

Interactive comment on “Regionalization of patterns of flow intermittence from gauging station records” by T. H. Snelder et al.

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Re: Hydrol. Earth Syst. Sci. Discuss., 10, 1511–1551, 2013, www.hydrol-earth-syst-sci-discuss.net/10/1511/2013/. doi:10.5194/hessd-10-1511-2013 Title: Regionalization of patterns of flow intermittence from gauging station records Authors: T. H. Snelder, T. Datry, N. Lamouroux, S. T. Larned, E. Sauquet, H. Pella, and C. Catalogne We sincerely thank the reviewer and your constructive comments on our paper. These have helped us to improve the scientific content of our paper.

We have replied to the anonymous reviewer in the order of their the comments. We have attached as supplementary material a marked up copy of the revised manuscript to show how the changes have been made where not explicit here.

Full Screen / Esc

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Specific comments Anonymous Referee #1

1. Did runoff or flow characteristics (intermittence, degree of intermittence) have any control over the distribution of gauging stations in France? If so, how might that affect the predictions for the ungauged portions of the network? Were locations of gauges in the network variable (upstream, middle or downstream end of segments) or did they tend to occur near the mouth of catchments (downstream end of segments, near confluences)? In other words, could drying frequency and duration be related to proximity to confluences and therefore influence how representative their data are for segments?

We do not have the information required to answer the first question definitively. However, it is unlikely that intermittent flow is a primary reason for establishing gauging stations. More common reasons are water supply monitoring and flood warning.

The second and third questions refer to the position of gauges within stream segments. Again, we do not have the information about why and where gauges were established at small spatial scales.

The fourth question refers to the degree to which the proportion of gauging stations on intermittent and perennial segments matches the proportions of intermittent and perennial segments in France (i.e., the representativeness of the gauging network). We show at the end of the paper that the gauging network under-represents intermittent segments in France. We dealt with the non-representativeness of the gauging network by modelling intermittence as a function of the environmental variables.

2. Regional weather data used in the model were from 1961-1990. Why not for a longer period of record (through to 2009)?

We could only use data that were available as explanatory variables, as stated in the Methods section. 1961-1990 was the period of reference for climatologists, and climate maps were only available for this period.

Is it possible that drought conditions (unusually dry and warm) were associated with

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)

[Discussion Paper](#)



zero flows recorded at some gauges (Subclass 1, perhaps some of Subclass 2) and these reaches might really be perennial reaches that were prone to drying under drought conditions? Yes, the effect of widespread drought conditions can be seen in Fig 3 with zero-flows being most frequent and longest in duration during 1976, followed by 1989-1991, and 2003 and 2005. We have modified the first paragraph of the results section to specifically state this. We note that river segments with zero flows during any period in the time series used for analysis were defined as intermittent, regardless of drought conditions. The definitions of perennial and intermittent reaches or segments used by the authors should be stated at the start of the introduction. Most definitions of perennial streams characterize them as having year-round flow except in periods of drought. The authors need to indicate to the readers why they did not consider drought in classifying streams (or climatic measures that might be useful in associating zero-flows to drought over longer time scales, rather than average annual rain and temperature for climatic variables). The first sentence of the paper defines intermittence. It is explicit in our analysis that sites with one or more days of zero flow were classified as intermittent. We also point out the word drought has many definitions (climatic, hydrologic, agronomic, hydrogeologic). Introducing drought as a factor in defining sites as intermittent would increase the subjectivity of the categorisation.

We did include climatic variables (nDryDays, dDry) that are used to describe droughts (i.e., periods without rainfall). We reported that these variables did not improve our models.

