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Hydrology and Earth System Sciences Discussions

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Interactive Comment

Interactive comment on "Developing a novel approach to analyse the regimes of temporary streams and their controls on aquatic biota" *by* F. Gallart et al.

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We want to thank the Editor for the successful choice of two expert reviewers and the two reviewers for the effort they made to understand, discuss and improve the manuscript. We realise that this is an intricate paper because it does not follow the classical structure of scientific papers and it makes some working propositions not yet fully validated in the experience. Yet, the paper has been written by both hydrologists and ecologists and tries to meet some compromises that may be somewhat confusing and not agreed by all specialists.

Preliminary comment

As a global response to the reviewer's queries, we decided to make a relevant forward change in the more challenging part of the paper: the 'aquatic states' definition. We realised that the names we used to define these states raised confusions with the names of the features or mesohabitats: we used 'riffles' and 'pools' for both the features and the states. Therefore, mimicking the widely accepted nutrient availability grades in aquatic Ecology (i.e. Eutrophic, Mesotrophic, Oligotrophic), we used the Greek suffix 'rheos' as indicating flowing water and renamed the proposed aquatic states as 'Hyperrheic' (exceptional flow), 'Eurheic' (full flow), 'Oligorheic' (scarce flow) 'Arheic' (no flow) and 'Hyporheic' (subsurface flow). For the driest sate, as it characterizes a condition when alluvium moisture is similar to the moisture in soils elsewhere, we selected the term 'Edaphic', suggesting that this is no more an aquatic but a terrestrial environment. This last term was preferred to 'arid' to avoid any conflict with climate types, as this aquatic state may happen in headwater streams of humid areas with a wide range of water content in the alluvium. We will open the possibility to further define a new 'Mesorheic' state as a drier version of 'Eurheic' state when there are still some riffles but the contact with the riparian vegetation is lost (Boulton, 2003).

Following the suggestion made by referee #2, we enclose a table with this new nomenclature compared with the other available approaches for the 'aquatic states' in Table 1.

We have to recognize that the proposal of these neologisms opened a debate among the co-authors; particularly hydrologists have a more quantitative culture and are reluctant to manage classifications with terms of Greek or Latin origin.

Referee #1 Specific comments (referee comments shown between [brackets])

[The title highlights the control of temporary streams hydrology on the aquatic biota. However the authors are vague when describing the mechanisms by which flow regimes influence the biota. The authors should either adapt the title or improve this aspect throughout the entire manuscript.]

More details will be given on these influences throughout the manuscript. Particularly, the following sentences will be included:

"If attending to extreme states, Floods are considered to be important disturbance events on aquatic biota, as they imply an indiscriminate "washing" effect of most species. Only the most resilient and resistant species are found just after a flood event. This obviously diminishes ecological quality metrics if sampling is done recently after a flood. On the other edge, no aquatic invertebrates –except in resistant forms (e.g. cysts, cocoons, diapausing eggs) – are present when there is no surface water. Even, when only Disconnected Pools are present, biotic communities are not representative of the actual ecological status of the stream since conditions may vary among and within pools along time depending on many factors (e.g. pool size, stochastic assemblage of refugees. . .) even in reference conditions. Only when flow is present (either in the Eurheic and Oligorheic states) the diversity of habitats and the environmental conditions are the adequate to sustain a biological aquatic community representative of the biological quality. Only in these two cases is possible to apply the ecological status metrics used for permanent streams."

[The method has a main weak point: the definition of the boundaries between aquatic states. It is, in my opinion, essential to determine whether the estimation of threshold flow values without field observation is sufficiently accurate and reproducible among scientists before the method can be used routinely in temporary stream studies. The authors identified these issues and are currently conducting research to address them.]

Indeed, this is the main weak point of this part of the method. Nevertheless, this is not a particular problem of our approach, because the other available approaches published which define comparable states are similarly subjective and less quantitative when defining the boundaries between them. Anyway, the difficulties to determine the aquatic states from available flow records and to predict them with rainfall-runoff models are

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not an argument against the validity and possible usefulness of these states. Given the present methods, the aquatic states are only identifiable by field surveys and related to measured water discharges by direct comparison. Nevertheless, it may be expected that emerging technologies (e.g. LIDAR, RADAR) will hopefully make possible the remote identification of these transient states in extensive drainage systems.

