Lumped hydrological model for reasonable, long-term predictions of groundwater storage and depletion

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Excessive groundwater pumping due to immense agricultural, industrial and municipal demand poses a major threat of aquifer depletion in many areas around the world. The impact of climate change on the global hydrological cycle has further exacerbated the situation. Accurate and reliable prediction of long-term aquifer balance terms is a key prerequisite to manage groundwater sustainably. To deal with uncertainties of such predictions, lumped (conceptual) hydrological models could help with their computational speed that allows for Monte-Carlo simulation. Compared to more complex models, lumped models are fast, lean on data requirement and capable to quantify uncertainty. However, lumped models are mainly designed to simulate river discharge only, not aquifer storage. Even the standard practice for calibrating lumped hydrological models only includes river discharge, as data on groundwater storage is not directly accessible. In this study, we hypothesize that we can extend the HBV model by additional water budget and groundwater storage terms, and calibrated it on both groundwater storage data and discharge data. Then, we test whether its predictions of groundwater storage levels withstand validation tests. To avoid problems with unavailability of data for calibration and validation in a first proof of concept, we build a virtual reality with a MODFLOW-based model, driven with synthetic weather data over a period of more than 50 years. For rigorous testing, we cast calibration into the framework of Bayesian parameter inference, and validate with metrics that assess the appropriateness of the Bayesian prediction distribution of groundwater storage. We test our idea in the Wairau Plain aquifer, New Zealand. Poor understanding of recharge mechanisms and hence declining groundwater levels are the major hindrance for sustainable groundwater management in our study area. We pay specific attention to river-groundwater exchange processes, to the forecast of aquifer storage dynamics, and to groundwater depletion in a hypothetical, persistent drought. The purpose is to provide a proof of concept whether lumped models can be adapted and made suitable to predict declining groundwater resources up to full depletion, as an uncertainty-aware decision support system for sustainable management.