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Discussions

Interactive comment on "Dynamics of water fluxes and storages in an Alpine karst catchment under current and potential future climate conditions" *by* Zhao Chen et al.

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Reply to comments by Ronald Green on our manuscript "Dynamics of water fluxes and storages in an Alpine karst catchment under current and potential future climate conditions" by Zhao Chen et al.

Reply: We thank Ronald Green for his effort and useful comments that will contribute to further improve the manuscript. According to his comments, we will perform the following changes.

Comments:

The study area is only 35 km2, but varies in elevation from 1,000 m to 2,230 m. Mean precipitation at 1,240 m is 1,836 mm/yr. The study domain has two sub-areas, one is a karst area with a subsurface drainage system. The other is a non-karst area with a surface drainage system. The conceptual and numerical model has a number of sub-basins. The karst sub-basins incorporate a conduit/diffuse flow regime. Discharge is measured hourly at four springs, at varying elevations: 1,035 m, 1,080 m, 1,120 m, and 1,122 m, but only for 11/2013-10/2014 at the two lower springs and 7-10/2014 for the two higher springs. The duration for which data are available is not long. This may be the source for the excessively high estimation of recharge percentage of precipitation.

Reply: We thank Ronald Green for pointing this out. The relatively short time series of discharge measurements is related to the remoteness of this alpine terrain and the difficult accessibility of the springs, which are partly located in steep gorges. We will discuss the possible overestimation of recharge percentage of precipitation below.

Air temperature, precipitation, and relative humidity were measured at nine stations across the study domain. The authors cite Wending and Muller (1984) as the source for the Turc-Ivanov approach to calculate evapotranspiration. This may be an original source for this approach, however it is not readily available (and not in English). The authors might consider adding Conradt et al. (2013) (HESS) as an additional more accessible citation on this.

Reply: We thank Ronald Green for this useful suggestion. We will add Conradt et al. (2013) as the reference for the Turc-Ivanov approach.

Precipitation, temperature, and relative humidity are measured at nine weather stations. Each data type is input at a 100 m x 100 m grid using combined inverse distance weighting and linear regression gridding. I suspect this is key to the ability of the authors to match discharge at the four gauging stations as illustrated in Figure 4.

Reply: We appreciate this observation.

Simulations considered incremental decreases in precipitation in conjunction with incremental increases in evapotranspiration. These changes in input resulted in decreases to recharge. Frei (2004) provides projections for temperature increases by 2030, 2050, and 2070. Gobiet et al. (2014) is cited as a possible source for climate projections.

Reply: For the climate change simulation, only the scenarios by Frei (2014) are considered.

The authors acknowledge that their calculation that recharge is 95.5% of precipitation may be overestimated. They noted that Malard et al. (2016) estimate average infiltration rates for mountainous karst catchments across Switzerland vary between 60% and 90%. The source of the over-estimation may be inherent in the pipe network model used to replicate groundwater flow coupled with the optimization routine used to estimate recharge values. The pipe network software package does not allow for matrix-pipe hydraulic communication. Adding the pipe network to the analysis is an advancement to Alpine water-resource assessment, but not including matrix-pipe communication is a limitation. This could be addressed in future work. Given the high density of precipitation measurement stations (nine) in such a small area, I would think that that precipitation is fairly well constrained. Likewise, all discharge from the basin is measured at the four springs. Unless the basin water budget is not consistent with this conceptualization, it should be possible to provide an independent estimate of recharge using this simplified water budget analysis.

Reply: Our model does consider baseflow resulting from prolonged water storage and slow flow in the rock matrix. This slow flow component is then introduced into the network of karst conduits. It is true that the model is limited in simulating conduit-matrix interaction, but the general configuration of the karst system suggests that at most places and most of the time, the conduits drain the adjacent matrix, because conduits are mostly located in the troughs of plunging synclines. We think that the main reason for the overestimation of recharge is that evapotranspiration is under-

estimated and evaporation from snow is not taken into account. The automatic model calibration constrained the model with the overestimated recharge rate. We will discuss this critical point more in detail in the revised manuscript. Independently, we agree with Ronald Green that the conduit-matrix interaction should be considered in future work to better understand aquifer hydraulics and contaminant transport.

Authors should define FDC. I believe it is Flow Duration Curve, but not positive.

Reply: Yes, it is Flow Duration Curve and we will define it in the revised manuscript.

Are tables 1a and 1b from Frei (2004)? If so, please provide citation. Details on the distributed karst catchment model used in this study are in Chen and Goldscheider (2014). The model was derived from a distributed hydrologic-hydraulic water quality simulation model - Storm Water Management Model (SWMM versions 5.0). The GW system was modeled as a pipe network with no hydraulic communication between the matrix and the conduits. Recharge was input as focused point sources. This modeling approach is possible, in part, due to the relatively small size of the study domain (35 km2) and by virtue of the fact that the pipe network (i.e., conduits) has been well defined using tracer tests (Gremaud and Goldscheider, 2010). This limits the ability of the model to be used for predictive simulations. It would be interesting, that given the fact that the conceptual model of the system is fairly well known, if an alternative mechanistic GW flow model could be developed to test the predictive ability of a model.

Reply: Yes, tables 1a and 1b are based on Frei (2004). We will add the reference. The tracer tests were not done by Gremaud & Goldscheider, who worked in another alpine karst system, but by Goldscheider (2005) and Göppert & Goldscheider (2008). Concerning conduit-matrix-interaction, see our reply above: It is true that the model does not simulate bidirectional hydraulic interaction, but it does consider matrix flow by means of a reservoir model that accounts for water storage and slow flow in the adjacent rock matrix. Most of the conduits are located in the troughs of synclines, so the geological structure of this karst system justifies the selected modeling approach. Still, we agree with Ronald Green that alternative modeling approaches (such as MODFLOW-CFP) could further improve the understanding of this karst system. We are working on that.

The authors used 5000 Latin hypercube runs to determine best fit input parameters. Flow predictions at the four gauges were quite good. There is the risk the authors over-parameterized the model domain. Given the modest duration of data, there was no opportunity to validate the model for time series data not used in the calibration.

Reply: This is a fair comment, and we are aware of this problem. However, in order to minimize the risk of over-parameterization, we have developed a multi-step model calibration strategy (please see section 3.4.2). Furthermore, to better assess the model, despite the relatively short observation period of only one hydrological year, we propose to perform a split sample test by using multiple bootstrapping of subsets of the observation period (section 3.2). This approach is already used by Hartmann et al (2012). We will include and discuss the test result in the revised manuscript.

Two recommendations for future work on this watershed. (i) Validate the model using future data series. (ii) Develop a mechanistic model to replicate GW flow. This should allow for independent confirmation of the conceptual model and state variable properties currently estimated.

Reply: We thank Ronald Green for these two valuable recommendations. We are thinking to simulate the catchment by applying the MODFLOW-CFP, which is able to consider conduit-matrix interaction and can also be used for transport simulations, which is very useful in this case, because we have data from over 16 tracer tests done in this alpine karst system.

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