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Regional stochastic estimation of the groundwater catchment for distributed hydrological modelling

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Rainfall-runoff modeling typically assumes that the groundwater catchment boundary coincide with the topographic one. While this is often a reasonable assumption for large and and mesoscale catchments ($> 10^3\,\mathrm{km}^2$), this assumption may lead to large errors of streamflow in small scale catchments ($\leq 10^2\,\mathrm{km}^2$), in particular in certain geological settings. The Ammer catchment (135 km^2) in the upper Neckar river basin (Germany) is a prime example where groundwater and topographic catchment boundaries are significantly distinct from each other. The catchment is characterized by a complex sequence of fractured, karstic Triassic rock formations. These strata gently dip into ESE direction governing groundwater flow. Analysis of tracer experiments conducted in the 1970s indicates that the boundary overlap could be less than 80 percent. Further, a modelling study of the upper Neckar river basin using the distributed hydrological model mHM showed Nash-Sutcliff efficiencies (NSE) < 0.4 for simulated runoff in the Ammer sub-basin whereas higher efficiencies (NSE ~ 0.7) were obtained for most of the other 21 sub basins in the region. In this study we present a methodology to simultaneously estimate the regional groundwater catchment boundaries of the Ammer and its surrounding basins. In a first step we derive the best possible fit between mHM simulated and observed runoff for the individual sub-basins in the Ammer region and determine the trade-off between the fits of the individual basins using the muliobjective optimization method AMALGAM. We further present a strategy to estimate the regional groundwater catchment boundaries with the aim to improve runoff predictions in the Ammer catchment while not deteriorating runoff predictions in the surrounding basins. Our strategy involves a modification of the mHM model to account for ground water import/export from neighboring catchments while maintaining full mass balance of the surrounding basins. Groundwater catchment boundaries are then obtained by innovative stochastic optimization techniques based on Simulated Annealing that are constrained by expert knowledge about the hydrological system, e.g. a minimum overlap of groundwater and topographical catchment boundaries. The methods developed herein are useful for both plausibility and hypothesis testing as well as hydrological modelling of small scale catchments where conventional models fail due to the mismatch between groundwater and topographical catchment boundaries.