Hydrology and
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Discussions

Interactive comment on "Reducing the ambiguity of karst aquifer models by pattern matching of flow and transport on catchment scale" *by* S. Oehlmann et al.

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Dear referee,

We thank you a lot for your critical and helpful comments. Some reorganisation regarding the results and discussion chapters was also suggested by the first referee and will be implemented. During the reorganisation we shall pay special attention to shorten Chapter 5 and improve its structure so that the legibility is improved. We agree, that the choice of the fitting parameters is important and will make sure to outline that more clearly in our discussion chapter. We placed Table 4 with the fitting parameters after

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chapter 4 since it includes results and is therefore the outcome of chapter 4. We will however put a reference into chapter 3 (field site and model design) that the measured parameter values can be found there for the reader to get a first overview.

We used steady-state flow conditions for all simulations, but the average annual discharge was only used for the calibration of the average hydraulic heads. For the tracer test simulation, the recharge was adapted to spring discharge during the respective tracer test. You can find this information in our manuscript at the end of Chapter 3 (p. 9292 l. 17 19). In the following, we respond to your specific comments:

Comments

1) P 9288, Line 5 let -> led Also stating that "simulation led to equation" is a bit logically reversed ... I suggest reformulating.

Answer: We aimed to clarify with that sentence that the equation given in our paper is not the original one given in the Comsol Multiphysics interface but a simplified version neglecting reactive transport, sorption of the tracer at interfaces and interactions with air. We will rephrase the sentence to avoid the confusing formulation.

2) P 9289-9292 The modelling domain is rather poorly described. A 3D model or cross-section with model structure & boundary conditions, would help. As this is to some extend given in Oehlmann et al. (2013), published in the same journal, the citation is probably sufficient. However, this depends on the editorial policy.

Answer: We intended to keep the chapter short to avoid lengthening our manuscript by repeating what was already described by Oehlmann et al. (2013). We will adopt your suggestion and introduce a figure showing the model structure and boundary conditions in addition to figure 1 showing the area itself (Fig. 1, this response).

3) P 9293, Line 10 – 15 Why is n correlated with conduit volume ? I see no physical reason for that. Same question goes for "higher conduit areas go along with higher n values and vice versa".

Answer: The correlation is not based on a physical process that produces a higher wall-roughness for large conduits, but results from the fact that we calibrated the model for spring discharge which again is related to conduit diameters. During all our parameter variations meeting the spring discharge was the paramount criterion (p. 9292, lines 25-27). So, all presented results give the annual average discharge of 0.5 mˆ3/s for the annual average recharge of 1 mm/d. The discharge is the product of the velocity inside the conduit uc (Eq. 4) and the conduit cross-section at the spring. A higher conduit volume leads to higher conduit cross-sections, since the lateral extent is constant. This means the conduit velocity has to decrease to produce the same spring discharge for higher conduit volumes. This can only be achieved by a larger roughness or a lower hydraulic gradient, since the only other parameter in Eq. (4) is the conduit radius, which increases with increasing cross-section.

Reduction of hydraulic gradients inside the conduits is hampered by the exchange with the fissured matrix. Inflow from the fissured matrix into the conduit system increases with lower hydraulic heads in the conduit system (Eq. 5) and higher conduit radii (Eq. 6). In all considered cases the fissured matrix provides enough water to keep up hydraulic gradients within the conduit system. Therefore, as a consequence a decrease in the conduit flow velocity leads to a higher conduit roughness n, leading to the conclusion that high conduit volumes require high n-values. We will improve the respective paragraph in our manuscript to state this more clearly.

4) P 9294 Tracer velocities for two tests are calibrated by varying n. From Table 1 one sees that the spring discharge in TT 2 was double of that in TT1, while the discharge in the model is in between (0.5 m3/s).

Answer: The different spring discharges during the two tracer tests were already considered by adapting the recharge. Therefore the spring discharge difference cannot be used for improving flow velocity calibration.

5) P9295, Lines 10-25 The roughness coefficient Kc is defined in Eq 14. In hydraulics,

n is defined as Manning roughness coefficient. Kc is given as 1/n (Eq.14) and here also called roughness coefficient (L15, P9295). This makes no sense. Also higher, Kc higher is the velocity s I also do not understand the reasoning behind: "While the flow cross-section gradually grows with time, the surface-volume-ratio increases as well leading to a higher roughness, further enhanced by exchange processes between the individual conduits. This would lead to an increase of the Manning coefficient towards the spring for a simulated single conduit." Please explain the reasons or give citations.

Answer: We agree that the description is confusing. We differentiated between the Manning coefficient/conduit roughness n and the roughness coefficient Kc=1/n, as it is employed in Jeannin (2001). We will edit the manuscript so that n is only referred to as Manning coefficient.

