Response to the interactive comment by Daniel Wilusz on

"Sensitivity of young water fractions to hydro-climatic forcing and landscape properties across 22 Swiss catchments" by Jana von Freyberg et al.

This is a very interesting manuscript about the sensitivity of the young water fraction (Fyw) in streams to discharge and watershed characteristics across many Swiss sites. Although I did not read it as carefully as a reviewer might, it seemed well-reasoned and concluded with an insightful conceptual model informed by novel ideas and analytic techniques.
I am writing to observe that aspects of the paper (referred to hereafter to by the authors' initials FASWK) seem relevant to previous work, including work I co-authored with Harman and Ball and reported in the paper Sensitivity of Catchment Transit Times Under Present and Future Climate (Wilusz et al. 2017, referred to hereafter as WHB). WHB analyzed the relationship between the young water fraction and rainfall variability in 2 subcatchments of the Plynlimon experimental site using a lumped parameter transit time model calibrated to a 10 year data record. I was excited to see that many of the findings in WHB were consistent and complementary to findings in FASWK. I list these points of mutual relevance and complementarity below, in case the authors may also find some of the connections interesting and/or sufficiently relevant to reference in the manuscript.

We thank Mr. Wilusz for commenting on our work. We have replied to his remarks below.
Comments of Mr. Wilusz are shown in italics. Responses from the authors are presented in regular font below each comment. Citations from the manuscript are in Times New Roman, changes of the cited manuscript text are <u>underlined</u>.

1. *WHB found that every 1mm/day increase in average annual precipitation was associated with a 0.03 and 0.04 increase in the Fyw (WHB, Figure 5d) in the 2 subcatchments studied. In the parlance of FASWK, this metric could be referred to as a kind of "precipitation sensitivity of Fyw". Given the high runoff ratios in the Plynlimon catchments (0.78-0.90, see WHB, Table 2), the precipitation sensitivity of Fyw should be closely related to the discharge sensitivity of Fyw. The values of the precipitation sensitivity of Fyw at Plynlimon multiplied by the runoff-ratio are near the middle of the range of discharge sensitivity of Fyw values reported in the 22 Swiss catchments (FASWK, page 16, line 7-8). The fact that the ranges overlap in the two manuscripts at different (albeit hydrologically similar) sites - even though the models and timescales used for estimation were different – is further evidence that the sensitivity of Fyw to hydro-metric fluxes is a robust and reproducible metric that could "contribute to future (inter-comparison) studies" (FASWK, page 19, line 30) and "be a potentially useful hydrologic signature" (WHB, page 19). Of note, a significant strength of the method proposed in FASWK is that it used lower temporal resolution tracer data, which is more commonly available.*

We agree with Mr. Wilusz that the overlap in ranges of the discharge sensitivity between the Plynlimon sites and the Swiss catchments is an interesting finding. We will include this comparison in the revised version of the manuscript.

P16, L5: "At the Aach catchment, only two streamwater samples were collected during high-flow conditions, resulting in an unrealistic and highly uncertain value for m_S. At the remaining 21 sites, the linear slopes of the Q-F_{yw} relationships range between zero (within error) at Ilfis and Sitter, and 0.0732±0.0360 d mm^{-1} at Mentue, with an average value of 0.0202±0.0046 d mm^{-1}. On average, we find that every 1mm day^{-1} increase in discharge is associated with an increase of 0.0202±0.0046 in F_{yw}. From this analysis, we excluded the Aach catchment because only two streamwater samples were collected during high-flow conditions, resulting in an unrealistic and highly uncertain value for m_S. At the remaining 21 sites, the discharge sensitivities of F_{yw} range between zero (within error) at Ilfis and Sitter, and 0.0732±0.0360 d mm^{-1} at Mentue. These values are similar to those found by Wilusz et al. (2017) for two neighbouring catchments in Plynlimon, Wales. For the two sites, Wilusz et al. (2017) combined a rainfall-runoff model with a rank StorAge Selection (rSAS) transit time model and estimated an increase in F_{yw} by 0.031 to 0.040, respectively, with every 1mm day^{-1} increase in average annual precipitation. Multiplying their "precipitation sensitivities of F_{yw}" by the site-specific runoff ratios (0.78 and 0.90) yields average discharge sensitivities of F_{yw} of 0.0242 and 0.0360 d mm^{-1}, respectively, which are within the range of values we obtained for our 22 Swiss study sites. Even though the methods, tracers and timescales Wilusz et al. used to estimate F_{yw} differed from ours, the similarity in the discharge sensitivities between their sites and ours suggests that this may be a robust and reproducible metric that could be useful in future catchment (inter-comparison) studies."

