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Optimizing monitoring design to increase predictive reliability of groundwater flow models at different scales

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Mathematical system models have become popular to make predictions about the impact of water resources management strategies and other projected future changes to the natural system. Monitoring networks are essential to track the states of the system as well as for the calibration and evaluation of corresponding hydro-system models. However, the installation, extension, and maintenance of observation networks often come with considerable expenses. It is, therefore, important to design monitoring networks in an optimal and cost-efficient way.

In this study, the worth of a set of observations is defined by its ability to reduce the uncertainty of a model prediction. It is dependent on the problem-specific prediction target and its sensitivity to particular model parameters. For the estimation of predictive uncertainty, we adopt the uncertainty analysis approach by Moore and Doherty (2005) and extend the method to simultaneously optimize multiple observations using a modified Genetic Algorithm (GA) that can also sample from past states for higher efficiency.

The proposed optimization algorithm is applied to derive the optimal placement of multiple hydraulic head and conductivity measurements to complement existing groundwater monitoring networks in two aquifers of distinctively different scales. The first case study is a regional aquifer (6346 km^2) in the Central Canterbury Plains area of New Zealand. The prediction targets considered are the flux of groundwater discharging into the sea, low-land stream discharge, and stream ex-/infiltration fluxes. The second case study is a local shallow riparian aquifer (0.01 km^2) located at the river Steinlach near Tübingen, Germany. The prediction target considered herein is the hyporheic exchange flux. For both studies, calibrated steady-state Modflow models have been developed.

In both case studies and regardless of the prediction target, the optimization results show a higher utility of hydraulic conductivity observations compared to hydraulic head observations, which is counter-balanced by their higher costs and their lower reliability at the regional scale.

References

Moore, C., and Doherty, D. (2005). Role of the calibration process in reducing model predictive error. Water Resources Research 41(5), W05050.