The connection between the conduit cross-section and the conduit roughness results from the assumptions that are usually made while simplifying conduit geometries for numerical simulations. From the conduit flow equation (Eq. 4) it is obvious that flow velocity increases with increasing cross-section. This is only the case, however, if the increase of the cross-section is due to a single conduit widening towards the spring. In our case, one simulated conduit segment represents an unknown arrangement of single conduits, which interact and the spring consists of a certain discharge area, not a single outlet. Considering the conduit cross-section increasing towards the spring, we need to specify how much of the increase is actually due to the single conduits widening and how much is due to additional conduits, not distinguishable in the simulation, adding to the bundle of conduits. We assume that both effects play a role: the widening of each single conduit and the addition of further conduits to the bundle while flow focuses towards the spring. Since we cannot determine the relative importance of the two processes, we use one parameter to calibrate it, which is Kc. The decrease of Kc with the conduit cross-section towards the spring is therefore a calibrated estimate of the relative importance of the widening of each single conduit and the addition of conduits to the bundle. We will of course improve the explanation in our manuscript to

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clarify our approach.

6) P9298 Line 25 COMMENT: In turbulent regime, the diffusion boundary layer is present and the diffusion can play role in overall dissolution. However, the faster the flow, the thinner the layer ...

Answer: Thank you for your comment. We will rewrite the sentence.

7) P9299 Line 5 The work of Hückinghaus (1998) is being cited with conclusion: "This could further slow down the preferential evolution of downstream conduits ..." The consequence would be that the cross-section would decrease after intersection ? In scenario 5, however, the cross-section at intersections always increases (Eq. 15). Does this mean that the result of Hückinghaus is not considered ?

Answer: Hückinghaus (1998) stated that of two equivalent paths, given by initial fractures, enhanced conduit solution occurred along the path with fewer intersecting conduits. Hückinghaus (1998) made no statement as to the relative diameters of the conduits before and after the intersections after breakthrough, which is the case here. Taking into account other studies cited it appears unlikely that the cross-section actually decreases after the intersection. This would lead to a significant increase of flow velocities triggering higher solution (e.g. Clemens, 1998) and steeper hydraulic gradients close to the spring, which contradicts field observations in the Gallusquelle area (Oehlmann et al., 2013).

We put the reference to Hückinghaus (1998) to show that there are different, processes and boundary conditions at work that are not all acting in the same direction. We will improve the paragraph to say that the results from Hückinghaus (1998) are one of the reasons why we did not consider a cross-section increase at conduit intersections from the beginning and not a reason for simulating conduits getting smaller at the intersections.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 11, 9281, 2014.

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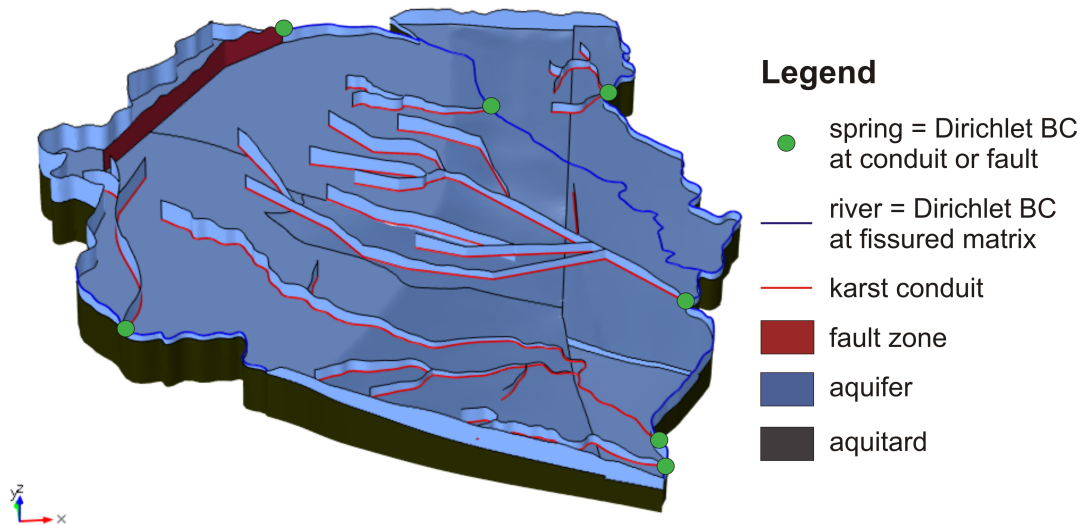Interactive Discussion

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Legend

● spring = Dirichlet BC at conduit or fault

—— river = Dirichlet BC at fissured matrix

—— karst conduit

▮ fault zone

▮ aquifer

▮ aquitard

Fig. 1. Three-dimensional view of the model. At the upper boundary, which is hidden to allow a view into the model domain, a constant recharge Neumann boundary condition is applied.