As we are aware of these limitations, we used the information on the occurrence of the aquatic states only as a diagrammatic form in the Aquatic States Frequency Graph, and we renounced to use this information for more quantitative or classification purposes. Yet, if 10 years records are used, the resolution of the monthly frequencies can not be larger than 10%, so these statistics can not be used in a more rigorous manner.

On the other hand as we recognize that there are many differences between temporary streams, this point is left open for discussion and in each stream the exact method to decide the threshold may be adapted to the particularities of each stream.

[The method is poorly performing when dealing with the analyses of the drier aquatic states. This is problematic because the drier states are most likely to impact biota strongly. Moreover, promising avenue of the method consists in the framework it offers for the study of these drier stages. The authors should discuss in more details potential solutions to overcome this limitation.]

The problem with drier states is that there is practically no information on their occurrence. As recognized by this reviewer, we tried to open the method to analyse also the drier states, although we were nor able to get information on their occurrence. Remote sensing of ground moisture and water balance modelling are methods that may be considered to overcome this limitation and will be included in the discussion of the revised manuscript.

From the point of view of biological communities, the differences in drier states are not much relevant. Aquatic communities are substituted by terrestrial communities and at the moment no method to establish the ecological status using terrestrial invertebrates has been defined. The MIRAGE project has worked in this topic but no definitive results are available.

[The authors are, in my opinion, right when saying that biological sampling should be adapted to the hydrological regime. However they remain elusive when explaining how to determine the optimal sampling period. The authors did not discuss the possibility of pooling seasonal biotic samples for an entire year to account for temporal variability. Addressing shortly these issues would improve the repeatability of the method.]

For all the above reasons (effects of aquatic states on biological communities), the ecological status can only be measured when the stream is at the Eurheic (riffles) or Oligorheic (connected pools) aquatic states, and this condition has been present for at least 3 months prior to sampling in order to let biological communities to assemble. Under these hydrological conditions, the same methodology as used for permanent streams can be applied to temporary streams (García-Roger et al. 2011). Other methods more adequate for drier conditions were investigated within the MIRAGE project but are beyond the frame of this paper.

The current methods to establish the ecological in the European Water Framework Directive require only one sample per season at the most representative time of the year. This time is usually in the spring (but depending on the previous flood), specially in Mediterranean temporary streams. Living organisms in intermittent streams are adapted to the presence of a dry period and the relevance of this period may be deduced from the presence of a community whose richness and diversity do not change in a range, with some minimum values in dry years and maximum ones in wet years, as has been demonstrated by Munne and Prat 2011. Furthermore, we hope that our approach will provide a framework making easier further research on this field.

[The authors spend considerable efforts describing the ecologically relevant aquatic states with the goal of evaluating the ecological quality of temporary streams using fauna characteristics. However there is few information on how these states influence

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the aquatic biota beside the fact that the hyporeic zone can serve as a refugee during dry periods. The reader has to dig into a large list of reference. Although well known,a few sentences summarizing how the functional and structural characteristics of the aquatic biota change according to these states will improve the message. The same is true for the influence of streams with high/low Mf and Sd values on the biota?]

This point will be tackled together with the first one in the revised manuscript. We will claim that the influence of the availability of the diverse mesohabitats on biota is well known by ecologists, has been repeteadly explained in the literature and several papers are being cited, some of them from some of the authors of this paper (e.g. Bonada et al, 2006, 2007).

[The authors highlighted the possibility to adapt the method using EC and temperature data. However the discussion about the method to, and the advantages/disadvantages of doing so did not go over the fact that few data are currently available. Several questions that, in my opinion, can be answered easily in a few sentences were left aside. What are the advantages/disadvantages of EC and temperature over flow data? How can we adapt/improve the method using the former two metrics? Which type of data is, according to the authors, the best for applying the method (beside considerations of the availability of the data)?]

These methods were taken from the literature as used for obtaining information on the permanence of water in pools when discharge is no more measurable. Electrical conductivity should provide the best results, because it may inform not only on the presence of water but also on its quality, but sensors are more expensive and less reliable. Temperature records may provide also information on the presence of water, the sensors being cheaper and more reliable. The combination of the two types of sensors in a reach or set of pools would hopefully provide the best results. However it should be noted that temporary streams are very variable in EC and temperature regimes, so the use of these sensors will be region-specific and for this reason the method should be implemented according to regional specificities.

[In addition, providing more explicit or detailed explanations concerning certain aspects will improve our understanding of the method. Below is a list of bullet points that summarizes these aspects:

-The link between ASFGs and Mf and Sd should be stated more explicitly: it is not clear how complementary these two things are and how they can be complementarily used in practice.]

