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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Estimation of heterogeneous aquifer parameters using centralized and decentralized fusion of hydraulic tomography data from multiple pumping tests" *by* A. H. Alzraiee et. al

Anonymous Referee #3

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The authors develop and test an EnKF approach which incorporates temporal moments of drawdown data in a centralized and decentralized manner to estimate the hydraulic conductivity and specific storage of a 2D synthetic aquifer. Temporal moments are utilized to overcome the computational burden associated using the full parabolic equation for inverse modeling. A novel localized fusion algorithm is implemented to further save on the computational effort which I thought was clever but perhaps the authors may consider comparing this search radius approach to the full inversion case because features in the far field could have impacts in the near field (I am thinking of

strongly heterogeneous porous media and in particular fractured rocks). However, this demonstration is up to the authors as they have already done a significant amount of work. The algorithm is also expanded to estimate the geostatistical parameters and some useful conclusions are drawn about the estimation of these parameters.

Overall, I thought that the study was well thought out and the paper is generally well written although minor edits are necessary. I also think that some efforts are needed to distinguish this study from another similar HT study based on EnKF by Schöniger et al. (2012). This will simply require some additional explanations. I think that the conclusions are substantiated through the numerical study, therefore I recommend publication of the manuscript after minor revisions.

Comments (P?L? refers to page and line numbers of the PDF page)

Title: suggest removing from multiple pumping tests; hydraulic tomography already implies the use of multiple pumping tests for inverse modeling.

P3L16: Pumping and slug tests are not classical examples of inverse methods. The analyses using type curves or straight line methods are. Please pay attention to your writing throughout the manuscript.

P4L11: Please cite the various temporal moment analysis of hydraulic tomography conducted (e.g., Zhu and Yeh, 2006; Schöniger et al., 2012).

P4L14: In talking about 3D settings, you should mention the work done by Illman et al. (2009) and Berg and Illman (2011) with the latter you already cite. You may also consider citing Berg and Illman (2013, 2014) for additional examples of 3D studies.

P4L20: Here you should perhaps cite the work of Illman et al. (2012) who found that predictions of solute transport were better with estimates from HT surveys in comparison to traditional geostatistical analysis (i.e., kriging) and effective parameters (effective conductivity and macrodispersivity).

P5L3: While the nonuniqueness issue is true for all inverse methods, it was really un-

fortunate that Bohling and Butler (2010) was published without the necessary caveats. In particular, Bohling and Butler (2010) generalized their conclusions to all HT studies without considering the merits of inversion methods other than their own. Therefore, I think you should add the statement "based on their pilot point inverse method" after "reliability of HT estimates, and".

P6L7: Please carefully discuss the differences of your approach with that of Schoniger et al. (2012) in this paragraph.

P8L11: I do not think one needs to use a lot of drawdown data for inverse modeling. The key is to capture the salient features of the drawdown curves.

P11L19: Schöniger et al (2012) had to apply nonlinear, monotonic transformations to the observed states (head), rendering them Gaussian. Do you have to do something similar to make your approach work? You should say a few words here and perhaps in more details in the discussion section.

P12L12: Is there a way to include other covariance functions? If so you should state it here.

P12L20: So this step should be very computationally intensive especially for 3D cases. How does your approach compare to other inverse methods such as pilot points (Vesselinov et al 2001b and others), SSLE (Yeh and Liu, 2000; Zhu and Yeh, 2005), etc. Perhaps this point should be addressed in the introduction and in the discussion section.

P23L7: Table 4 is nice but I would also like to see scatterplots of each case to get a pictorial representation of the fit quality.

P24L16: Are you estimating K and Ss separately? How about the simultaneous estimation of K and Ss? This should perhaps be added as a new case.

P25L20: “3600 measurements per single pumping test”. However, no one ever uses all the data for transient inversions so this is kind of misleading, I think. Only a few points

from the drawdown curve are typically utilized.

P27L17: “what” field?

P27L26: replace “priorly known” with “a priori”.

P28L5: Note that the work of Yeh and Liu (2000) found that the choice of correlation lengths and variance did not influence their estimates. Perhaps you should say a few words about this study.

P29L16: replace “stationary” with “stationarity”.

References:

Berg, S.J., and W.A. Illman. 2013. Characterization of hydraulic conductivity heterogeneity with steady state hydraulic tomography: Field study in a highly heterogeneous glaciofluvial deposit. GroundWater 51, no. 1: 29–40. DOI:10.1111/j.1745-6584.2012.00914.x

Berg, S. J. and W. A. Illman. 2014, Comparison of hydraulic tomography with traditional methods at a highly heterogeneous site, Ground Water, doi: 10.1111/gwat.12159, Article published online.

Illman, W.A., X. Liu, S. Takeuchi, T.J. Yeh, K. Ando, and H. Saegusa. 2009. Hydraulic tomography in fractured granite: Mizunami Underground Research site, Japan. Water Resources Research 45: W01406. DOI:10.1029/2007WR006715

Illman, W.A., S.J. Berg, and T.-C.J. Yeh. 2012. Comparison of approaches for predicting solute transport: Sandbox experiments. Ground Water 50, no. 3: 421–431. DOI:10.1111/j.1745-6584.2011.00859.x

Vesselinov, V.V., S.P. Neuman, and W.A. Illman. 2001b. Three-dimensional numerical inversion of pneumatic cross-hole tests in unsaturated fractured tuff: 2. Equivalent parameters, high-resolution stochastic imaging and scale effects. Water Resources Research 37, no. 12: 3019–3042.

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