: Ward, A. S., Schmadel, N. M., & Wondzell, S. M. (2018). Simulation of dynamic expansion, contraction, and connectivity in a mountain stream network. Advances in Water Resources, 114, 64-82.
P 6 L 33- P 7 L 1: Add example of empirical generalization from field studies, such as: Zimmer, M. A., & McGlynn, B. L. (2018). Lateral, vertical, and longitudinal source area connectivity drive runoff and carbon export across watershed scales. Water Resources Research, 54(3), 1576-1598.
This study also relates network expansion and retraction to solute transport dynamics as well, which is suggested in this study, but few if any citations are provided.

> Thank you for these suggestions. We will add references to these papers and other stream network model studies to the manuscript.

5. TABLE 1: While it is clear why the topographic map does not have an associated streamflow, please add brief explanation in caption as to why streamflow magnitude is not provided for complete network.

> We will add the clarification to the table that we never observed flow in the complete stream network but that we assume that this is the case for peak flow conditions during very large events.

6. TABLE 2: This is an incredibly interesting results table and definitely made me think about possible travel times in other catchments and across wetness conditions. While I think the authors main

points from this paper were to show that travel times decrease substantially as the system wets up, the absolute values for the reported median travel times are very small. The median surface travel times are on the order of minutes – how did the authors determine this? Based on the catchment and previous field observations, does it seem reasonable that 71% of the water travel time are less than 2 days?

> The main point of the study was indeed to show that the changes in the flowing stream network geometry can significantly affect the travel time distribution. We did not intend to derive actual travel time distributions for this catchment but rather focus on how the distributions differ between the different stream networks.
>
> We don't know the average surface and subsurface velocities in the catchment and therefore state clearly that these are assumed values. We test the effect of using different velocities and show that the effect of the chosen velocities on the shape of the travel time distribution is minimal (see Figure 6 in the manuscript). Furthermore, we discuss on P5L4-31 the implications of using uniform and constant velocities.
>
> The average surface velocity of 0.5 m/s is typical for mountain streams. The average subsurface velocity of 5 10^{-4} m/s is high compared to the hydraulic conductivity of the soil near the surface in the grasslands areas of the Studibach (5 10^{-7} to 1 10^{-5} m/s) but is not unrealistic for the forest sites (>1 10^{-4} m/s; van Meerveld et al. (2017)). For comparison, Anderson et al. (2009) determined subsurface velocities of 10^{-4} m/s (and up to 10^{-1} m/s) for preferential flow pathways in forest soils, whereas Uchida et al. (2001) mention velocities of 5 10^{-3} m/s (and up to 2 10^{-1}m/s) for pipeflow in forest soils. Most of the flow in the clay soils of the Studibach occurs through preferential flow pathways in the topsoil layers. However, as discussed on P6L1-12, the flowing stream network wouldn't be fully extended for many days in a row and the velocities will decrease as the catchment dries out. Therefore, in reality the travel times will be much longer than shown in Figure 4 (see Figure 6b).
>
> We do not know the travel time distribution for the catchment but the streamflow response in the catchment is very flashy. Previous studies have shown that the event water contributions to streamflow in the Alptal catchments can be very large (Fischer et al., 2017; von Freyberg et al., 2018b) and that the young water fraction can be very high (von Freyberg et al., 2018a).

7. It is also interesting that the median travel time for the topographic map survey is 4.5days and the subsurface travel time is 4.5 days, which are both longer than the “dry” conditions survey, and yet the fraction of the catchment with travel time less than 1 day is greater for the topographic map. Perhaps this is driven by the hydrologic connectivity of the river network in the topographic map survey. This is an interesting dynamic that could be expanded on in this paper and could be related to recent papers on the topic of discontinuous network extents, such as:

Godsey, S. E., & Kirchner, J. W. (2014). Dynamic, discontinuous stream networks:hydrologically driven variations in active drainage density, flowing channels and stream order. Hydrological Processes, 28(23), 5791-5803.

Whiting, J. A., & Godsey, S. E. (2016). Discontinuous headwater stream networks with stable flowheads, Salmon River basin, Idaho. Hydrological Processes, 30(13), 2305-2316.

> It is indeed interesting that the stream length and median travel time for the flowing stream network during dry conditions and the network from the topographic map are rather similar but the connected stream length (Table 1) and the area that likely contributes to the stream are very different (Figure 4). We already highlight this on P5L5-8. We also highlight the effect of the dry section in the flowing stream network on the travel time distribution and the area with travel times shorter than two days on P5L9-13.
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> We already reference the mentioned publications but will include more information on them.

8. FIGURE 2: What is the role of disconnected stream channels in the model results? Do water parcels flow through these disconnected sections at the same rate as those coming from the terrestrial

landscape outside the channel extent? Do the authors think that subsurface flow map be faster within the subsurface channel network than in the hillslopes adjacent to the network?

> The disconnected section causes the second peak in the travel time distribution (see P5L9-13).
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> We only used one subsurface flow velocity in our calculations. We agree that the flow may be faster through the channel bed than on the hillslopes but adding a different velocity for the area around the channel will make the results less clear. As mentioned throughout the text, the velocities were kept constant in order to avoid blurring the effect of the change in the stream network geometry on travel times by having different velocities. Of course in reality there will be a distribution of velocities, rather than one velocity for the entire catchment, and this velocity distribution will change as the catchment wets up or dries out. We describe this limitation and the effects that this has on the travel times on P5L24-31.

Technical corrections and editorial suggestions

P 5 L 11: missing “x” between “5” and “10”.

> We will add a · between the 5 and the 10 (here and elsewhere in the text).

P 6 L 13: Delete “did” at end of sentence.

> We will remove the "did"

TABLE 2: Change “travel times smaller than one and two days” to “travel times shorter than one and two days”

> We will change the text of the caption accordingly.

References:

Anderson, A. E., Weiler, M., Alila, Y., and Hudson, R. O.: Subsurface flow velocities in a hillslope with lateral preferential flow, Water Resour. Res., 45, W11407, doi:11410.11029/12008WR007121, 2009.

Fischer, B. M. C., Stähli, M., and Seibert, J.: Pre-event water contributions to runoff events of different magnitude in pre-alpine headwaters, Hydrol. Res., 48, 28-47, 10.2166/nh.2016.176, 2017.

Uchida, T., Kosugi, K., and Mizuyama, T.: Effects of pipeflow on hydrological process and its relation to landslide: a review of pipeflow studies in forested headwater catchments, Hydrological Processes, 15, 2151-2174, 2001.

van Meerveld, H. J. I., Fischer, B. M. C., Rinderer, M., Stähli, M., and Seibert, J.: Runoff generation in a pre-alpine catchment: A discussion between a tracer and a shallow groundwater hydrologist, https://publicaciones.unirioja.es/ojs/index.php/cig/article/view/3349, 10.18172/cig.3349, 2017.

von Freyberg, J., Allen, S. T., Seeger, S., Weiler, M., and Kirchner, J. W.: Sensitivity of young water fractions to hydro-climatic forcing and landscape properties across 22 Swiss catchments, Hydrol. Earth Syst. Sci., 22, 3841-3861, 10.5194/hess-22-3841-2018, 2018a.

von Freyberg, J., Studer, B., Rinderer, M., and Kirchner, J. W.: Studying catchment storm response using event- and pre-event-water volumes as fractions of precipitation rather than discharge, Hydrol. Earth Syst. Sci., 22, 5847-5865, 10.5194/hess-22-5847-2018, 2018b.