Response to Anonymous Referee 2

REPLY TO GENERAL COMMENTS:

"The manuscript describes a methodology for the calibration of the hydrological model HYDROGEIOS based on a systematic delineation of Hydrological Response Units (HRUs) defined using a Curve Number approach. The methodology is applied at the Nedontas River basin in Greece where it is shown that it results in good model skill primarily in terms of river discharge. The manuscript is focused and well written, and clearly within the scope of HESS. However even though I believe it is a very well designed application, my opinion is that its scientific contribution is limited."

We thank Anonymous Reviewer 2 for his detailed and constructive review, as well as for characterizing our work as "*very well designed application*". Although we cannot agree with his last statement about the limited scientific contribution of this paper, we acknowledge that our objective was not developing a new hydrological theory or improving an existing one, but guiding practitioners towards providing efficient model parameterizations in the context of hydrological modelling. Obviously, key aspects of the proposed methodology, such as the estimation of CN's, the formulation of hydrological response units and the configuration of the calibration problem, are necessarily based on empirical evidence. Although empiricism may not be attractive from a pure theoretical perspective, it remains essential element of the everyday hydrological practice.

REPLY TO SPECIFIC COMMENTS:

1) A major issue with the present study is the quantification of the relative importance between the model calibration and the model skill. To my understanding HYDROGEIOS introduces a large degree of empiricism to resolve hydrological processes, and key properties might be neglected (for instance there is no reference on the model description concerning snow accumulation and melt). In other words, can the importance of calibration be quantified given the potential limited skill of the model due to its parsimonious structure?

The aim of our paper was to provide a methodology for delineating HRUs within hydrological modelling, on the basis of distributed CN information. The proposed delineation approach can be applied to any fully- or semi-distributed model, provided that the parameters that are associated with the modelled processes are mapped at the HRU scale. In this context, emphasis is placed on the model schematization and parameterization, and not on the model structure (i.e. the governing equations).

The choice of HYDROGEIOS for employing and evaluating the proposed delineation method was made because this model is very flexible in the formulation of HRUs, in contrast to other tools that imply several constraints on the configuration of geographical inputs. In addition, we are very familiar with this model (two of the authors have contributed to its development) and have good knowledge of the model behaviour in such kinds of basins (i.e., with significant interactions of surface and groundwater processes).

It is true that HYDROGEIOS does not incorporate a snow modelling component, which is evidently of high importance in mountainous basins and generally cold climates. It is also true that the representation of snow accumulation and melting would require adding more parameters, thus increasing the model complexity. Hence, one should balance the potential advantages, from a more complete representation of the water cycle, against potential losses of model performance, due to increased complexity (a typical dilemma in hydrological modelling, also discussed in our article). Nevertheless, we thank the reviewer for his valuable suggestion for possible improvement of the modelling framework, which can be implemented in a future version of HYDROGEIOS.

On the other hand, the reviewer's statement about the *limited skill of the model due to its parsimonious structure* is not justified by the case study results, since the model performance at the three monitoring stations was very satisfactory across both the calibration and validation periods, despite ignoring the snow processes. Apparently, in this basin, the snow processes are of relatively limited importance with respect to the other water balance components.

2) They key classification of the CNs is based on the empirical equation of eq. (1). This equation was produced for river basins in Greece and Cyprus and in the present manuscript it is also validated for a catchment in Greece. Could those results be extrapolated to different areas? Was the Nedontas catchment used for the derivation of eq. (1)?

The empirical formula for CN estimation based on permeability, land cover and slope classes was actually derived within a recent research project, involving the collection of flood data across a number of experimental basins in Greece and Cyprus. At each basin, some dozens of flood events were analyzed, to provide, among other things, representative CN values. This formula ensures good fitting to the empirically estimated CNs, which were a little lower than the CN values suggested by the classical SCS procedure that are based on soil and land use data.

Details on the research objectives, materials, data and outcomes, including the derivation of eq. (1), are given in the following report (in Greek, also available at http://www.itia.ntua.gr/ 1495/):

Efstratiadis, A., A. Koukouvinos, E. Michaelidi, E. Galiouna, K. Tzouka, A. D. Koussis, N. Mamassis, and D. Koutsoyiannis, Description of regional approaches for the estimation of characteristic hydrological quantities, *DEUCALION – Assessment of flood flows in Greece under conditions of hydroclimatic variability: Development of physically-established conceptual-probabilistic framework and computational tools,* Contractors: ETME: Peppas & Collaborators, Grafeio Mahera, Department of Water Resources and Environmental Engineering – National Technical University of Athens, National Observatory of Athens, 146 p., September 2014.

Common characteristic of most of the examined basins was the relatively small scale (up to ~150 km^2), the quite significant extent of highly-permeable geological formations and the steep slopes. Therefore, it is reasonable to assert that this formula is safe to use in areas with similar characteristics, while, for basins with very different properties, further investigations may be essential for (a more general) validation.

In the revised version, we will add a paragraph providing synoptic information on the derivation of the proposed formula and its possible range of applicability.