3. Related to #2, the division of the intermittent segments into subclasses appears to be based on evenly distributing the stations by DUR and FREQ data as opposed to possibly more meaningful divisions (functional or policy or management related). The distribution of stations appears to be skewed toward more perennial waters (most to left of 0.5 mFreq in Fig.4 and median DUR only 7.3 days) and away from what authors later describe (P1530 L16-18) as channels permanently above the water table (i.e., ephemeral). The authors characterize two different types of classes in the dis-

Full Screen / Esc

Printer-friendly Version

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Discussion Paper



cussion (P1530 L12-18) based on the channel and groundwater table elevations (and therefore predominant sources of flow) that would probably be a more functional way to classify temporary streams. Are ephemeral or episodic streams (*sensu* Williams 2006 *Biology of Temporary Waters*) lacking or absent in most regions of France or are they common but lack stream gauges? How do the authors foresee their 3 subclasses and their associated boundaries being useful or meaningful to those who might use these maps? (e.g., distinction between 4 days versus 6 days of zero-flow per year on average seems rather arbitrary). My point related to #2 above is if gauges were more likely positioned in segments with perennial flow (or nearly perennial flow) than in segments with infrequent and short durations of flow then the authors should reconsider how to classify/interpret their dataset.

The intermittent gauges were subdivided into the three intermittent sub-classes to create three approximately equal groups. This allowed us to model the relationship between the groups and the explanatory variables. What we wanted to know was whether different types of intermittency could be associated with (or discriminated by) differences in the explanatory variables. Unequal group size would have reduced our ability to model the small classes. We did not imply that the sub-classes have specific meaning, either from a management or biological perspective. We note that any method of grouping or clustering the sites into 3 groups would be somewhat arbitrary.

It might be more meaningful especially from a policy or management perspective, if in fact some of the stations the authors identified as intermittent Subclass 1 and/or 2 are really perennial sites that under drought conditions (or perhaps abstraction) are particularly susceptible to having zero-flows.

See the preceding responses about definitions of intermittent segments. All of the sites in each of the intermittence subclasses were intermittent, not perennial. With regard to water policy and management, it is prohibited for abstraction to reduce flows to zero due to the law (*Loi sur l'Eau et les Milieux Aquatiques*), which prohibits water abstraction when discharges are below a fixed threshold.

If the authors are attaching significance to the subclasses it would seem useful for readers to know where across the two gradients or on the biplot (Fig.4) the misclassifications were most prevalent. I suspect that they were near the borders, but may only be restricted to the intersection of the 3 subclasses or predominant along 1 boundary.

We have indicated the misclassified catchment on this graph. There was no discernible pattern associated with the misclassifications.

4. The focus on of the paper is on the discrimination of perennial from intermittent and among subclasses of intermittent segments and their relationship to environmental variables. Which is fine, but the authors do not consider in their analysis or interpretation of results that stations may also vary independently by other hydrological aspects or indices (perhaps more so than zero-flow duration and frequency) and those indices could have strong(er) associations with environmental variables. This is somewhat surprising because some of the authors have used largely the same dataset to develop models to more broadly classify river segments based on largely the same environmental variables.

The analysis was concerned only with flow intermittence. The association between other aspects of the hydrological regime and the environmental variables was dealt with by the earlier paper (Snelder et al. 2009) and is out of the scope of the current study.

5. Another consideration for the authors is to apply their perennial-intermittent model for station catchments that were discarded because of various modifications due to reservoirs, diversions, abstractions, etc. Does the predicted classification by the model agree that the assumption that the modifications were severe enough to switch the flow regimes of any of these stations? If so, any patterns regarding the type or magnitude of modification?

This is an interesting idea, but it is not in the scope of this study. We think it is likely that the poor discrimination of our models would lead to equivocal results, especially given

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the difficulty in obtaining data describing the modification of flows in the catchments.

Specific comments:

P1512 L10-11: Annually? Over the entire period of record (35 yrs)?

Over the entire period of record. We have clarified this in the abstract.

Seems like one (or a few) dry period over 35 years might be so infrequent that the stream could be considered perennial and zero flow may be caused by severe drought conditions?

We defined intermittent streams to be those with at least one instance of zero flow in their time series. We consider this is pragmatic and appropriate because any other definition would involve making subjective judgements concerning the frequency of events required to be judged intermittent.

P1514 L6: “consumptive use” implies non-sustainable use. Is the intent by the authors that specific? If not, suggest a different description (e.g., human use).

Changed to human use.

P1514 L15: This statement really applies only to US federal regulations (i.e., Clean Water Act). State regulations can be more protective of their intermittent streams. Change “few” to “fewer.”

Changed.

