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Hydrology and Earth System Sciences Discussions

Interactive comment on "Hydrologic system complexity and nonlinear dynamic concepts for a catchment classification framework" *by* B. Sivakumar and V. P. Singh

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General Response to Referee Comments (RCs), Short Comment (SC), and Guest Editor Comment (EC)

We thank B. Selle (RC – C2189) and two anonymous referees (RC – C2302 and RC – C2384) for the Referee Comments, M. Sivapalan for his Short Comment (SC – C2426), and Attilio Castellarin (Guest Editor) for his Editor Comment (EC – C2495) on our manuscript.

At the outset, we are pleased with the recognition by the RCs, SC, and EC that our

manuscript addresses an important and interesting topic that is suitable for publication consideration as part of the Special Issue entitled "Catchment Classification and PUB" in Hydrology and Earth System Sciences. The RCs, SC, and EC also recognize that the proposed classification framework is novel and worth-testing. The major concern they raise, however, is that the manuscript does not present implementation of the proposed framework.

We indeed recognize(d) that our classification proposal needs to be implemented on real hydrologic systems for evaluation of its practical applicability and effectiveness. However, we would also like to point out that the germination of an original idea (in this case, the classification proposal), strongly supported by scientific reasoning (in this case, system complexity as a basis and nonlinearity as a suitable methodology), is clearly a fundamental advancement in science. Once the original idea having scientific merit is in the public domain (through publication), its applicability and effectiveness can be tested by ANYONE interested, and it is not a requirement that it must always be tested first by the proposers.

This was indeed our view when we submitted our manuscript, with a new classification framework proposal, supported by our reasoning for considering complexity as a basis and nonlinear dynamic concepts as a suitable methodology (At least philosophically, our view still remains the same). And we are pleased that the RCs, SC, and EC are generally positive on the scientific merits of our proposal, as they also recommend/demand on its testing. While we certainly considered the full implementation of the proposal and have been working towards it since, we must also emphasize that it is a lengthy and enormously challenging task and needs to be carried out in multiple stages (each requiring careful interpretation), as clearly recognized by at least one of the referees (RC – C2302). This is because of the various factors in play, including: (1) the need to apply at least a few methods (that are also preferably supplementary and complementary) to obtain more evidence and gain more confidence in the identification of complexity; (2) interpretation of the above outcomes to properly assess the role

of type and scale of catchments as well as requirements of hydroclimatic data, among others; and (3) selection of the appropriate type and complexity of hydrologic models for further implementation and verification of the classification framework.

In view of these, we believe that one reasonable way forward in the implementation of our classification proposal is to carefully test each step of the proposal as extensively as possible, before moving to the next (as also clearly noted by RC – C2302). This is the approach we have adopted here in the revision, and focused on the essential first step, i.e. identification of complexity. We have employed a popular nonlinear dynamic method, the correlation dimension method, to streamflow data observed at a large network of gaging stations (117 stations) in the western United States. We have identified the complexity of these time series based on their dimensions (which is also an indication of the number of variables dominantly governing the underlying dynamics) as well as on attractors. Based on careful examination and interpretation of the results, we have classified the 117 streamflow series into four distinct groups: Low-dimensional (L); Medium-dimensional (M); High-dimensional (H); and Unidentifiable (U). These results indeed provide clues as to the type and complexity of models that may be appropriate.

Our on-going studies focus on the verification, and possibly confirmation, of the present results through application of still some other nonlinear dynamic-based methods as well some linear ones. Further verification in the future will also be done through: (a) establishing relationships between the data patterns/complexity and the actual catchment/process properties; and (b) studying the outputs simulated from existing hydrologic models and varying their complexities. We also intend to test these on (in addition to the western US) a wide variety of catchments and hydrologic data representing different climatic conditions, catchment characteristics, land use properties, and types of data, among others. Again, implementation of all these steps is a lengthy and enormously challenging task. We will report the details of our investigations and outcomes in our future publications. We hope the revised manuscript, presenting the analysis of

a large number of streamflow time series (117) and also their preliminary classification based on dimensionality and complexity, is sufficient for a technical publication.

With the first step of complexity identification our new focus in the revised manuscript, we have made substantial modifications to the earlier version; indeed, we have almost re-written the manuscript. These numerous changes can be seen throughout the manuscript, and we do not feel it necessary to list them all in our Response. However, we would like to highlight a few major ones here, for the benefit of the RCs, SC, and EC, as well as the audience.

1. We have modified the Abstract, especially the latter part (focusing on the streamflow data analysis).

2. We have modified Section 1 (Introduction) appropriately, especially the latter part (focusing on the streamflow data analysis).

3. In Section 2 (Classification in hydrology: a brief history and scope), we have added some appropriate references (especially more recent ones) to put the classification and our study in a broader context.

4. We have substantially modified Section 3 (Complexity and hydrologic systems) and Section 4 (Nonlinear dynamic concepts and relevance to hydrology). All of previous Section 3 (Sections 3.1 and 3.2) and Sub-section 4.1 have now been combined together and significantly shortened and presented as Section 3. Also, Sub-section 4.2 has now been revised (and condensed) and presented as Section 4, focusing on Correlation dimension method (with Phase space reconstruction described as an initial step of the correlation dimension method).

5. The previous Section 5 (Identification of complexity of hydrologic time series) has now been completely removed. Consequently, previous Table 1 and Figures 1 and 2 have also been removed.

6. The new Section 5 (Data, analysis, and results), presenting the analysis of the

streamflow time series from 117 stations in the western United States, has now been added. The section includes: Sub-section 5.1 (Data), 5.2 (Analysis and results), and 5.3 (Discussion). Also added are: new Table 1 (streamflow stations/data statistics/results) and new Figure 1(a) to 1(h) (Phase space diagrams) and new Figure 2(a) to (h) (Correlation dimension – Local slopes) – results for two sample time series from each of the four streamflow groups identified.

7. The previous Section 6 (Catchment classification framework: a proposal) has now been completely removed (Consequently, previous Figure 3 has also now been removed.

8. The previous Section 7 (Conclusions and further research) has now become the new Section 6. Appropriate modifications have also been made to this section, especially in light of the analysis of 117 streamflow time series.

9. All necessary additions/deletions and other changes have now been made to the References.

In view of these substantial modifications and improvements we have made to our mansucript, we sincerley hope that the revised version is acceptable for publication in the Special Issue “Catchment classification and PUB” in Hydrology and Earth System Sciences.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 8, 4427, 2011.