3) Even though it is not the scope of the paper to introduce the hydrological model, more information about the parametrizations (and equations) used for the simulation of the hydrological processes would be helpful.

Obviously, the scope of this paper is not to introduce a new model, but using an existing tool to demonstrate the advantages of the proposed approach. For the reasons explained in our response to comment #1, we preferred employing HYDROGEIOS, which has been successfully applied in a number of hydrological studies in Greece and Cyprus, as well as Italy (Rianna *et al.*, 2011). The model rationale is explained in the articles already published in HESS (Efstratiadis *et al.*, 2008;

Nalbantis *et al.*, 2011), while the full equations of the most recent version are given in the technical documentation by Efstratiadis *et al.* (2014). For your convenience, we have prepared an extended synopsis of the modelling framework in a supplement to the revised version of the paper.

4) To my understanding, model validation (and calibration) is carried out using river discharge which lumps all components of the water cycle. Given the relatively large differences in the magnitude of the rest of the components are there data to validate it? In a sense can the authors prove that the good performance in terms of discharge is a real feature without error compensation between the rest of the components of the hydrological cycle (e,g, ET, leakage etc)?. Can the authors construct an objective function for calibration that includes multi-source information?

Although in Table 4 we only provide performance measures in terms of efficiency, high flow efficiency and average bias at the three monitoring stations, these were not the sole criteria of the calibration problem. Within the configuration of the objective function, we have also assigned penalty terms, to account for unrealistic patterns of the internal model variables, particularly groundwater levels. This is clearly explained in p. 19, lines 16-23:

"For the calibration of the above model parameters the coefficient of efficiency or Nash-Sutcliffe index (Nash and Sutcliffe, 1970) was used, as well as a variation of it, calculated only for the observed and simulated flow values that are above the mean value of the observed time series, in order to preserve the high flows of the hydrograph. As already mentioned, this is a very important aspect in fine time scale simulations, aiming to reproduce the observed floods and their peaks. Finally, a trend penalty was used to control the generation of unreasonable trends in the groundwater level behavior, based on the Mann-Kendall rank correlation test (Kottegoda, 1980, p. 32-34)."

HYDROGEIOS comprises a numerical scheme for groundwater routing through a network of interconnected tanks, representing broader sub-areas of the underlying aquifer. Inflows to this system are the percolation through the saturate zone and the infiltration losses across the river network, while outflows are the baseflow through springs, the underground losses to the sea and the abstractions through pumping (if they exist). The reviewer correctly mentions that a good representation of the total hydrograph (which is actually lumped information) does not ensure a similarly good representation of its individual components, in terms of surface and groundwater runoff (baseflow). For, if the model is let free to generate any possible combination of the two components, it may exhibit a high efficiency by leaving some upstream groundwater tanks empty and, simultaneously, accumulating the excess water in the downstream ones, to provide the desirable groundwater runoff. For this reason, we use the trend penalty term, at least ensuring a reasonable fluctuation of the simulated (yet impossible to observe) groundwater levels.

Moreover, in the hybrid calibration procedure, we assess whether the simulated fluxes result in a realistic water balance; if not, the optimization problem is reformulated (e.g. by changing weights, parameter bounds, etc.) to guide calibration towards more realistic solutions. This is discussed in the following section (p. 9, lines 24-34):

"Parameter optimization was carried out by employing a hybrid strategy, combining human experience and automatic tools (Boyle et al., 2000; Mazi et al., 2004a, 2004b; Rozos et al., 2004), aiming towards a realistic set of parameters that would ensure satisfactory predictive capacity for all model responses … The calibration was then focused on the optimization of the HRU parameters as well as on the most significant groundwater parameters, in order to attain a good fit of the hydrograph at the basin outlet, especially during high flows, and a satisfactory fit of the spring discharges. Once a relatively good solution was achieved, the calibration focused on the improvement of specific aspects of the model responses, while ensuring a realistic water balance of the basin".

Regarding your final question, about the possibility of constructing an objective function that includes multi-source information, in p. 14, lines 14-15 we clearly explain that:

"According to the available information, the user may use multiple criteria aggregated in a weighted objective function."

For details on the criteria used within the parameter estimation module of HYDROGEIOS and the recommended calibration strategy, please refer to the original publication by Efstratiadis *et al.* (2008), as well as to the supplementary material.

We remark that in the revised article, in accordance to the suggestions by Reviewer 1, we will also include some additional criteria, by means of typical flow signatures, to allow an even more comprehensive evaluation of the model performance across the three monitoring sties.

5) The introductory and motivation part of the study is quite unbalanced compared to the rest of the sections of the manuscript. The reader needs to reach page 7 to start understanding what the methodology of the present study is. I strongly recommend the authors to tighten those sections to improve the readability of the paper.

Thank you for this remark. According to suggestions by all reviewers, we will reorganize the material provided in the first two sections, in order to better highlight the key methodological issues of our research and the major questions to be answered.

6) Figure fonts are very small. Please increase them to improve readability.

Thank you for your suggestion. In the revised version we will take care to improve the readability of all figures.

References

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