Title: Calibration of Hydraulic Conductivities in Groundwater Flow Models using Double Constraint Method and Kalman Filter

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Abstract

To model groundwater flow, two types of problems must be solved: (i) the forward problem and (ii) the inverse problem (calibration). Forward modeling is based on prior estimates of the model parameters. For instance, in MODFLOW the hydraulic conductivities in the model's grid blocks have to be specified. Calibration means choosing conductivities in such a way that the heads and fluxes calculated by the model honor the measured heads and fluxes. Modeling in such a way that not only heads and fluxes, but also parameters are determined, is generally called inverse modeling.

The Double Constraint Method (DCM) is a relatively simple, yet very instructive approach to inverse modeling of hydraulic conductivities. As a first task of the thesis, the DCM is combined with MODFLOW to calibrate a large scale groundwater flow problem (the Kleine Nete catchment). This was done by applying Darcy's Law to find the hydraulic conductivities from the flux and head boundary conditions. The DCM-MODFLOW combination was tested and applied to the Kleine Nete catchment and the Schietveld catchment (Belgium). Convergence rates were tested for different update rules. Tests show that only a few or even no iterations are necessary to obtain an acceptable accuracy, which makes the calibration procedure numerically efficient. The Schietveld model was also calibrated using UCODE-2005 and compared with the calibration results of the DCM.

To improve the characterization of hydraulic conductivities, the different calibration results obtained under different hydrological conditions (e.g. different recharge rates) were used in a Kalman Filter to estimate the time-independent ("true") conductivities as well as the estimation accuracy. In this approach only the Kalman Filter's variances, not the covariances, play a role, which reduces the computational requirements considerably. In the Kleine Nete study we found a considerable decrease (approximately 77%) in the uncertainty of the estimated conductivities compared to the uncertainty obtained from "observations" (i.e., inverse model runs) using the DCM. In addition, the approach could distinguish the regions in which the measured heads influence the calibration from the regions where heads obtained from the monitoring wells have no influence on the calibration.

Finally, in a number of practical cases we have to decrease the number of grid blocks. Grid block reduction requires upscaling resulting in equal hydraulic conductivities for a cluster of neighboring grid blocks. Such upscaling was done by the DCM as a complement to MODFLOW and applied to the Kleine Nete catchment. As a result we identified coarse scale conductivities while decreasing the number of grid blocks with the advantage that a model run costs less computation time and requires less memory space. In addition, ranking of models was investigated.