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The role of zonation of river bed conductivities on river-aquifer exchange fluxes and on state-parameter updates with the Ensemble Kalman Filter

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A proper characterization of river-aquifer exchange fluxes is important for groundwater management because of their influence on regional water balance and groundwater quality. Different studies have shown that the heterogeneous distribution of hydraulic conductivities around or within a river bed strongly influences the exchange fluxes between river and aquifer. However, it is often unclear how much heterogeneity has to be represented in a model in order to achieve an adequate representation of river-aquifer interactions. We performed a sensitivity analysis for the effect of zonation of river bed conductivities (L) on the characterization of aquifer states in a Monte Carlo framework. Additionally, data assimilation techniques were used to improve model predictions and model parameters for the different zonation approaches. For our synthetic simulation experiments we used a 3D finite element model of the Limmat aquifer in Zurich (Switzerland) which includes river-aquifer exchange as well as groundwater management activities such as bank filtration and artificial recharge. Ten synthetic L-fields were generated which showed a rather high degree of spatial variability (standard deviation: ∼1.7 log10(m s-1)). Reference runs with these synthetic L fields (total simulation period: 609 days) yielded the basis for the comparison of the different zonation approaches. Different ensembles were generated that either reproduced the full heterogeneity of the reference fields (457 leakage zones) or where the number of leakage zones was reduced to 5, 3 or 2 zones. These ensembles were propagated forward in time either without updating (open-loop simulations) or using 100 head data for updating hydraulic heads and leakage coefficients of the different ensembles with the Ensemble Kalman Filter (EnKF). Results from unconditional simulations showed that all four zonation approaches led to approximately comparable errors with respect to reference runs. When EnKF was used to jointly update hydraulic heads and L values the decrease in hydraulic head errors was more pronounced for the more spatially distributed zonations (i.e. 457 and 5 zones) than for 3 and 2 zones where the errors showed a more systematic character. This is most likely related to the fact that for the 457/5 zones the general spatial patterns of the reference fields are still resolved by the ensemble whereas for 3/2 a stronger spatial averaging takes place. The net fluxes between river and aquifer were also adequately represented by the 457 and 5 zone ensembles whereas for 3 and 2 zones the net fluxes where underestimated for most of the reference runs. The updating behavior of L during the simulation period showed that the ensemble with 457 zones converged towards the spatial structure of the references fields. In contrast, the ensemble variance for 5, 3 and 2 zones decreased rather fast.

In summary, it is concluded that a higher spatial distribution of leakage zones generally leads to a better performance of EnKF in river-aquifer systems in terms of state and parameter prediction. Nevertheless, EnKF is able to correct in part for an incorrect parameterization of riverbed heterogeneity, but this mainly concerns the hydraulic head values, whereas the parameter values are only significantly improved when basic spatial features of the true L-field are represented correctly.