The ASFG is more informative but undergoes some subjectivity in the selection of the flow thresholds. On the other hand, Mf and Sd6 do not inform on the temporal pattern of the states, but they are much more objective, as the only threshold is the 0 flow value. Mf and Sd6 are used as descriptors of temporariness and predictability, two issues that define temporary streams. Through the combination of these values we can potentially analyze a gradient of streams: from ephemeral (short-lived and highly unpredictable) to permanent (constant and completely predictable) streams.

Mf and Sd6 are indicators of the river regime and its shifts along intervals of time of at least of one year, but the river regime does not inform of the actual availability of habitats for the aquatic fauna. ASFG provides this information, and the ASFG may be different from one river regime to another or even in a same river regime,depending on other factors not detected by the metrics.

[-Can we compare the ASFGs in a more formal and/or quantitative framework than by simply looking at the patterns on the graphics?]

As commented before, the relative subjectivity of the selection of the flow thresholds between states and the limited length of the records dissuaded us to use more formal or quantitative analyses of this information. Furthermore, as previously specified, the flow thresholds are more site-specific and the exact method to establish them depends on the stream.

[-What are the patterns of the flow duration curve that suggest a minimum discharge threshold?]

When monthly discharges were aggregated from daily ones, spare points of very low discharges revealed the occurrence of null flows within these months. When monthly values were obtained from models, a loss of linearity and a sharp decrease in discharge may be used as a proxy to detect minimum discharge threshold. This part is also open for further discussion, if the method is being applied by more people, patterns of how to define the thresholds will appear, and probably they will be more regional than global.

[-Table 2. can potentially be moved to supplementary material + it is not clearly stated whether the authors used a correction algorithm (e.g. Bonferonni, Holmes) for multiple testing when assessing significance? If not, this should be done.]

The alternatives of moving the table to supplementary material and making the Bonferroni correction for multiple test will be considered

[-Although the message behind Table 3 is clear, it would be difficult for me to repeat the same analysis. More detailed explanations on how the maximum likelihood factor analysis was done and how the factor loading were calculated would improve the repeatability of the method.]

This analysis was simply made to show the value of the Sd6 metrics as complementary to the Mf one. A more formal description of the method will be made if it is retained in the revised manuscript.

Referee #2 General comments

[This large group of authors has proposed a framework that can be used to conduct assessment of temporary rivers using information extracted from the hydrologic record, or from streamflow simulations. Clearly, temporary streams are hydrologically and ecologically distinct from perennial streams, and the simple adoption of classical methods from perennial streams is inappropriate. In this reviewer's opinion, the authors are not sufficiently assertive in making it clear that methods from perennial streams are a poor

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fit.]

It has been clearly stated elsewhere that methods used for the ecological status assessment of perennial (we have used the term “permanent”) streams are not always adequate for temporary ones (Dewson et al. 2007; Buffagni et al. 2009; Munné and Prat 2009; Benejam et al. 2010; García-Roger et al. 2011). First, a higher incidence of pool mesohabitats occurs in temporary streams so a mesohabitat-based approach is needed (i.e. taking a number of samples proportionally to mesohabitat relative frequency; see García-Roger et al. 2011). Second, a sampling calendar is needed in order to make comparable the results from perennial and temporary streams, hence sampling should be restricted to those periods in which water effectively flows in the temporary streams. In drier conditions, this kind of methods is simply inadequate. This study is being used to better characterize the hydrological conditions what is important in the design of sampling campaigns when dealing with temporary streams. We have cited all these works in our ms within this context. Nevertheless, we will rewrite the relevant paragraph to make it more explicit.

Munné and Prat (2011) demonstrated that the performance of classical methods for evaluatng the Biological Quality are more dependent on the antecedent conditions (wet or dry) than on the season (spring or summer), and this is true for temporary streams. In many studies and even in the intercalibration exercise of the EU, it has been demonstrated that if temporary streams flow for at least three months in winter-spring time, the richness and diversity is similar to permanent ones, and biological metrics used for permanent streams (including the ICM-Star method) can be applied.

[The manuscript has considerable promise, but requires major and extensive revisions and further review. The major concerns are identified in my comments to the authors below, but the main points are: - The paper suffers greatly from the lack of detail about the hydrology of these temporary rivers. In general this class of rivers is very diverse and different types have unique properties and it is difficult to determine if these eight represent much of that breadth.]

