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Hydrology and Earth System Sciences
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Discussions

Interactive comment on "Calibration of a semi-distributed lumped karst system model and analysis of its sensitivity to climate conditions: the example of the Qachqouch karst spring (Lebanon)" *by* Emmanuel Dubois et al.

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Answer to comments of Anonymous reviewer 2 -2020-06-16

Dear Referee,

We would like to thank you for your comments and positive review that aimed at improving our paper. As suggested, we have reviewed the text and completed the missing information. Hereafter we describe the main modifications that will be made to the document based on your comments. The interactive comments are addressed

first (labeled C#), followed by comments from the annotated manuscript (labeled mC#, comments from the supplementary material).

C1: A lot of important information is provided in the introduction but a clear research gap still needs to be defined, which the authors intent to fill with this particular work. A1: We thank the Referee for this useful comment, and we will provide the missing information by adding L61: "Nevertheless, little information is found in the literature about the use of time series analysis in groundwater flow modeling for complex karst aquifers to enhance model calibration and estimate the sensitivity of water resources to climate change while lumped models seem to be a good tool to address this question."

C2: Some clarification of the spatial discretization of the model is necessary. MIKE-SHE is a distributed model, which is here applied fully distrusted at the surface but it is operating completely lumped in the subsurface of a set of sub-catchments. Using a sub-catchment approach, this seems to be a semi-distributed application of the MIKESHE model using a fully distributed surface routine, right? A2: That is exact, and we agree that clarification is needed on the spatial discretization of the model. Indeed, only the surface routine is fully distributed (atmosphere and unsaturated zone). Lumped reservoirs are used for the saturated zone (at the subcatchment scale – for the five interflowing reservoirs I1 to I5 in Fig.3) and for the entire system with two baseflow reservoirs for the entire study area (reservoirs B1 and B2 in Fig. 3). In order to clarify this point, Fig. 3 will be modified to add the spatialization details at each level, as follows.

Additionally, the L67 (Introduction) will be rephrased as follows: "A semi-distributed/lumped model, composed of a spatially distributed superficial and unsaturated zone, and a saturated zone composed of interflowing lumped reservoirs, developed using MIKE SHE (DHI, 2016a, b), is calibrated here using observed spring discharge time series."

C3: Mangin's method and the decomposition of spring hydrographs are usually applied to hydrograph recessions. Please elaborate how recessions were defined/ extracted for the entire time series. A3: We agree that information on how recessions were estimated from the time series is missing. We will therefore add L142: "Considering the very similar annual recession for the spring and summer period in 2015, 2016, and 2017, annual recession was considered from the last major flood (occurring in March/April) until the first rainfall event in October (Fig. 2)."

C4: Please explain in more detail the model calibration procedure and how it is linked to the spring flow characterization. A4: Indeed, the explanation of how the model calibration is linked to the spring flow characterization was missing. In order to rectify this, L195 will be rewritten as follows: "The model uses 20 parameters defining the atmosphere, the unsaturated zone, the saturated interflow reservoir, and the base flow reservoirs. The time constant of each reservoir from the unsaturated zone is determined from the flow characterization and the recession analysis, therefore reducing the uncertainty in some parameters and the total number of parameters for calibration."

C5: Some clarification on how and how many scenarios were derived from the IPCC projections for the climate change analysis. Mentioning table 2 already here might be helpful. In many regions, climate change is projected to have strongly different effects on P and T throughout the seasons. Why did this study choose a delta approach for entire years? A5: We agree that a clarification on the climate scenarios is needed, and that a mention of Table 2 in section 3.3.5 would be helpful. For that purpose, we will add after L212: "A combination of those conditions for ten consecutive years (annual gradient of warming temperature and decreasing precipitation) were applied to the average year (derived from averaging the monitored daily precipitation and temperature) to obtain seven scenarios of changing climatic conditions for the 2030 horizon (Table 2). If annual gradients have been chosen for simplification purposes, the changing conditions in semi-arid conditions actually concern the rainy season (October to April of the following year) when exchanges between the atmosphere and the system are active (runoff, evapotranspiration, infiltration. . .)."

