

## ***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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Dear Prof. Goldscheider,

We would like to thank you for your review and positive feedback. As suggested, we will rephrase some sentences to clarify the text, avoid repetitions, and correct some mistakes. Hereafter we describe the main modifications that will be made to the document based on your comments (major comments addressed are labeled C# and replies are labeled A#). Minor comments are labeled MC# with the reply directly underneath it.

C1

C1: Title: The title is too long (almost three lines). Please shorten to two lines. A1: We agree that the title needs to be shortened, and we are considering to change it as follows, to also emphasize on the climate change aspect of the work (as mentioned in following comments): “Calibration of a lumped karst system model and application to the Qachqouch karst spring (Lebanon) under climate change conditions”

C2: Abstract: Something is wrong with the first sentence, which is also too long. Please rephrase. A2: We agree that this sentence is too long and needs clarification. To reflect more the climate change aspect of the study as well, this first sentence will be rephrased into: “Flow in complex karst aquifers is challenging to conceptualize and to model, especially in poorly investigated areas, in semi-arid climates, and under changing climatic conditions. It is yet necessary for implementing long term sustainable water management practices.”

C3: 62-65: The research objectives are relevant, but maybe you could add 1-2 additional objectives. Objective no. 2 is very general and could be complemented by a more specific research question, also including the practical relevance of your research, such as the expected climate change impacts and the implications for freshwater availability. Furthermore, objective no. 2 is not completely clear. What do you mean by “its sensitivity” – the sensitivity of the model or of the karst aquifer? A3: We thank you for this useful comment. To homogenize with the discussion section, and as suggested, the objectives of the study (lines 62-65) will be rephrased as follows: “The objectives of this work were 1) to acquire new knowledge of the hydrodynamic functioning of a complex karst aquifer derived from statistical and correlation time series analyses, 2) to illustrate how a semi-distributed lumped model can be calibrated on the basis of this knowledge, and 3) to assess the impact of climate change on the spring hydrodynamic to provide insight on fresh water availability. The approach is demonstrated on the Qachqouch karst spring in the region north of Beirut (Lebanon), a Mediterranean region governed by semi-arid conditions.”

C4: Section 3.3.2 describes the decomposition of spring hydrographs after Jeannin &

C2

Sauter in a very general way, but it is not clear if and how this approach was used in the present study. Similar problem in section 3.3.3. In the “material and methods” chapter, please always say clearly what you did in your study, and how you did it, instead of describing general theory. A4: We agree that information about the use of these methods was missing, and as suggested, a sentence will be added to clarify the use of time series decomposition at the end of the section 3.3.2: “This time series decomposition was applied to the spring flow rates (box 3, Fig. 2) to verify if spring flows could be relevantly linked to three conceptual reservoirs.” As well, the use of correlation analysis in the study will be detailed at the end of the section 3.3.3: “Auto-correlation and cross-correlation analyses were performed on precipitation and on the Qachqouch flow rates time series to estimate the memory effect of the system and the delay between precipitation and the hydrological response of the karst system (box 3, Fig. 2). Auto-correlation and cross-correlation of simulated flow rates were compared to those of the input data, as an additional validation method (box 4, Fig. 2).”

C5: Conclusions: Already in the first sentence of the conclusions, you undersell the importance of your study with respect to climate change impacts on groundwater resources, because you only mention the sensitivity of your MODEL to climatic conditions, which is a rather academic perspective. However, climate change impacts on groundwater resources is a major topic, particularly in the Mediterranean area. I would suggest to emphasize more clearly that your model allows to better predict climate change impacts on groundwater resources, and explain why this is important and how your model could help to make better management decisions. This is a general recommendation, not only concerning the conclusions, but also title, abstract and introduction. A5: We thank the reviewer for this useful comment. To emphasize the climate change aspect of our work, beside the modifications of the title and the clarification of the work objectives (previous comments), the first paragraph of the conclusion (lines 377-381) will be changed to: “This work aimed at acquiring new knowledge of the hydrodynamic functioning of a complex karst aquifer derived from statistical and correlation time series analyses to optimize the calibration of a semi-distributed lumped

C3

model. The model developed for the Qachqouch karst spring in Lebanon (semi-arid climate) was used to assess the impact of climate change on the spring hydrodynamic behavior to provide insight on fresh water availability under climatic constraints. Flow rates were analyzed statistically for a better conceptualization of the system, to allow the calibration of a semi-distributed linear reservoir model. The model was then used to reproduce current conditions and to analyze the impact of dryer and warmer possible future climate conditions on flow rates.” We will also modify the lines 394-396 to underline the use of the main conclusions of the climate change analysis for fresh water management: “The climate change simulations brought new insights about possible future spring flow conditions, therefore allowing decision makers to develop more adapted scenarios for long-term fresh water management. The next steps of management plans should entail coupling of climate change scenarios at the catchment scale with land use change scenarios to improve overall future predictions and investigate solutions to alleviate the expected future depletion of semi-arid karst aquifer systems.”

