

Interactive comment on “Influence of aquifer heterogeneity on karst hydraulics and catchment delineation employing distributive modeling approaches” by S. Oehlmann et al.

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Dear referee,

We thank you for your advice that will help to improve our work. In the following, we answer your specific comments. The revised version of the manuscript is attached to this answer, including the mentioned corrections and revised figures. Page and line references refer to the attached revised manuscript.

Comments

1. Their own original contribution could be more clearly indicate, considering this is the
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first time that such work considering the input of results of modeling can be used for the delineation of catchment areas

Answer: We believe that our contribution becomes obvious in our work. Nevertheless, we now emphasize the novelty of the proposed approach in the introduction (p. 3, l. 11).

2. In the introduction, in the first paragraph, lines 10 to 13, it is necessary to add that hydraulic lines contour are used as well.

Answer: A respective sentence has been added to the introduction (p. 2, l. 13–15).

“Common approaches for catchment delineation in porous aquifers like the mapping of geomorphological and topographical features and water balance approaches (Goldscheider and Drew, 2007) are only of limited use in karst systems. Delineating catchment areas from hydraulic head contour lines requires an observation well network, which covers the highly conductive conduit system. On groundwater catchment scale these data are scarce in carbonate areas (Sauter, 1992).”

3. In the second chapter, Methods and approach, in the first paragraph, lines 27 to 29, it is necessary to give details on the basic module.

Answer: Two short sentences were added referring to the functionalities of the basic module that were used in this work (p. 3, l. 32 – p. 4, l. 2). The module has lots of other interfaces ranging from surface water flow to heat transfer and acoustics, which are not mentioned in the paper, since they were not relevant for this work.

“The interfaces used in this work belong to the Subsurface Flow Module, which provides equations for modeling flow in porous media, and to the basic module. The basic module includes interfaces, where mathematical equations can be defined by the user and employed for any physical application. This concept is described in more detail for scenario 3 (Sect. 2.3).”

4. At the end of the paragraph, lines 2 of the page 4, default hydrogeology tools are not
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they the hydrologic tools used to deline surface catchment area based on topographic lines ?

Answer: Yes, they were developed for surface water catchments, but can be applied to groundwater catchments as well. We added a short passage to clarify that point (p. 4, l. 8–11).

“Catchment areas were derived by importing the simulated water tables from Comsol® to ArcGIS® 10.0 and using the default hydrology tools. Generally, those are used for deriving catchment areas from topographic lines. Since the concept of water flowing towards the lower potential is true for groundwater as well as for surface water, they can be likewise used for delineating groundwater catchments from groundwater contour maps.”

5. In the chapter 3, Field site, prefer the term of hydraulic conductivity instead of solubility in the line 17.

Answer: We agree and changed the term.

6. In the chapter 4, Model design and calibration, it is necessary to clarify and to modify the figure 4, where was implemented the conduits network based on the geometry of dry valleys, specifically on z, at which depth.

Answer: The position of the conduit network has been presented in Fig. 3 (see next comment) so that the alignment of conduits with dry valleys can be observed. The depth of the conduits is aligned with the water table depth of scenario 1, as mentioned in the manuscript (p.8, l. 17–19). Since this depth is not constant throughout the model area, it was judged inconvenient to add this information to the figure. However, we added additional information to Sect. 4 to give an idea about the depth without having to consider Fig. 5b to find the depth of the homogeneous water table.

“Vertically, the highly conductive conduits were positioned approximately at the elevation of the water table simulated in scenario 1. Therefore, the conduits lie between 710

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m and 600 m a.s.l. with a dip towards the springs.”

7. On figure 4, the position of the conduits network used in the scenario 3 and 4 has to be represented.

Answer: We presented the conduit network in figure 3. Please find the revised figure in the attached revised manuscript. The vertical position of the conduits approximately corresponds to the water table, which is now mentioned in the manuscript (see answer to previous comment).

8. In the first paragraph of the page 9, line 6, it is necessary to add the reference of the figure 2 and to modify this figure adding the location of the 20 observatory borewells (instead of measuring stations - wording).

