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Discussions

Interactive comment on "Tracer test modeling for local scale residence time distribution characterization in an artificial recharge site" *by* C. Valhondo et al.

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Reply to comments by Prof. Marc Walther

1. Introduction

We thank Prof. Marc Walther (and will also do it in the acknowledgement section of the revised version of the paper) both for his kind assessment of our work and for the time he has devoted to improving the paper, as can be derived from the length of his comments. In the spirit of HESS discussions, we discuss below the issues that are potentially controversial or that require further explanations. Editorial corrections will be included in the revised manuscript, when a full response to all reviewer comments

will be produced but are not addressed here. Overall, the reviewer raises a number of issues that are critical for a good model, but are hard to explain in detail in the limited length of a paper. Since HESSD remains open, we will use this response to clarify many of those issues, which are relevant but will not be included in the revised version of the paper for lack of room, as a sort of "supporting information". This implies that, if Prof. Marc Walther does not mind, we will cite his comments (Walther, 2016) and our responses in the final manuscript. We also have taken the freedom to alter the order of the comments to facilitate responding in a coherent way. Comments are structured around three "major points: a) The description and motivation of the used "tracers" (amino-G, TCE, EC) ... b) The information given on the modeling tool . . . the modeling strategy and . . . information on the calibration strategy should be provided. c) Finally, I would like to encourage the authors to state a more profound argumentation why they set up the heterogenous models in the way they did. For example, why were 9 layers chosen and not 5, 15, or 40?". We structure this response around these three points, starting from the second one.

2. Modeling tool and strategy. Calibration strategy.

The modeling tool used for calibration is TRANSDENS (Hidalgo et al.,2004), which is a development over TRANSIN (Medina and Carrera, 1996; Medina and Carrera, 2003). Both codes have been developed by the Hydrogeology Group (UPC-CSIC). Both use the Finite Element Method to solve the equations governing coupled flow and transport through porous media. A strict Galerkin method is used for transport, which places strong constraints on the adopted dispersivity, but which was not an issue in this case because of the strong heterogeneity. The singularity of these codes lies on their versatility to accommodate geology, zonation, time dependence of aquifer parameters and model inputs, and especially inverse modeling. That is, they allow automatic calibration of aquifer parameters (transmissivity, storativity, recharge, boundary heads and flows, leakage, dispersivity, molecular diffusion, porosity, retardation, linear decay, boundary concentrations) using the methods described by Medina and Carrera (1996) and Medina and Carrera (2003). A short explanation will be included in the revised document in the section 2.3.1 "Boundary conditions and model parameterization". The model structure was defined to accommodate two requirements: (1) the need for detailed description of layers at the (local) transport scale and (2) the need to seek appropriate boundary conditions controlling the flow field. Overall, our large scale model is a portion the regional model of the Llobregat delta main aquifer (Abarca et al., 2006). The regional model boundaries were the natural edges of the Llobregat delta main aquifer. Our model, which is limited to a small portion of the Llobregat River alluvial aquifer, increases the detail at the local scale (around the infiltration system). Therefore, we distinguish two domains:

(1) A single layer large scale domain in the model structure (heterogeneity patterns and B.C.s) is identical to that of the regional model. The large scale domain extends up to the natural lateral edges of the Quaternary Terrace. Thus, zones of constant transmissivity were those of Abarca et al. (2006) which were based on a detailed sequential stratigraphy analysis by Gámez et al. (2009). A Neumann type boundary condition was prescribed identical to the regional model for these edges to account for the inflow from lateral creeks (marked in Figure 1C already and they will be added to Figure 1A). This lateral inflow is probably non uniform in space, but was treated as uniform both for simplicity and because alluvial fans probably distribute this inflow spatially. The Northern and Southern edges of the large scale domain were defined according to two batteries of piezometers located perpendicularly to the regional flow. We prescribe the piezometric head in those boundaries using a Dirichlet type boundary condition.

(2) A multilayer local scale domain was adopted for the zone affected by the tacer experiment. Its triangular shape of the local scale domain is based on a particular transmissivity zone defined in the regional model. This facilitated calibration, discussed below. Nine layers were adopted to represent aquifer layering (see section 3, below).

These two models are totally coupled. That is, both are solved together in every model

run. That is, the division is made for practical reasons (it would not make sense to extend layering to the full domain, because it would neither be possible to calibrate, nor it would affect the results. It would have been possible to solve first the large scale model, second, extract heads at the edges of the local scale model and, third, treat these edges as Dirichlet boundaries using those heads. Results would have been identical and we would have saved some CPU time. However, we did not do it because the saving is not dramatic and, with our tools, it would have been tedious (we would have had to transfer head at every node and time step).

The calibration and modeling strategy consisted of three steps. First, starting from the parameterization of the regional model by Abarca et al. (2006), we used updated meteorological and piezometric head data. Meteorological data was used to compute recharge and lateral inflows using the same procedures as for the regional model. The large scale model was “recalibrated” using the newly collected heads and the transmissivity values of the regional model as prior estimates. As it turned out, changes from the values of the regional model were minimal. Second, we calibrated the porosity and hydraulic transmissivity of the local scale domain, and the preferential flow through the reactive barrier using the piezometric head and amino-G acid concentrations obtained from the tracer test. We performed the calibration for the homogeneous and heterogeneous scenarios. Third, we validated the model by reproducing observed values of TCA and EC (see Section 4, below).