C6: Figure 1: The graphical quality of this map should be improved. The hatching for geological units is distracting. I would suggest to use transparent colors instead, on top of some more intense grey shading showing the topography of the area. A6: We agree that the graphical quality of the figure 1 needs to be improved. As suggested, transparent color for the geological formations will be used in Fig. 1 rather than hatching, making the new version of the figure as per attachment

MINOR CORRECTIONS: MC1: 16, 17 and elsewhere: m3 should be m3 This will be done as suggested.

MC2: 73: km2 should be km2 This will be done as suggested.

MC3: 80: Rearrange sentence to avoid misunderstanding. The spring is located at 64 m asl, not the aquifer. To avoid confusion about the spring elevation, the misleading sentence L80 will be rearranged into: “Similar to the nearby Jeita spring (Margane et al., 2013, 2018), the Qachqouch spring is located at 64 m asl and originates from the

C4

Jurassic karst aquifer (Fig. 1)."

MC4: 84: quaternary should be Quaternary This will be done as suggested.

MC5: 84: The expression "high level of karstification" is misleading in this case. In fact, the Messinian salinity crisis created a very low topographic level of karstification. You probably mean high degree of karstification, very intense and very deep karstification. As suggested, L84 will be corrected to: "and Quaternary glaciations also contributed to creating a high degree of karstification (very intense and very deep) in the Mediterranean area in several stages"

MC6: 112: Why do you put all measured parameters in brackets? This is the most important information. As suggested, the list of measured parameters will be taken out of the brackets.

MC7: 124-128: three times "was used" on 5 lines. Avoid repetitions. To avoid repetitions, L124-128 will be rewritten into: "Spring flow rates were evaluated by a frequency analysis (Dörfliiger et al., 2010; Mangin, 1971; Marsaud, 1997). Flow rates and their frequency of measurements were linked with a log normal distribution, except for outliers arising from variation in flow dynamics. Following hydrograph decomposition, the method developed by Mangin (1971, 1975) was used to estimate the dynamic volume ( $V_{dyn}$ ) available in the aquifer during the depletion flow of a karst spring."

MC8: Heading 4.1 could be shortened. The heading 4.1 will be shortened to: "4.1 Qualitative assessment of the system"

MC9: 217: "between 44 and more than 50 Mm<sup>3</sup>" (call me pedantic, but "between 44 and > 50 Mm<sup>3</sup>" is an improper use of language and mathematical symbols). This will be done as suggested.

MC10: 290: "increases the reduction" – slightly confusing. Better say "leads to stronger reduction". This will be done as suggested.

MC11: 320-323: Very long and extremely intricate sentence that contains a surprisingly

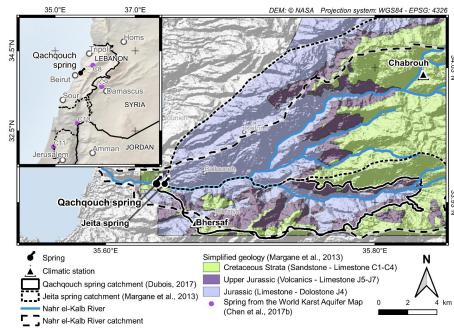
C5

insignificant message. Please split into several sentences, rearrange and rephrase. The sentence of L320-323 will be re-written into: "Even though the Qachqouch karst system has been reported to be less complex than that of the neighboring Jeita spring (Doummar, 2012; Margane et al., 2018), it is still comparable to other Middle Eastern karst systems (Fig. 5). Parameters  $k$  and  $i$ , representing the extent of the phreatic zone, the regulating capacity of the system, and the type of infiltration (Bakalowicz et al., 2008; El-Hakim and Bakalowicz, 2007; Mangin, 1975), classify the Qachqouch spring close to other Lebanese karstic aquifers."

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C6



**Fig. 1.** Location of the Qachqouch karst spring near Beirut (Lebanon).