Answer: Done. Please find the revised Fig. 2 in the attached revised manuscript.

9. Additional graphical representation of difference between observed and simulated data should be provided, and not only the RSE in the table 1, even if a visually observation show the main differences, using GIS tools.

Answer: We agree that the work would benefit from a more detailed presentation of the differences in hydraulic head values and especially hydraulic gradients for our scenarios. Please find our new figure (Fig. 6) in the attached revised manuscript.

10. As said above, the location of the observatory borewells and the instant values used to draw the hydraulic head contour map have to be added to the figure 5a. In the figure 5b to 5e, it could be good to add the contour of the delineation of the catchment area of the Gallusquelle based on the figure 5a, in order to have a better visualisation of differences.

Answer: The observation wells were added to the figure. The instant values were judged to make the figure confusing, if they were added to each well. For seeing the measured values please check the new Fig. 6 in the revised manuscript.

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11. In addition, it is necessary to discuss the modeling approach considering uniform recharge and steady state flow equations; are they a limitation or not ?

Answer: The approach is not limited to steady-state flow equations and uniform recharge. They were chosen to provide an average water balance and a more simplified environment. Actually, the possibility to extend the modelling approach to different flow conditions is a significant advantage of the method. A corresponding remark has been added to the text (p. 15, l. 32 – p. 16, l. 3; see also answer to the next comment).

12. In the conclusion, it is necessary to develop a little bit more the additional value of the results of the modeling regarding the delineation of the catchment area of the Gallusquelle, using modelling in comparison to more conventional way using hydraulic head contour map and dye tracing connections, and the uncertainty of the results.

Answer: A paragraph was added to the conclusion chapter to address this issue (p. 15, l. 30 – p.16, l. 3).

“Using numerical models for catchment delineation allows for the combination of several methods and observations under the consideration of the geological and hydrogeological properties of the area. The model can be used for advanced simulations of transient groundwater flow and transport and can also account for heterogeneous distributions of recharge or aquifer properties. It therefore represents a flexible tool for risk assessment and prediction in heterogeneous flow systems.”

13. In addition, it is necessary to discuss as well more in details the suggestion of using input of karst genesis simulation and to add some references about it.

Answer: Since the karst genesis simulation was not conducted (yet), we decided not to discuss the possibilities, advantages and disadvantages in detail. However, we added a paragraph to the conclusions providing information about the benefit of such a simulation and added some references where more information can be found (p. 16, l. 18–25).

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“Karst genesis simulation would provide process-based information about conduit widening towards a karst spring. Such simulations were employed for instance by Kaufmann and Braun (1999), Liedl et al. (2003), Bauer et al. (2003), and Hubinger et al. (2011). They simulate the temporal evolution of a small fracture or fracture network due to solution with coupled transport and hydraulic models. Under the constraints of recharge conditions and initial geometries they derive the conduit size distribution. A detailed overview of the basic techniques and processes is given by Dreybrodt et al. (2005). The implementation of a karst genesis module would be possible with Comsol Multiphysics[®], given sufficient input data.”

14. The question of minimum data to have to be able to carry out such modeling approach for the delineation of catchment area may be also discussed in one or two sentences

Answer: A short comment on the minimum necessary data was added to the conclusion chapter (p. 16, l. 4–11).

“The uncertainty of the results depends mainly on the available input data. The modeling approach allows an integrated analysis of data from different sources. Theoretically, the method requires average annual spring discharge and hydraulic head measurements in the catchment. Nonetheless, the measurement of the discharge of several springs in the proximity of the investigated spring catchment is advisable for the simulation of catchment boundaries. In addition, deriving some knowledge about the location and properties of the karst conduit network from natural or artificial tracers, groundwater contour lines, direct investigations or the morphology of the land surface is highly recommended.”

Please also note the supplement to this comment:

<http://www.hydrol-earth-syst-sci-discuss.net/10/C5294/2013/hessd-10-C5294-2013-supplement.pdf>

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