3. Heterogeneity structure.

As mentioned above, the area around the recharge basin was simulated as multilayer to be able to reproduce measurements and to analyze the effect of layering. The 14m-thick aquifer was divided into seven 2m-thick layers in the local scale domain. These 2m-thick layer emulate the material differences of the alluvial deposits. There are two additional 0.3m layers inside this domain representing the reactive barrier of the infiltration basin. The number of layers was chosen to obtain a sufficient precision in the vertical discretization while maintaining the numerical burden below a reasonable level.

Increasing the number of layers would have allowed us a finer discretization and better numerical accuracy but would have also increased computational and processing times. Each of the layers was assigned flow and transport parameters representing the properties of the aquifer materials, as derived from the cores of the boreholes drilled in the area. Each layer was homogeneous in the horizontal direction. It is clear that this is a simplification. Horizontal variation is expected both for the horizontal permeability and, especially, the vertical permeability (fine sediments layers, which control vertical permeability, are probably not continuous in reality). We simulated them as continuous both for simplicity and for robustness. It is clear that the calibrated permeabilities represent effective values, but are probably very sensitive to the location of measurement points. This is why we felt we had to perform validation runs (see Section 4, below). From the numerical point of view, layering is simulated using a quasi-3D approach, where horizontal connectivity is simulated via (sub)horizontal triangular elements. These elements are linked by 1D elements that reproduce the vertical connection between the layers. The approach is similar to cell centered finite differences or finite volumes. It is also similar to prismatic finite elements (actually identical if two integration points are used along the vertical direction). However, we find it more practical from a parametrization point of view in that our approach facilitates parametrizing separately the horizontal conductivity (controlled by sand layers) and the vertical conductivity (controlled by the fine sediments layers). The hydraulic conductivity of the 1D elements located at the edges of the local scale domain is very high to avoid a barrier effect where the monolayer and multilayer domains merge. The parameters of the rest of 1D elements are such the vertical water and solute fluxes are well represented.

4. The description and motivation of the used "tracers" (amino-G, TCE, EC)

Because of all the simplifications described above, the final model might have been an artifact. Therefore, we felt that it was necessary to test its validity. To this end, we simulated the evolution of both recharge and aquifer tracers to simulate flow and transport both during periods of time much longer than those used for calibration and compris-

ing intervals of both artificial recharge and non-recharge. The selection of tracers was based on an “opportunistic” basis: 1) Amino-G was selected as tracer because it is easy to analyze with high accuracy and precision using fluorometers (we also injected a metal complex, but did not use it for calibration). 2) TCA was selected as a tracer because it was already present in the aquifer but not in the recharge water. Therefore, it complements the data of the artificially added amino-G acid. Furthermore, it provides information about the rate at which aquifer water returns to the space occupied by recharge water once recharge stops. 3) EC data was also used to validate the model. EC is highly variable in time both in the river (i.e., recharge water) and the aquifer, because high salinity comes from the salt mines located in the Llobregat River Basin far upstream from our site. The large amount of EC data (from 2012 to 2014) available in most of the monitoring points allowed us to evaluate the model under flow conditions different from those prevailing during the tracer experiment. We stress that no calibration was made using TCA or EC measurements. Validation simply consisted of changing the modeled time interval, and changing initial and boundary concentrations, as well as concentration of recharge inflow (zero for TCA, and continuously recorded at the infiltration basin for EC). As shown in the paper, results were very good, far better than we had anticipated, although actual recovery of aquifer water when recharge stops was a bit faster than modeled, which leads as to conclude that a MRMT model might have done a better job at reproducing the effect of unmodelled heterogeneity, albeit at the cost of added complexity.

References

- Abarca, E., Vázquez-Suñé, E., Carrera, J., Capino, B., Gámez, D., and Batlle, F.: Optimal design of measures to correct seawater intrusion, Water Resources Research, 42, n/a–n/a, doi:10.1029/2005WR004524, w09415, 2006.

- Gámez, D., Simó, J. A., Lobo, F. J., Barnolas, A., Carrera, J., & Vázquez-Suñé, E. (2009). Onshore–offshore correlation of the Llobregat deltaic system, Spain: Development of deltaic geometries under different relative sea-level and growth fault influences.

Sedimentary Geology, 217(1), 65-84.

- Hidalgo, J. J., a. S. L.,Medina, A., and Carrera, J.: A Newton-Raphson based code for seawater intrusion modelling and parameter estimation, in: Groundwater And Saline Intrusion Selected Papers from the 18th SaltWater Intrusion Meeting, 18th SWIM, IGME, Madrid, S., 15, pp. 111–120, IGME, doi:84-7840-588-7, 2004.

- Medina, A. and Carrera, J.: Coupled estimation of flow and solute transport parameters, Water Resources Research, 32, 3063–3076, doi:10.1029/96WR00754, 1996.

- Medina, A. and Carrera, J.: Geostatistical inversion of coupled problems: dealing with computational burden and different types of data, Journal of Hydrology, 281, 251 – 264, doi:10.1016/S0022-1694(03)00190-2, 2003.

- Walther, M., 2016, Comments to “Tracer test Modeling for Local scale characterization of an artificial recharge site”, HESS Discussions, http://editor.copernicus.org/index.php/hess-2016-197-RC2.pdf?_mdl=msover_md&_jrl=13&_lcm=oc108lcm109w&_acm=get_comm_file&_ms=51

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