Predicting baseflow at the basin scale with an integrated surface and subsurface flow model

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The sustainable management of water resources under a changing climate is a major challenge of the 21th century. Basin-scale models are often preferred to investigate the potential effects of climate change on the terrestrial portion of the water cycle because they correspond to the scale of water policy decision. Potentially longer and more pronounced drier periods may increase the occurrence of low-flow periods, with reduced groundwater recharge and baseflow to streams and rivers. Integrated Surface and Subsurface Hydrological Models (ISSHMs) are well suited to investigate these low-flow events but their high computational cost can be a limiting factor to provide rigorous model calibration and uncertainty analysis at the basin scale.

We use here the integrated modeling platform HydroGeoSphere (HGS), which is an ISSHM that couples three-dimensional variably-saturated subsurface flow and two-dimensional surface water flow. HGS can also simulate snow accumulation, snowmelt, and evapotranspiration. The main input to the model is precipitation, which is then redistributed along the surface and in the subsurface by solving the governing flow equations. However, to reduce the simulation times, we have developed an additional module to externally compute the surficial components and generate spatially and temporally variable recharge. This recharge becomes the input function assigned to the integrated HGS model, instead of actual precipitations. Although we simplify the representation of groundwater recharge, we still simulate integrated surface and subsurface flow at the basin scale with HGS. This approach provides a computationally tractable integrated model at the basin scale where low flow processes are explicitly considered and generated in an integrated fashion, which is the main goal of the study.

We applied this model to a 36 900 km^2 basin in the Southern part of the province of Quebec, Canada. The basin includes the watersheds of eight main rivers, for which water availability issues related to reduced baseflow are increasing. A highly parameterized approach was chosen to introduce flexibility during calibration and allow consideration of sparse datasets within the basin. The model calibration follows a stepwise approach where the recharge model and the integrated HGS model are first calibrated independently with a gradient-based approach constrained by Tikhonov regularization and singular value decomposition. The recharge model is calibrated against snow accumulation and actual evapotranspiration for the whole basin and against mean baseflow and mean runoff for each monitored sub watershed. The integrated HGS model is calibrated against transient groundwater levels and baseflow. Using an ensemble generated from the posterior covariance matrix, the Iterative Ensemble Smoother approach is then applied to constrain the whole surface and subsurface model against all the available observations at a minimum computational cost. Thereafter, an ensemble of equally probable ISSHMs will be available to predict baseflow in a climate change context.

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