P1515 L26-27: One study that I am aware of that the authors overlooked that uses models (though not using RF or related techniques) with environmental variables and that are developed with gauge data to extrapolate intermittent-perennial membership to ungauged locations is Wood et al. 2009 Estimating locations of perennial streams in Idaho using a generalized least-squares regression model of 7-day, 2-year low flows. SIR2009-5015 for various regions in the state of Idaho in the US.

Full Screen / Esc

Printer-friendly Version

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Discussion Paper



We have added the reference.

P1516 L20-25: Briefly describe the distribution of the gauges and the reason for their placement across the network. Did intermittence have any bearing on the distribution of the gauges in the network? How were the gauges that the authors excluded because of modifications (reservoirs, diversions, abstractions) distributed in the network? (3800 total gauges and only 628 used here and 763 used by Snelder et al. 2009) Were areas related to environmental variables used in the models? Would the distribution of modified flow regimes potentially affect the uncertainty of model predictions for certain HER regions compared to others? If so, on any these, fronts then the authors should account for these in their analyses and/or interpretations/explanations.

See responses to Comment 1, Referee 1 above. Historically gauging stations were established close to large cities, and at sites with water management issues. There are many reasons for the placement of gauges, but we do not have that information for the gauges in our study. We removed gauges that the HYDRO data manager had coded as modified. This is stated in the methods. We are not able to comment on whether the distribution of gauges with respect to intermittence varies among the HER regions or whether this influences the levels of uncertainty between HER regions.

P1516 L22-24: Were recording intervals similar across stations that were used to produce daily mean discharge?

All the daily discharges are computed using continuous records using standard devices. There is no reason to suppose that there is discrepancy in recording intervals.

May not apply to gauging stations in this study, but flow events <1 day on ephemeral drainages occur and if intervals are infrequent these might be missed and affect FREQ and DUR.

Intermittency is defined at a daily time-step. We agree that flow events <1 day can occur.

Full Screen / Esc

Printer-friendly Version

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P1517 L1: Provide an explanation of why the authors chose 35 years (but as low as 23 years) for this study but a minimum of 20 years (over 30 year period) for Snelder et al 2009. (628 stations here vs 763 in Snelder et al. 2009). Does having 21% fewer stations with longer periods of records improve differentiating intermittent versus perennial segments? Seems like 20 years should be a sufficient timeframe for characterizing segments as being either intermittent or perennial, but longer periods might improve documenting perennial sites that may be prone to drying under drought conditions (subclass 1 and maybe subclass 2).

More data are generally required to derive reliable statistics for extreme values (such as zero flows). This is the main reason we chose to use a longer period in this study. Our choice recognised the trade-off between the record duration and the number of sites available for the analysis.

P1517 L2-3: Were there stations with years having multiple gaps <20 days?

See our response to the issue of gaps after the following question.

Provide the range for cumulative number of missing days for a year. Please indicate whether or not there were there any gaps <20 day long that occurred immediately prior to or after a zero-flow period? If there were, how were these handled in terms of determining DUR? How might this influence certainty in classifying (and therefore predicting) among the intermittent subclasses? Indicate whether the authors used the calendar year (Jan-Dec) or hydrologic year (Oct-Sept) or some other separation between years in organizing the data. Please indicate whether there were any drying events that extended from one year to the next and explain how these were handled in calculating FREQ and DUR for those consecutive years sharing the same zero-flow period (and thereby affecting mFREQ and mDUR).

We used calendar years of record. Because zero flows tended to be summer events, calendar years reduced the likelihood that periods of zero flow would be split by transitions from one year to the next. We have included an additional plot to show this

[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)[Discussion Paper](#)

(Figure 3).

We have looked at the overall level of gaps in the data used for analysis. Gaps (of any duration) accounted for 0.14% of the days in the entire flow records of all 628 sites. The proportion of gaps in the record was similar for intermittent gauges (0.2% of the days in the entire flow record for these 123 sites.) We have included these figures in the first paragraph of the results section. It is unlikely that such a small proportion of gaps will strongly influence the results.