The purpose of the paper is not to explore the hydrology of temporary rivers; this has already been made recently by other authors (e.g. Kennard et al., 2010) using extensive data sets. On the contrary, we tried to define a small set of tools fully adapted to the temporariness of the stream regimes, based on the current knowledge and usable with limited information. Indeed, the types of streams analysed in the paper are very limited and within the Mediterranean climate, but the methods were designed taking into account other types of climates. Frankly speaking, the main methodological limitation is the fact that the Sd6 metrics uses a 6-month period to analyse the predictability of the flow occurrence, but it was named this way precisely to open the possibility to be modified for analysing shorter (Sd3) or longer (Sd9) periods that might be more adequate for other types of climate.

The purpose of the authors is clearly explained in table 3; we are exploring the aquatic states and use them for measuring the ecological status only when the conditions are appropriate for it.

[- The graph they propose should not be based on percentage of available habitat, but amount of actual habitat and the amount of streamflow.]

This question suggested us that we did not succeed to adequately explain the concept of 'aquatic states' and the resulting Aquatic State Frequency Graph, and lead us to modify the names of the states into Hyperrheic, Eurheic, Oligorheic, Arheic, Hyporheic and Edaphic (see the preliminary note and Table 1).

Note that the Aquatic State Frequency Graph (Figure 4) shows the monthly (temporal) frequency of each aquatic state but not the spatial pattern of mesohabitats. The spatial distribution of the diverse habitats in the studied reach at the survey moment is pooled into a single class of Aquatic States. These aspects will be explained in more detail in the revised manuscript.

[- The 'classification' they propose suggests new uses for words that are part of the temporary rivers lexicon and will only confuse the situation if adopted. A better solution

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would be to use the hydrological terms for the hydrology and ecological terms for the habitats.]

One of our main targets of the research conducting to this manuscript was to merge hydrological and ecological aspects. The definition of the aquatic states in the Table 1 above is the best example of this effort. We hope that the changes in nomenclature here introduced will provide an acceptable response to this question

[- The manner of determination of thresholds is unclear and does not appear to be robust or generic to temporary rivers. This might only require them being more specific about how they determine the thresholds for these eight rivers, but they should be much more cautious about suggesting that these could be used more broadly.]

If the reviewer refers to the flow thresholds defined for the aquatic states, the question has been already addressed above. Alternatively, reviewer may be referring to our proposed interim differentiation between regime types (permanent, intermittent with pools, intermittent-dry and episodic) based on combinations of two metrics: flow permanence and seasonal predictability. We recognize in the manuscript that the thresholds are interim, but we claim that they are based on the available classifications, that use criteria less adapted to the temporary streams than ours, or need long data series rarely available in temporary streams

[Throughout the manuscript the English is difficult to follow. Sentences are frequently unclear, very awkward, or often not even sentences. As none of the authors appears to be a native English speaker, I have tried to suggest alternative wordings that might address these problems, at least sufficiently so that I could make my points. The manuscript clearly remains in needs of a thorough English edit. These types of sentences are highlighted in the accompanying pdf. In many places, I have made suggestions in my detailed comments below. These have been highlighted in the attached ms, and so suggestions made in the detail comments.]

The suggestions are welcome. A professional native English speaker will check the

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revised ms.

Key parts to the process:

[While the plot is an intriguing proposal, it might be better to develop this not in a percentage basis but an area basis, since the amount of aquatic habitat is also highly variable. In addition, it is likely that within a type there will be large community differences between the start of a type and the end of a type. As a hypothetical example, when a pool forms there will be early colonizers, yet after prolonged dry periods the pool will be smaller in volume/area, the community is likely to have changed and as the pool disappears, the community will no doubt be different to when it was formed.]

As stated before, the frequencies in the ASFG refer to the monthly (temporal) frequencies of the states (transient sets of mesohabitats occurring in the reach) and not to the spatial frequency of these mesohabitats in the reach.

In fact, our method aims mainly helping the establishment of a calendar for the better moments for representative biological sampling. As stated in the ms, these aspects have been developed and put in practice in García-Roger et al. (2011).

[Need to provide a convincing argument that a hydrometric record can provide generalized criteria that are 'universally' applicable to temporary streams. They propose the same for approach for simulated flows. It is never made clear how the turn points are 'assigned' on the flow duration curve.]

As stated above, there are not universal threshold flow values between aquatic states for temporary streams, but these are adapted to each stream. It depends on so many variables (size of catchment, riparian forest, geometric characteristics of the reach, permeability of the channel bed...) that universal thresholds can not exist. Turn points are assigned on the basis of field observations and hydrological measurements.

