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Improving baseflow in within-grid large-scale hydrologic models through a groundwater response-time scale

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Accurate representation of baseflow remains challenging in within-grid large-scale hydrologic models, where groundwater is often represented as a single storage compartment per grid cell that exchanges water only vertically with the overlying soil column, without lateral groundwater flow between neighboring cells. Here we test how groundwater formulation, infiltration physics, and calibration strategy control baseflow skill in the mesoscale Hydrologic Model (mHM) [1]. We systematically compare two within-grid groundwater schemes (the linear scheme originally implemented in mHM and an exponential scheme newly implemented following Niu et al. [2]) and two soil infiltration representations (infiltration capacity and the one-dimensional Richards equation [3]) across 200 catchments in Germany. We use individual-basin calibration to quantify the best achievable performance of each model variant and multi-basin calibration to test parameter transferability and identify a single German-wide parameter set. Parameters are estimated within the Multiscale Parameter Regionalization (MPR) framework [1], and the baseflow index (BFI) is explicitly included in a joint calibration discharge (Q) and baseflow index (Q+BFI).

Including the baseflow index in calibration substantially improves long-term runoff-baseflow partitioning and daily baseflow dynamics, while maintaining the performance for streamflow, evapotranspiration, soil moisture, and terrestrial water storage anomalies. Incremental calibration experiments further show that baseflow skill in exponential formulations commonly used in SIMGM- and TOPMODEL-type approaches is primarily controlled by two parameters that are often prescribed as fixed values: the decay rate f and the maximum baseflow Q_{Bx}. Calibrating only f improves baseflow markedly, while calibrating only Q_{Bx} yields smaller gains. Calibrating both is required for reliable baseflow dynamics.

Across both individual-basin and multi-basin calibrations, the exponential groundwater scheme reproduces the weakest baseflow performance. This deficiency can be attributed to the absence of an explicit response time scale: the scheme reacts either too rapidly or too slowly to recharge variations, and therefore fails to capture observed baseflow behavior. To address this, we introduce a single damping parameter that represents a groundwater response time scale, analogous to the delay process that is explicitly represented in linear groundwater formulations. We refer to this modified formulation as the damped-exponential scheme. Introducing this damping markedly improves baseflow performance and yields comparable performance to the linear formulation at both basin and Germany-wide scales. The improvement is not limited to streamflow partitioning: the damped-exponential scheme also better reproduces groundwater dynamics, supported by comparisons of water-table depth variability at 118 monitoring wells across Germany.

References:

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