2. *WHB found that the annual flow-weighted average Fyw is highly linearly correlated with annual precipitation (WHB, Figure 5d) across time. This is consistent with the finding in FASWK of a significant linear relationship between Fyw and Pbar (FASWK, Figure 6 upper right panel) across space.*

One should of course expect F_{yw} to be higher under wetter conditions as a general rule, but our results and those of WHB are apples and oranges. WHB compare model results across years; we show site-to-site comparisons based on real-world data. Naturally WHB's model results show a strong correlation; the internal consistency of model behavior all but guarantees this.

3. *The conceptual model in FASWK classifies Case 1 and 3 catchments as having a "constant mixing fraction of young and old water" and Case 2 catchments as where "the relative contribution of fast and slow flowpaths vary dramatic in response to hydro-climatic forcing and antecedent wetness " (FASWK, page 17). The paper Kim et al. (2016) introduced a related classification scheme, in which the classification "external variability only" was akin to Case 1/3 catchments, and the classification "both internal and external variability" was akin to Case 2 catchments (see Kim et al. 2016, Figure 6). Kim at al (2016) showed how these two classifications could be mathematically embodied and parameterized in a forward modeling framework using the theory of StorAge Selection (SAS) functions (Botter et al. 2011, van der Velde et al. 2012, Harman 2015). In addition, analysis in Harman (2015), Kim et al. (2016), Benettin (2017), and WHB showed how a hydrologic system could be analyzed to rigorously test whether it exhibited external only variability (Case 1/3) or external and internal variability (Case 2). (Note a subtle difference between the two classification schemes is that FASWK is based on a distinction between flow pathways that are slow versus fast (as described in Figure 10), while the classification of Kim et al (2016) is based on a distinction between pathways that contribute older age-ranged storage to discharge versus pathways that contribute younger age-ranked storage to discharge. The*

difference may be relatively unimportant for the kind of analysis done in FASWK that looks at long-term average behavior in humid catchments.) To summarize, the relevance of this literature to the FASWK manuscript is: (a) the SAS mathematical framework has been used to rigorously classify watersheds as something similar to Case 1/3 or Case 2; (b) the parameterization of SAS functions could be informed by its designation as either Case 1, 2 or 3; and (c) the parameterization of SAS functions could be informed by the relationships reported in FASWK between the Fyw and watershed properties.

We do not see a clear conceptual link between our classification scheme and that of Kim et al. (2016). It is also not clear how useful SAS functions will be for "rigorously classifying" watersheds, given the apparent difficulty in accurately estimating SAS functions from field data. One of the major advantages of the F_{yw} approach is that it can be applied to catchments where extensive tracer data are not available.

4. *WHB incorporated the sensitivity of the Fyw to hydro-climatic forcing into a forward modelling framework to do a first-order projection of the impact of climate change on the Fyw at the Plynlimon sites. WHB projections showed the Fyw would decrease significantly in summer, and increase significantly in winter. This illustrates one of many ways information about the sensitivity of Fyw to hydro-climatic forcing could be used to help answer management relevant questions, as suggested in FASWK page 18, lines 14-17.*

We thank Mr. Wilusz for this remark, which we will implement into the revised version of the manuscript: "Based on our analysis, we developed a generalized conceptual description that relates F_{yw} and its discharge sensitivity to dominant streamflow generation mechanisms (Sect. 6.3., Fig. 10), which could be useful for analysing the effects of future climate change on catchment hydrologic behavior. It remains to be tested […]"

5. *The use of the sensitivity of the Fyw to hydro-climatic forcing and landscape properties for intercatchment comparison behavior has roots in the literature. For example, Harman (2015) defined and proposed using a "sensitivity of event water fraction to discharge" (Harman 2015, page 23) as a useful transport-sensitivity metric. As discussed above, WHB used something akin to a "precipitation sensitivity of Fyw" for a 2-catchment comparison. WHB also has a brief literature review summarizing previous work relating age distributions to hydro-climatic fluxes (WHB, section 1.1). In addition, some researchers are using SAS functions for catchment classification and intercomparison (see for example Rinaldo et al. 2015), and SAS functions could be seen as a generalization of the discharge sensitivity of Fyw, to the extent that knowledge of SAS functions and flux history is sufficient to estimate the discharge sensitivity of Fyw for any control volume of interest.*

The concept of linking event water fractions (or young water fractions) to hydro-climatic indices is not new (either to our work or that of WHB), and indeed, most of our correlation analysis (Sect. 5 and 6.2) was inspired by those earlier studies (which we reference accordingly). Thus, we do not claim to have invented the expression "discharge sensitivity of F_{yw}" as a novel concept of looking at these relationships. We rather introduce the expression in Sect. 6.2 for reasons of convenience, i.e. instead of using the lengthier expression “linear slope of the Q-F_{yw}-relationship”.

References

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