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

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Below you will find our responses (in plain text) to the comments from Anonymous Referee #3 (in bold text). We thank Anonymous Referee #3 for his/her time and effort in helping us to improve our manuscript.

The authors present a novel methodology to characterize karst conduit systems. Based on analytical and numerical models they investigate the effect of various system properties on transmission and retardation of heat signals. Finally, the analytical solution allows to characterize the conduits hydraulic diameter based on measured transmission and retardation of heat signals. A conducted field experiment is used to demonstrate the approach. The paper is well structured

and written, extensive, and comprehensible.

What I missed was a proper explanation of the underlying conceptual model. After the introduction, the paper starts immediately with a description of the mathematical model. I'd suggest to add some description of the conceptual model prior to the mathematical model, i.e. which processes are considered and which are neglected (maybe Fig. 1 can be modified). In doing so, the authors could help readers to understand some of the limitations of the approach (which are, however, well explained in the latter part of the manuscript, p 9617, line 17ff).

We will add an explanation of the underlying conceptual model.

One significant conceptual limitation is the missing consideration of variable conduit hydraulics that interact with the matrix. From my understanding, the models assume constant (steady-state) hydraulics for most of the setups (except what is described in section 6.3.2) and there is no interaction between conduit and matrix hydraulics (hydraulically isolated conduit). In consequence, the models cannot consider processes related to varying hydraulics like storage, or water transfer with the surrounding matrix. I assume that for some real situations these processes can be significant: for example an event induced increase of discharge will result in an increase of conduit hydraulic heads; subsequently, this head change potentially affects water transfer with the matrix continuum (matrix storage) or with other fractures or cavities (conduit storage). The authors touch this topic (discussion of water addition along the conduit; p9619, line 19ff). I suggest to discuss this limitation more in detail (in section 8.2 and / or related to the conceptual model). Maybe the paper from Birk et al. (2006) is helpful because the numerical model used there overcome some of the limitations.

We will discuss the limitation of neglecting matrix exchange in more detail. Hydraulic interaction between the conduit and matrix could cause variations in the hydraulic di-

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ameter and/or flow velocity as well as affect heat flux in the matrix. Still, we have been able to reproduce output temperature signals relatively well at three sites without considering matrix exchange (Covington et al., 2011; Luhmann et al., 2012).

Specific comments:

The authors use two different model setups with a cylindrical conduit and a fracture (see Fig. 1). For me the reason in doing so is not always comprehensible. The fracture model setup is introduced at page 9594 line 20. Maybe the authors can add some explanation why this setup is considered (I found something on p9611 line 11).

We will add more discussion. One reason we use the fracture model setup is because it is simpler than a cylindrical model setup. Heat exchange in a cylindrical conduit can be approximated by heat exchange in planar coordinates in many cases (Covington et al. (2012). Furthermore, flow in karst aquifers occurs not only through cylindrical conduits, but also through fractures with a planar geometry. In Luhmann et al. (2012), planar simulations reproduced the thermal signal much better than cylindrical simulations, suggesting that a planar geometry assumption for the particular flow path is much better than a cylindrical one. The planar geometry is also in agreement with field observations.

Can Equation 13 be moved to section 3.1 (similar to Equation 24, which is in 3.2)?

We will make this change.

Can Equation 12 be generalized (for planar and cylindrical case)?

We will make Eq. (12) more general.

Some numerical models have different conduit lengths but the discretization remains at 1000 discretized elements (page 9602, line 10 ff). Why is the discretization along x not kept constant (i.e. same element size)?

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The COMSOL model used is dimensionless, so each element is always the same fraction of the entire conduit length (i.e., 1/1000). However, increasing the number of elements for a relatively long conduit does not affect simulation results.

At p9619, line 19ff water addition along the conduit is discussed. What about losing water (flow from conduit to matrix or to some other storage)?

Flow from the conduit to the matrix will affect heat flux in the matrix. The changed heat flux in the matrix would only have a small, indirect influence on the temperature in the conduit, while flow from the matrix to the conduit would have a direct and significant effect on the conduit temperature.

In Figure 2 the numerical models for small transmission differ from analytical results (first elements along the x-axis until F $\sim$ 0.05). Is there an explanation why corresponding numerical results seems to be zero?

All of these cases include relatively small diameters. Smaller cylindrical conduits have larger conduit wall surface area to water volume ratios and a greater ratio of thermal penetration depth to conduit radius, which causes additional heat exchange when compared to equivalent planar systems. In this case, the simple correction factor in the cylindrical analytical solution overestimates the amount of transmission that would occur. However, the differences here are relatively minor and no different than the differences in other regions of Fig. 2.

Some further data for the field experiment would be helpful to understand the situation without reading Luhmann et al. 2012 (e.g. distance between sinkhole and spring, some information about the sinkhole like distance to the conduit). What about heat recovery?

We will add some additional data.

If possible, please discuss the results of the field study (D_{H}) little more. The obtained hydraulic diameter D_{H} seems very small. Luhmann et al. (2012) helps

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to understand these results but some short interpretation can be given here too.

We will further discuss the results of the field study.

Suggested technical corrections

Equation 15: explanation for X, Y (and R in equation 25)

The functions $X(x)$, $Y(y)$, and $T_t'(t)$ in Eq. (15) and $X(x)$, $R(r)$, and $T_t'(t)$ in Eq. (25) are factors giving $T_\mathrm{r}'(x,y,t)$ and $T_\mathrm{r}'(x,r,t)$, respectively, when multiplied.

Page 9611 line 9: add "m" behind DH = 1

We will add the unit.

Table 3, first data line: delete comma at L/V value

We will correct this.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 11, 9589, 2014.