P1517 L19-21: Was 2.5 km² the drainage area of the smallest gauged catchment? If so, please indicate that here or explain why the authors chose this as the minimum catchment size.

This section is describing the digital river network. The resolution of catchments was limited to 2.5km² or larger. The catchment resolution is determined by the resolution of the DEM from which it was developed. Table 1 indicates that the minimum area of the gauged catchments was very similar to the digital river network (both are shown as 0.3km² in Table 1). We have noted this in the section.

P1518 L14-21: Was the time frame for nDryDays and dDry based over the same time-frame (1961-1990) as the other climatic variables?

No, these variables were computed between 1970 and 2005. We have added this to the manuscript.

P1518 L23-25: Was the 1:250,000 scale maps have sufficient resolution to include channels at all of the gauge locations? Based on the authors' statements on P1514 L24-27, maps of this scale exclude channels. In the US, the 1:250,000 scale maps are consider coarse and exclude many tributary streams (therefore much of the channel length), especially those with smaller catchment areas. Using maps of this scale should underestimate the actual drainage density, but the degree might vary among regions or networks (underestimate drainage density for "round" networks more so than for "long"

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper



networks).

Our results are established and valid for one (national) scale. The objective was to identify national-scale patterns. We agree that our analysis did not include local effects. The spatial scale of our analysis is considered in the discussion section.

P1519 L5-12: Please clarify/specify whether or not Hard and Perm values were weighted based on catchment surface area or some other means.

Yes, Hard and Perm values were weighted based on catchment surface area. This has been clarified in the text.

P1521 L14-15: The DEM-based or the river channel map network?

The digital river network. Clarified in text.

P1526 L16-19: While I think these partial dependence plots are very useful for readers to interpret the variables' relationships to the classifications, how does one objectively separate these types of responses into these 3 types (increasing, decreasing, and U)? To me, Perm response (identified as U) looks a lot like Rain response (identified as decreasing) and the WinSumRain response (identified as U) looks like the Tmax response (increasing) or the Rain response (decreasing). Are these supposed to describe only the pattern between the rug marks along the x-axes? If so, then the patterns might be more clearly differentiated if the authors limit the response line between the deciles.

As these are graphical depictions of data, a degree of subjectivity is involved. We have interpreted the shapes of the responses over the parts of the predictor gradients with the largest density of data (as shown by the ticks indicating the deciles).

P1526 L19-22: Would the low and evenly weighted importance measures suggest that there was also little difference between the reduced model retained and other models?

No. The retained variables can be thought of as making a significant contribution to the predictions. The variables that were not retained made no significant contribution.

Full Screen / Esc

Printer-friendly Version

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P1526 L22-24: Drainage density also insignificant?

Correct. Clarified in the text.

P1526 L26: DEM-based?

Correct. Clarified in the text.

P1526 L25-27: So does the legend in Fig. 8 reflect the probability thresholds in the along the x-axis of the right panel of Fig. 6 and the 39% estimate is based on concluding that all of the segments coded in Fig. 8 with probabilities greater than or equal to 0.35 are intermittent and those less than 0.35 are perennial? Also does this 39% estimate exclude portions of river network with modifications that the authors chose to exclude from the station dataset? If not, then do the authors think a more realistic value would be higher, lower, or about the same (modifications are rare)? Something that could be briefly addressed in the discussion.

Yes the threshold of 0.35 is the “best” threshold to define intermittent and perennial segments. This is a good point and we have added this to the caption of Fig. 8 (Now Fig. 9). The prediction is made to the entire network and therefore represents the pattern of intermittent rivers in the absence of human water resource use. We think the effects of human water use on intermittency are complex and could result in increases or decreases depending on many factors. This is beyond the scope of the present study.

P1526 L28: for consistency suggest capitalizing Hydro-Ecoregions (as on P1516 L9).

Done throughout.

P1527 L13: Should be Fig. 9b (no Fig. 8b)?

Corrected.

P1527 L20: Maybe cite Fig. 7 here as well (to show relationships of these variables with intermittence)?

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper



Done.

