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Hydrology and Earth System Sciences Discussions

Interactive comment on "Predictability, stationarity, and classification of hydraulic responses to recharge in two karst aquifers" *by* A. J. Long and B. J. Mahler

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Authors' responses to review comments by S. Birk (Referee #1), RC C4645

Reply to general comments: We agree that the paper would be strengthened by expanding the discussion of hydrogeological aspects related to results of statistical analyses. Please see our responses to specific comments below.

Reply to comment 1: Yes, there is a mistake in eqn. 2, where s should be replaced with r, as it appears in Jakeman and Hornberber (1993). This is why it appeared that the higher order terms were omitted in the eqn. 1. This should make sense now,

where eqns. 1 and 2 are equivalent. The normalizing parameter c also appears in Jakeman and Hornberger, which states that the parameter c is chosen so that the volume of effective precipitation (recharge) is equal to the total streamflow volume over the calibration period. We also include c but determine its value in a slightly different way because our application is to groundwater. Jakeman and Hornberger applied this to watershed models, where rainfall input area is assumed equal to the watershed area, and it is assumed that all effective precipitation becomes streamflow. We have found this method useful for groundwater applications, except that we must apply c in a slightly different way because we don't have precisely defined recharge areas as in watershed modeling. Further, for karst watersheds, we often can't assume that the watershed boundaries are equal to the groundwater boundaries. Therefore, the normalizing parameter c can't be determined simply by equating model inflow to outflow. But we know that s cannot be greater than 1, so c must be applied to assure that this is the case. Also, K is a constant and should not have the subscript i.

Reply to comment 2: Yes, this is daily mean temperature. This will be clarified in a revised manuscript.

Reply to comment 3: Yes, a gradual change from wet to dry periods might make more physical sense in many cases. However, in karst aquifers, the change from wet to dry periods might be more abrupt than gradual in some cases because of the large heterogeneities that can exist. For example, different parts of the aquifer are saturated during wet and dry periods, and these different parts can have very different conduit or fracture networks. So, we don't know if the physical system is more gradual or more abrupt. But, we simply found that the threshold behavior related to long-term mean precipitation was an approach that produced good results, both for calibration and validation. It's true that this could be more directly related something like soil moisture, but it's more likely a combination of factors. The simplicity of this approach is certainly an advantage, particularly for application to the classification approach. Also, other approaches have scaled the magnitude of the IRF in accordance with precipitation, but this does not allow a change in IRF shape, which turned out to be important for our models. To adjust both overall scale and shape of the IRF continually would be overly complex for a lumped parameter model. The reviewer brings up an excellent point, and we will add a discussion of this in a revision.

Reply to comment 4: The statement about the 1-year moving average was an error in the manuscript. We actually used a 6-month moving average. Further, on the basis of this comment, we have decided to use a 4-month moving average to better capture seasonal variation.

Reply to comment 5: This is an excellent point and one that deserves a major revision of section 3.5. Upon further analysis, we can make several points to address this, many of which originated from the reviewer's suggestions. Because the differences between the wet- and dry-period IRFs seemed to be very informative, we have added an additional metric to better describe these differences. Several inferences can now be made to relate the revised PCA results to the physical systems.

The general curve type, either lognormal or exponential, that primarily composed each of the IRFs was the primary factor in relating the sites' IRFs to hydrogeologic factors. The two major categories, exponential and lognormal, have different plotting characteristics in PCA and also are separated spatially within the two aquifers. For both aquifers, hydrogeologic differences exist between these two areas. The Edwards aquifer is wide in the area occupied by the lognormal category, where groundwater flow is circuitous; the aquifer is narrow in the area occupied by the exponential category, where groundwater flow is generally straight. The circuitous flow path might be related to the delayed response defined by lognormal IRFs. For the Madison aquifer, the area occupied by the lognormal category is near the axis of the main anticline that defines the Black Hills uplift, where fracturing and subsequent development might be related to IRF characteristics.

Differences in springs and wells also were considered. Springs commonly discharge

water from a large surrounding area, whereas none of the wells used in this study are pumped. Despite these differences, there is no apparent distinction between springs and wells that is evident from PCA (figs A & B), which indicates that the difference between springs and wells is small compared with regional differences in the aquifers.

On the basis of revised PCA results, the Madison aquifer seems to have larger heterogeneity than the Edwards aquifer. First, the separation in principal component space of Madison aquifer sites, which is a measure of IRF differences, is significantly larger than that of the Edwards sites based on a rank-sum statistical test. Second, the Madison aquifer has larger differences between wet- and dry-period IRFs than does the Edwards aquifer. Third, the Madison aquifer has all four of the double-peaked IRFs, which suggests greater differences between conduit and fracture porosity for the Madison.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 9, 9577, 2012.