[The authors should reconsider their proposed terminology. The terms they suggest are already in the temporary streams vocabulary, and I suspect that this will promote confusion. A solution would be to adopt the hydrological definitions of ephemeral, intermittent, and episodic, and then couple these to the ecotype: pool, riffle etc. Then one could associate a difference between a perennial pool, an intermittent pool, an ephemeral pool, and an episodic pool. Such definitions the ecosystem feature.]

A new terminology is proposed above.

Specific comments (only the more relevant questions are addressed here, whereas most of the other comments will be used for improving the manuscript).

[Page 9. line 8-14. These choices [month, 10 years, and 50-100 m] seem pretty arbitrary and do not seem to be supported in any way in the text. Broad implementation of such a framework will require more critical thought. In other geographical locations, the presence of water is seasonal and regular [monsoons, snowmelt] but of much shorter duration that months. In other place the presence of water is shorter and less reliable – winter convective storms – but occurs over a much longer time period. The framework needs to be adaptable to these other condition and not only to a few streams in the European Mediterranean. Similar for the other measures – is 100m a reasonable length for all streams? Is 10 years of data sufficient? It is not appropriate to propose a framework the limits these parameters and assume that these are sufficient.]

We selected these scales, as 50 - 100 m is a sufficient length in such small streams for a good sampling of mesohabitats (Buffagni et al. 2006) and one month of duration is usually sufficient for the development of the aquatic fauna. Shorter temporal scales might be also used but we wonder if these would provide good results because the time needed by fauna for attaining a sufficient development. On the other hand, a fine temporal scale (one day) would result in too spiky forms in the Aquatic States Frequency Graph, because the short occasional events would not be pooled if the series is not many years old. These aspects will be discussed in the revised manuscript.

[Line 18-24. Before the authors provide a spreadsheet to do such an extraction they need to demonstrate how and why this threshold / flow duration curve provide a robust extraction of the types. I suspect that this would not hold in streams other that those used to develop these thresholds; it would be useful to have hydrographs for these rivers to allow the reader to understand the hydrology of these streams in relation to this procedure. There are a wide range of temporary streams – in some the timing of flow is regular with seasons, in others flow only exists during precipitation events.]

A discussion on the flow thresholds issues has already been made and will be included in the revised manuscript. The analysis of the temporal (monthly) patterns of occurrence of the aquatic habitats may be analysed for any climate type. If necessary, new aquatic states could be introduced in the future, such as one representing the no-flow conditions due to freezing temperatures.

The stream regime classification is just an update of the existing ones, so there is no reason to deem that it would be worse than those. The flexibility of the Sd6 metrics has been already discussed. We agree that hydrographs may help the reader in the understanding of stream regimes, although are not necessary for assessing the thresholds. Anyway, we will consider including them at expense of increasing ms length.

[Page 20 line 19-24. The authors are suggesting that modelled monthly streamflows will meet their needs – without any demonstration of proof of concept, or even any critical thought.]

Within the MIRAGE project several exercises have been made using this method with stream flows simulated by several models (SWAT, SIMGRO, Thornthwaite - Mather, SACRAMENTO) and the results were rather satisfactory. In some cases, there were some differences in the regimes between the observed and modelled flows, which were attributed to the role of water abstractions for irrigation. The main difficulty is that models usually do not simulate zero flows; therefore a threshold discharge must be assessed as null one.

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Aquatic state	Hydrology	Mesohabitats	Hydrological conditions Fritz et al (2006)	critical drought steps Boulton (2003)
Hyperrheic	flood, overbank flow	drift of bedload and fauna	surface flow continuous (4)	
Eurheic	abundant riffles	all mesohabitats available and connected		isolation from littoral vegetation loss of riffle
Oligorheic	pools connected by thin water threads	lentic fauna with most of lotic species present	flow only interstitial (3) surface water present but not visible flow (2)	
Arheic	disconnected pools	only lentic fauna	surface water in pools only (1)	drying pool loss of surface water
Hyporheic	no surface water but alluvium close to saturation	only hyporheic fauna active	no surface water (0)	drying refuges drying hyporheic zone
Edaphic	alluvium moisture as in interfluves	terrestrial fauna and some resistant phases of aquatic fauna		

Fig. 1. Table 1: Characterisation of the six 'Aquatic States' newly renamed.

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