C6: In the results/discussion, the link between model structure and spring flow characterization is not very clear. A6: We will include this recommendation and rephrase L270-273 as follows: "The previous analyses performed on the time series allowed refining the model geometry by matching the number of reservoirs with the conclusions of the flow characterization. Model parameterization also included setting to fixed values the time constants of the reservoirs, which are usually included in the calibration process. Model uncertainty has thus been reduced by optimizing the conceptual model on the system hydrodynamic functioning (Enemark et al., 2019)."

C7: Can you provide a sketch of the conceptual model of the system? A7: We thank the Referee for their suggestion. However, we believe that a conceptual model of the system by itself would be very similar to Fig. 3 and we chose not to add a new figure. However, we will add more details to Fig. 3 to make it clearer and underline in the text that this figure represents a conceptual model of the system. Please refer to A2 for the modified figure and L333-342 will be rephrased: "Although the model adequately reproduces flow discharge, it underestimates the summer low flows. Measurements recorded during flooding of the spring gauging station might be underestimated due to errors in the discharge water level rating curve for high flow rates. Another explanation could be that the fast flow linked to a highly-developed drainage system is oversimplified in this reservoir model (reservoirs I1 to I5 from Fig. 3). The thickness of the UZ, combined with its lithological heterogeneity, as well simplified in the model (Fig. 3), may contribute to the relatively stable summer low flow by allowing considerable water storage, which is represented by the B2 baseflow reservoir in the model (Fig. 3). In fact, the dolostone could be compared to low-permeability porous media drained by a high-permeability system, thus allowing a large storage capacity in the upper parts of the aquifer. Furthermore, the high degree of karstification of the area, resulting from both the eustatic variations (Messinian) and the quaternary glaciations, leads to a complex drainage system, with three identifiable flow components (fast flow, intermediary flow, and baseflow – Fig. 3) and a probable paleo-network under the current base level. This would enhance the storage capacity of the system, as well as induce rapid flow rate increases (Bakalowicz, 2015; Nehme et al., 2016).”

Revision from the additional material: mC1: L14 and 62: “a semi-distributed lumped model” – this is contradictory. Pick one: either semi-distributed or lumped. The text will be changed to “lumped model”.

mC2: L21: “Climate change conditions (+1 to +3°C warming, -10 to -30% less precipitation annually, and intensification of rain events)” – in which future? 50 years? 100 years? The text will be rephrased into “Climate change conditions at the 2030 horizon (+1 to +3°C warming, -10 to -30% less precipitation annually, and intensification of rain events)”

mC3: L24: “with flow rates decreasing by 34%” – corresponding to what change of Precip? The text will be rephrased into “with flow rates decreasing by 34 % for scenarios with 30 % loss of yearly precipitation

mC5: p°2: A lot of important information is provided in the introduction but a clear research gap still needs to be defined, which the authors intent to fill with this particular work. Please refer to A1 for our answer.

mC6: L67: “A semi-distributed lumped model developed using MIKE SHE” – Isn’t MIKE-SHE a distributed model? I think you need to define early in the manuscript what type of model you use. Please refer to A2 for our answer.

mC7: L127: “Following hydrograph decomposition, the method developed by Mangin (1971, 1975)” – Mangin’s method is applied to hydrograph recessions. Please elaborate how recessions were defined for the entire time series. Please refer to A3 for our answer

mC8: section 3.3.2: Same as above [mC7]: How were recessions extracted? To define how recessions were extracted, we will add this text after L160: “To decompose the discharge flow from the spring accordingly to this concept, all decreasing parts of the discharge flow between 2015 and 2018 were used. The peaks higher than 10 m3/s

were excluded because of the incertitude on the flow measurement, as well as the portions of sub-vertical and too irregular decreasing slope.”

