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Reduction of the ambiguity of karst aquifer modeling through pattern matching of groundwater flow and transport

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Distributive numerical simulations are an effective, process-based method for predicting groundwater resources and quality. They are based on conceptual hydrogeological models that characterize the properties of the catchment area and aquifer. Karst systems play an important role in water supply worldwide. Conceptual models are however difficult to build because of the highly developed heterogeneity of the systems. The geometry and properties of highly conductive karst conduits are generally unknown and difficult to characterize with field experiments. Due to these uncertainties numerical models of karst areas usually cannot simulate the hydraulic head distribution in the area, spring discharge and tracer breakthrough curves simultaneously on catchment scale. Especially in complex hydrogeological systems, this approach would reduce model ambiguity, which is prerequisite to predict groundwater resources and pollution risks.

In this work, a distributive numerical groundwater flow and transport model was built for a highly heterogeneous karst aquifer in south-western Germany. For this aim, a solute transport interface for one-dimensional pipes was implemented in the software Comsol Multiphysics® and coupled to the standard three-dimensional solute transport interface for domains. The model was calibrated and hydraulic parameters could be obtained. The simulation was matched to the steady-state hydraulic head distribution in the model area, the spring discharge of several springs and the transport velocities of two tracer tests. Furthermore, other measured parameters such as hydraulic conductivity of the fissured matrix and the maximal karst conduit volume were available for model calibration. Parameter studies were performed for several karst conduit geometries to analyze their influence in a large-scale heterogeneous karst system.

Results show that it is not only possible to derive a consistent flow and transport model for a 150 km^2 karst area to be employed as a prognostic tool but that the combined use of groundwater flow and transport parameters greatly reduces model ambiguity. The approach provides basic information about the conduit network not accessible for direct geometric measurements. The conduit network volume for the main karst spring in the study area could be narrowed down to approximately 100 000 m^3, even though standard tracer test evaluations predicted a volume of up to 200 000 m^3.