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Discussions

Interactive comment on "Thermal damping and retardation in karst conduits" *by* A. J. Luhmann et al.

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The subject paper builds on a sequence of recent papers that explore heat flow through karst media. The mathematical development builds on work by Hauns et al. (2001) and Covington et al. (2009, 2011, 2012) using data from a field-scale experiment described in Luhmann et al. (2012). Much of the mathematical model in the subject paper is introduced in the Hauns et al. (2001) paper and further developed in the Covington et al. (2009, 2011, 2012) papers and the dissertation by Luhmann (2011). The subject paper clearly describes the governing equations. The authors then discuss at length analytical and numerical solutions to the advection-dispersion equation to evaluate thermal damping and retardation for cylindrical and planar geometries chosen

for representing karst solution features.

The authors solve the equations for a sinusoidal signal chosen to represent the pulse of heated and tagged water injected into a sinkhole during the field-scale experiment. The authors make simplifying assumptions when solving these equations. Although solving the equations without making these assumptions would be challenging, there is some question whether these assumptions are appropriate. Of concern is the assumption of constant velocity. In particular, the temperature of the water input into the cylindrical or planar conduit is represented as sinusoidal but flow is constant (Eq. 34).

The field-scale experiment was described in a separate paper by Luhmann et al. (2012) which described how a volume of 13,000 L of water was heated and spiked with tracers, then injected into a sinkhole in 3-1/2 minutes. The temperature of the injected water was not reported, but groundwater temperatures at the spring discharge located at a distance of 95 m increased by a maximum of about 2.5âĂŸC. This input is consistent with the assumption of sinusoidal temperature at the upstream boundary, but violates the assumption of constant velocity in Eq. (34) thereby raising a question whether the numerical solution is valid. The solution may be valid if velocity is assumed constant during the injection of the pulse, however this assumption is not noted. Given the description of discharge in Fig 3a in Luhmann et al. (2012), however, this assumption does not appear to be supported.

When discussing the results, the authors introduce time-averaged or reference flow velocity (Eq. 37) when establishing the terms for agreement in thermal transmission between planar and cylindrical heat transport and determine a correction factor is needed. The correction term is dependent on the time-average flow velocity. Later on, the authors comment that scatter in the cylindrical solution at relatively slow velocities may be due to numerical scatter. This correction factor in the solution for planar flow may be needed to overcome the assumption of constant velocity.

The authors discuss the implications of assuming constant velocity in Section 6.3.2 and evaluate the impact of this assumption by comparing numerical simulations with and without constant velocity. The comparisons suggest that thermal retardation is affected by a maximum of 30% occurred when the ratio of recharge duration to flow-through time is decreased (Table 3). In other words, the discrepancy is increased for systems in which the duration of recharge is small relative to the velocity and the spatial distance between the locations of recharge and discharge (i.e., flow-through time).

The authors further elaborate on the qualifying assumptions in Sections 8.1 and 8.2 (Limitations). They note that velocity only occurs twice in the final solution, Eq. (36) and (38), and that it is included as the flow-through time (L/V). The Limitations section (8.1) provides minimal discussion on the ramifications when assuming constant velocity.

It would be informative for the authors to expand on the assumption of constant velocity. It is obvious that the severity of the assumption of constant velocity is dependent on spatial scale, introducing more uncertainty and inaccuracy when the flow-through time becomes relatively large. Providing a graph of how uncertainty or inaccuracy increases with flow-through time would be instructive. Partial data for such a graph is already provided in Table 3. Additional data could be provided with limited additional comparisons similar to those used to create the data in Table 3. Such a graph would provide readers a better sense on when the assumption of constant velocity relative to travel time inherent in the assessment become too large as to be unacceptable.

Would it be possible to report the temperature of the water that is input? This could possibly allow evaluation of the energy budget. It would be necessary to assume the thermal properties of the host rock and make assumptions on the constitutive relations of heat transfer, but insight on thermal damping and retardation could be gained by such an assessment.

In summary, the paper is well organized and well written. It relies heavily on the series of papers leading up to it (Covington et al., 2009, 2011, 2012; Luhmann, 2011; Luhmann et al., 2012). This is not to imply that the paper does not make a substantive

contribution, it does, but by relying on this proven path, a lot of the developmental work regarding the theory was well established. I would ask that the authors examine the concern that velocity may not be assumed to be constant and to consider exploring the energy balance. Evaluating the energy balance could provide insights on energy transport and thermal damping. This latter suggestion might be best left to a subsequent publication.

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