mC9: L180: “into several sub-catchments” – How many? The text will be changed for: “into five sub-catchments”

mC10: L194: “The complete model is therefore considered a classical lumped model for the saturated zone” – but only within each sub-catchment, right? Please refer to A2 for our answer

mC11: L195: “physically-based model” – better use the term "fully distributed" here because it’s about how the model is discretized for its different domains. The text will be rephrased for “fully distributed”.

mC12: L199-200: “Sensitivity analysis was conducted automatically on single parameters using the Autocal function (DHI, 2016) to identify the parameters to which the model is highly sensitive.” – Please add some more detail on how this sensitivity analysis works? Following L200, this text will be added: “The Autocal function performs a local sensitivity analysis by computing the ratio of the perturbation in the simulated discharge flow with the variation of a single parameter, one at a time.”

mC13: section 3.3.5 – Please clarify in a bit more detail on how and how many scenarios were derived from the IPCC projections. A table might be helpful here. Please refer to A5 for our answer

mC14: section 4.1.1 – Please explain this method a bit better in the methodology [Flow rate frequency]. We will add the following text after L126: “The evolution of the slope of the curve between the breaking points gives information about the dynamic of the system and the time series. Dörfliger et al. (2010) classified the possible configuration and their respective interpretation.”

mC15: L275-281 – Please move interpretations to discussion. The aforementioned paragraph only presents the comparison of the auto-correlation and cross-correlation of the simulated and observed spring flow, therefore meaning that the model reproduces the spring discharge correctly. We do not think that this paragraph would fit in section 5 since it does not bring a global and interpretative point of view on the functioning of the system. Therefore, we prefer to keep it as it is.

mC16: L283: “from seven potential scenarios for the study area (Table 2)” – these have to be introduced and elaborated in detail in the methods section. In many regions, climate change is projected to have strongly different effects on P and T throughout the seasons. Why did this study choose a delta approach for entire years? Please refer to A5 for our answer.

mC17: section 5.2 – Can you provide a sketch of that? Please refer to A7 for our answer.

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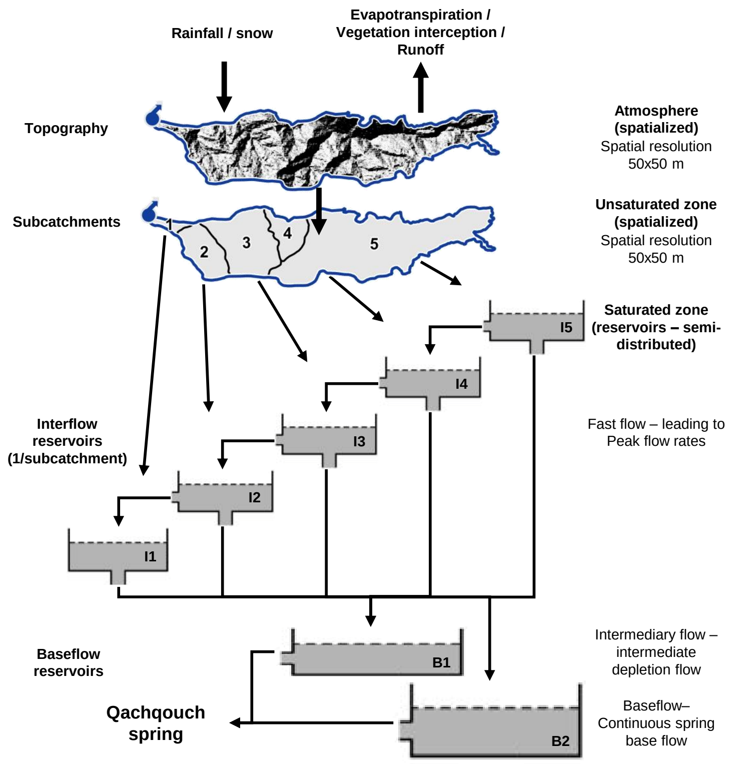

Fig. 1.