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Groundwater management under sustainable yield uncertainty

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The definition of the sustainable yield (SY) of a groundwater system consists in adjusting pumping rates so as to avoid groundwater depletion and preserve environmental flows. Once stakeholders have defined which impacts can be considered as "acceptable" for both environmental and societal aspects, hydrogeologists use groundwater models to estimate the SY. Yet, these models are based on a simplification of actual groundwater systems, whose hydraulic properties are largely unknown. As a result, the estimated SY is subject to "predictive" uncertainty. We illustrate the issue with a synthetic homogeneous aquifer system in interaction with a stream for steady state and transient conditions. Simulations are conducted with the USGS MODFLOW finite difference model with the river-package. A synthetic dataset is first generated with the numerical model that will further be considered as the "observed" state. In a second step, we conduct the calibration operation as hydrogeologists dealing with real word, unknown groundwater systems. The RMSE between simulated hydraulic heads and the synthetic "observed" values is used as objective function. But instead of simply "calibrating" model parameters, we explore the value of the objective function in the parameter space (hydraulic conductivity, storage coefficient and total recharge). We highlight the occurrence of an ellipsoidal "null space", where distinct parameter sets lead to equally low values for the objective function. The optimum of the objective function is not unique, which leads to a range of possible values for the SY. With a large confidence interval for the SY, the use of modeling results for decision-making is challenging. We argue that prior to modeling operations, efforts must be invested so as to narrow the intervals of likely parameter values. Parameter space exploration is effective to estimate SY uncertainty, but not efficient because of its computational burden and is therefore inapplicable for real world groundwater systems. For predictive analysis of the SY to be realistic for real world problems, we test a calibration method based on the Gauss-Levenberg-Marquardt algorithm. Our results highlight that the analysis of the SY predictive uncertainty is essential for groundwater management. This uncertainty is expected to be large and can be addressed with better a priori information on model parameter values.