P1528 L4-7: Drainage density and SumWinRain also insignificant? Interesting that these were among the best 3 predictors for Snelder et al.'s (2009) flow class 6 (representing intermittent stations), but are not useful predictors here (and drainage density apparently wasn't useful to separate perennial and intermittent). This seems like something that would be relevant for discussion but was overlooked by the authors.

Although this class included intermittent stations, Snelder et al.'s (2009) classification was based on many flow indices so it cannot be assumed that intermittence is predicted by Drainage density and SumWinRain.

P1529: These discussion paragraphs largely restate results and provide little additional insight than what was already stated earlier.

We reduced this to state only important insights.

P1529 L3-5: Suggest inserting "some" between "were" and "significant" because not all geology and climatic variables were useful in predicting intermittence.

Done.

P1529 L25-29: As opposed to what for Subclass 3? This information is again restated on P1530 L12-15.

Subclass 3 is dealt with earlier in the paragraph. We state that these appear to be headwater streams in warm dry locations that have frequent zero flow.

P1530 L1-7: Any snowpack in these regions with steep slopes (eastern France) to supply flows?

Some of them are partly controlled by snow melt processes in the Alps, Pyrenees and Jura.

P1530 L20-27: This points to the possibility of drought (climatic variation at varying

Full Screen / Esc

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Discussion Paper



temporal scales) influencing the weak spatial synchronization. If there are droughts that do not occur simultaneously over the entire country, wouldn't one expect that all stations would exhibit the same temporal pattern? Frequency is not always a clear measure of intermittence. An extremely dry year or ephemeral stream may result in just couple dry event that may last very long durations and interrupted by a single short flow period, whereas a less extreme dry year or stream with periodic connections to groundwater may have several drying events of short durations.

We agree that weak spatial synchronisation may occur at whatever scale the drought is manifest and do not necessarily occur simultaneously over the entire country. This is why we analysed spatial synchronisation at many spatial scales (using Mantel correlograms). We agree with the second point that frequency is not the only measure of intermittence. This is why we analysed spatial synchronisation using both the frequency and duration indices to describe intermittent behaviour.

P1531 L5: How important were the hydrologic indices for zero-flow in discriminating flow classes in Snelder et al. (using the same gauging stations) relative to the other kinds of hydrologic indices? How well does Snelder et al (2009) flow regime class 6 (“intermittent-flashy regime”) align the authors' assignments for stations in present study and with intermittence probabilities on Fig. 8 in this manuscript?

Class 6 in Snelder et al (2009) is consistent with the prediction of intermittence in small streams adjacent to the Mediterranean coast (i.e., HER region 6) in the present study. However, Snelder et al (2009) included a wide variety of other indices so their Class 6 does not include many other locations across France that the present study has identified as intermittent.

P1531 L9-11: This was not already reported/interpreted in the Snelder et al. (2009) paper?

This statement is important in the context of the present study. The Snelder et al. (2009) paper implicitly recognised that a wide range of indices were being combined to

[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)[Discussion Paper](#)

define the flow classes.

P1531 L29: Perhaps the ordinal assignment of geology make this a coarser predictor variable also? More detail on thickness and associated soil information might improve the predictive power?

Perhaps, geology and soil information is qualitative and has to be interpreted in hydrological terms. However, we don't have access to finer geological / soil information at such a large scale.

P1532 L1-5: The authors' language suggests a certainty that smaller-scale factors are needed to improve the predictions. While I do not wholly disagree with this statement, how it is stated seems a bit strong considering no data is presented here to support it. We have edited this to only suggest that smaller-scale factors would improve our models. Another consideration for the fair to poor performance of the models developed in this study that the authors do not address is that stations could vary more in other aspects of their hydrology (many detailed in Snelder et al 2009) than just DUR and FREQ and these other aspects or indices have associations with the environmental variables used in this study. This seems to be supported by what is presented in Table 3 of Snelder et al. 2009. Compare, for instance, flow classes 6 and 3, both of which based on Figure 3 have stations with periods when mean daily flows are zero. The PCA axes centroids for these two classes varied across other PCA axes than just PCA axis 9 (only accounted for 3% of the explained variation across all stations) which had the strongest correlation to DUR and/or PCA axis 6 (also only accounted for 3% of explained variation) which had the strongest correlation to frequency of low flows.

