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Application of continuum- and hybrid models in karst spring catchments

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Flow in karst aquifers is concentrated along highly permeable solution conduits embedded in the much less permeable fissured system of the surrounding rock. This complex and heterogeneous flow regime can be conceptualized as dual flow systems composed of slow, laminar flow in the fractured porous matrix as opposed to rapid, often turbulent flow in solution conduits. Flow in the fractured porous rock can be treated as a continuous flow field (continuum model), whereas flow in the conduit system is spatially localized and can be modelled by a discrete pipe network model. Hybrid models couple both flow systems and have frequently been employed in basic research, e.g., to simulate and analyse the mechanism of speleogenesis. In many practical applications, however, continuum models are employed. In these models the two flow components are lumped together and the conduits are represented by highly permeable cells (smeared conduit approach). Standard groundwater models imply that conduit flow is represented by a Darcian approach, thus ignoring potential effects of turbulent flow. On this account the USGS has recently released a MODFLOW-2005 Conduit Flow Process (CFP), which makes it possible to account for turbulent flow in the continuum approach (CFP mode 2). Additionally a discrete pipe network model can be coupled to MODFLOW. This hybrid model (CFP mode 1) employs the Darcy-Weisbach equation to represent turbulent flow in the karst conduits.
In this work, it is attempted to simulate the discharge hydrographs of a hypothetical karst spring catchment in which conduit systems are embedded in fissured porous rock using both the single-continuum approach (CFP mode 2) and the hybrid model (CFP mode 1). This study shows that the hydraulic response of the spring signal is influenced by the flow conditions in the conduit, i.e. the shape of the spring hydrograph predicted by a model that accounts for turbulent flow differs from that obtained with a laminar flow model. This further implies that inferences of aquifer properties from spring hydrographs are potentially impaired by ignoring turbulent flow effects. Thus, the adequate representation of turbulent flow in karst models might deserve equal or even more attention than the general pros and cons of continuum and hybrid models discussed in the literature. Moreover this study focuses on the applicability of the single-continuum approach (CFP mode 2) regarding the typical discharge dynamics of spring catchments. The continuum model is currently tested using the well investigated Gallusquelle catchment (Schwäbische Alb, Germany). The Gallusquelle hydrograph show significant variations in the spring discharge while the hydraulic head within the catchment changes only moderately. This strong variability within the hydrograph was already modelled using a double-continuum model but poses a serious challenge when using the lower-parameterised single-continuum approach.