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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Is inversion based high resolution characterization of spatially heterogeneous river bed hydraulic conductivity needed and possible?" *by* W. Kurtz et al.

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Dear referee,
We thank you for your thoughtful response to our manuscript and for the positive feedback on our work. Here are our replies to your comments:

Having said this, I have only one main concern, which regards the lack of details on the numerical experiments. In particular, I am referring to the fact that the aquifer properties (distribution of hydraulic conductivity- if spatially variable -, specific storage

coefficient, retention curve parameters, etc.) are not reported in the manuscript. This has two consequences for the potential reader: i) who wants to reproduce the same experiments is not able to do that and ii) one is left wondering whether the conclusions of the study are due only to the variability of the leakage parameters or the interplay between aquifer properties and riverbed properties play a significant role. The latter point is especially relevant, as much importance is given by the authors to the spatial variability of the fluxes between river and aquifer and thus it is crucial that the missing details be included and the discussion of results integrated in view of the new information. This can (and should) be done at the beginning of Section 4 and in Section 6.

We agree that we did not give enough details for the other hydraulic model parameters. K-values were obtained from inverse modelling using the pilot point method. Porosities were set to a constant value of 0.15. These values (and the van Genuchten parameters) were the same for the references and all ensemble members. Thus, the only stochastic parameters in our study were leakage coefficients. We will emphasize this point in the description of the model (and give details on the utilized parameters).

Page 5831: the title is too long, in my opinion. Suggest a shorter version, e.g., "Inversion-based high resolution characterization of spatially heterogeneous river bed hydraulic conductivity".

We consider shortening the title to: "Is high resolution inverse characterization of heterogeneous river bed hydraulic conductivities needed and possible?"

Page 5834, line 5: suggest rephrasing the sentence. The reader might think other inversion methods are compared in this study, while only different zonation methods

are investigated.

We will replace "classical approaches" with "zonation approaches".

Page 5836, line 27: the reference to Camporese et al. (2009) is not relevant for "the characterization of heterogeneous subsurface properties in groundwater modeling". A more appropriate reference is Camporese et al. (WRR, 2011), who used EnKF to assimilate concentration data derived from ERT in order to assess the distribution of heterogeneous hydraulic conductivity.

We included Camporese et al. (2009, WRR) to give an example of a study where discharge data were assimilated with EnKF but we agree that Camporese et al. (2011, WRR) might be more appropriate in the context of heterogeneity and we will include this reference in the next version of the manuscript.

Page 5844, line 1: two weirs and the confluence of rivers identify only four river reaches. How were the fourth point/fifth reach chosen?

One of the zones (defined by the two weirs and the confluence) was subdivided to provide a better spatial representation of river-aquifer exchange for the management activities in the Hardhof area. We will include this information in the model description.

Page 5844, lines 9-15: choosing the correct mean for the generation of the initial ensemble implies that the EnKF can work in an optimal situation, as it naturally reduces the uncertainty around a parameter space that already contains the true solution. I realize that this probably does not change the main conclusions of the paper, i.e., high- resolution inversion is better than limited zonation, but I suggest

highlighting this point later in the discussion (page 5852, lines 21-29).

We will mention this point in the discussion.

Page 5845, eq. (10): I suggest assessing the root mean square error through a double summation over the ensemble of realizations and the nodes. This would give a more robust estimate and would implicitly include information about the uncertainty of the ensemble.

A difficulty with the "double summed" RMSE(h) is that two characteristics (the mean behaviour and the variability) are lumped together in one value which makes the interpretation less straight forward. In our results we see that the zonated ensembles tend to have a lower variability than the heterogeneous ensemble (see e.g., Figures 9, 10, 11, 14) but they have a stronger deviation from the references with respect to groundwater levels, leakage fluxes and leakage coefficients. For our study, we think that an assessment of the prediction capability of the different ensembles is more appropriate in terms of the mean (or median) heads than a combined measure of mean behaviour plus uncertainty. One option to also assess uncertainty would be to plot the variability of heads for the different ensembles in a separate figure. Another problem is that we did only store the mean and variance of heads for all simulations (but not the full ensembles) in order to keep storage requirements and data processing in an affordable limit. As a consequence, all simulations would have to be rerun in order to calculate the "double summed" RMSE(h).

From page 5850, line 23, to page 5851, line 2: this is intuitive, but would be even better to see it. I suggest adding a figure showing the comparison between the correlation structure log(L)-h in a region of high flux and in a region of low flux. Also, adding the

information about the aquifer properties would allow giving more insight on why the performance is spatially variable.

We will try to include a figure that shows the correlation structure between log(L) and h for different leakage fluxes.

Page 5833, line 25: use "that" or "which" instead of "what". The same mistake occurs several times in the manuscript.

Will be changed.

Page 5833, line 26: better to use "conductivities" instead of "permeabilities". In the classic hydrogeology literature, the latter are measured in [L^2].

Will be changed.

Page 5834, line 13: to avoid confusion, please state at the beginning of the paper that "log" denotes always the logarithm to base 10.

Will be added.

Page 5840, lines 4-5: English here seems a bit awkward, suggest rephrasing the sentence.

Will be changed.

Page 5842, line 22 and elsewhere in the text: the units of leakage coefficients should

be (1/s), not (m/s).

Our simulation code does not directly use leakage coefficients (Equation 9) as input parameters but leakage coefficients combined with areal information. For our setup the input parameters were leakage coefficients multiplied with half of the river width (denoted L* in Figures 3, 5, 10, 11, 14) which have the unit m/s. For convenience, we decided to use L* directly to display our results because the river width in our model is almost constant and so the use of L* (instead of L) does not influence the findings of our study. We will make a remark on that in the description of the generation of reference fields and the ensemble.

Figs. 3, 5, 9, 10, 11, and 14: to avoid overlapping in the eastern part of the model domain, I suggest plotting the data using a 1D coordinate system that follows the river reaches.

One problem that arises in this case is that we have two polygon lines that represent the river. As a consequence, there is no unique reference point (for both polygon lines) for setting up a 1D-coordinate system. This will lead to slight positioning errors. Nevertheless, we will check whether it is possible to display the data in "river coordinates" with a sufficient accuracy.

Fig.6: to better show the benefits of joint update of states and parameters, I suggest adding to this figure the behavior of RMSE for an open loop simulation (no updates at all) and a simulation with update of system state only. Also, consider re-calculating the RMSE as previously suggested (Page 5845, eq. (10)).

We will include a figure for one reference where also results for open loop simulations and state update are included. Showing this information for all references and all ensembles (e.g. in Figure 6) is probably too confusing.

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