We do not think it is fruitful to compare these two studies in this way. As stated above the classification of Snelder et al (2009) includes many indices representing many aspects of flow regimes including; variation of flows, magnitude and duration of annual extreme flows, timing or predictability of flows, frequency and duration of high and low flow pulses and rate and frequency of changes of flow.

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

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P1532 L18: Clarify please what is meant by “reconfiguring the gauging network.” Do the authors here saying to move gauges from perennial to intermittent segments? Locating gauges randomly or probabilistically throughout the network?

We have replaced “reconfiguring” with “supplementing”.

P1532 L26-28: Particularly subclass 3 intermittent segments.

Agreed.

P1533 L3-5: Depends on the HER, correct? The drier and warmer HERs have higher error and a tendency to over predict gauges are intermittent according to Figure 9. Why didn't the authors include HER class as a predictor variable in the RF? Seems like that might be important predictor and support this statement.

This statement is based on the overall result and we consider it is true for that given r^2 was 0.73. The purpose of our models (in part) was to evaluate environment – intermittence relationships. Using the HER as predictors would not allow us to interpret these relationships.

P1533 L7-8: see also Ademollo et al. 2011 Trends in Analytical Chemistry 30:1222-1232 (did not carefully edit the references, these are just a couple typos that I happened to notice)

We have edited the references.

P1534 L7: Author name spelled differently than on P1533 L12.

Changed Benitoa to Benito.

P1537 L18: Should be “in the arid Negev”

Changed.

Table 1: Are these values for drainage density and Shape correct? How does one have a drainage density or Shape of zero? Is this because of the map scale used?

[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)[Discussion Paper](#)

Or are the values very small and the authors chose to round down to zero? If the later, then maybe show as e.g., >0.0001 . What about zero values for Hard and Perm? Do catchments with zero for these variables not have any of the geological categories listed in Table 2?

This was a significant figures issue. Corrected.

Values for Hard and Perm were errors. The minimum values are one as the categories are exhaustive.

Corrected.

Table 1: Check descriptions for Chalk and Lime.

Corrected.

Figure 1: spell out HER

Done.

Figure 2 (legend and heading): throughout main text these are called intermittence subclasses.

Corrected throughout.

Figure 3: y-axis labels move to left side for FREQ.

Done, also rotated X-axis labels.

Figure 4: Would be useful to identify the stations that were misclassified by the flow intermittence model (circle symbols or use inset). Could also identify those intermittent stations that the flow-regime classification model misclassified or at least indicate in the text how misclassifications were distributed among the 3 subclasses.

Done.

Figure 6: Spell out/define ROC and PCC in heading. Describe what the black circles

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper



represent in the right panel.

Done. The black circles on the threshold plot indicate the probabilities thresholds that maximize the classification performance as measured by Cohen's kappa and the percent correctly classified (PCC).

Figure 8: Legend includes one bin for "0.3 – 0.3" Is this supposed to represent the 0.35 probability threshold from which the 39% was derived? If so, please add explanation to the figure heading (maybe label as "0.35 threshold" in legend) ; otherwise delete this bin from the map and legend.

This was an error. Corrected.

Figure 9: Capitalize Hydro-Ecoregions in figure heading for consistency and follow with abbreviation in parentheses (later in heading referred to by HER). Maybe consider referencing Figure 1 in this heading. How balanced (relative to their area) are the stations across the various HERs? It requires the readers to look between Fig 1 and Fig 2 to give some sense of the distribution. If one considers HER 13 (Landes) it doesn't appear that there are as many stations in this HER as some of the others. So only 2 intermittent stations across only 8 or 9 total stations could make the proportion of intermittent gauges appear higher than it might actually be had more stations been located in that HER. Showing the total number of stations for each HER will help the readers more fully interpret Fig 9. Perhaps an efficient way to do this would be putting the number of stations within each HER in parentheses in the legend of Figure 1.

Done.

Figure 10: In the main text these are referred as 3 "subclasses."

Done.

Please also note the supplement to this comment:

<http://www.hydro-land-ecoregions-discuss.net/10/C954/2013/hessd-10-C954-2013->

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