Coupling strategies for the karst groundwater flow models

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ABSTRACT

Approximately 20–25% of the global population depends largely or entirely on groundwater obtained from karst aquifers [1]. For proper water management and protection, it is important to understand and be able to predict groundwater flow in karst. Numerical modeling is an efficient method for describing many physical phenomena and is frequently used in the karst hydrology. However, the existence of a highly permeable conduit network embedded in a less permeable rock matrix results in a highly heterogeneous permeability distribution and makes karst different from other aquifers. Among the different approaches for the karst flow modeling, hybrid spatially distributed models have been presented as the most realistic, including heterogeneity description and enabling tracer or contaminant transport analysis, but also the most complex karst representation. In hybrid approach, low-permeability matrix is discretized in three dimensions through the Darcy Law and Richards equation describing saturated and unsaturated flow conditions. Difficulties arise due to high nonlinearity in Richards equation, especially under dry conditions in epikarst, due to large pressure (head) gradients around the water table and/or description of boundary conditions. The karst conduits can be fully described by 3-D Navier-Stokes equations (NSE). However, due to complexity of numerical solving of NSE, different approximations are often used. Karst conduits can be described by pressurized or free surface flow. Special attention should be devoted to the transition between these two flow regimes. Problem is usually solved by using small Priesmann slot considering flow by 1-D or 2-D St. Venant shallow water equations (open channel flow). Despite these simplifications, application of St. Venant equations is not easy task due to its hyperbolicity and stability. Final simplification can be consideration of non-inertia 1-D diffusive wave equation for conduits enabling unified description of both flow regimes. Except complex two components of this Multiphysics coupled problem, special attention must be paid to the coupling strategies between porous matrix and karst conduits. In case of NSE for conduits, coupling should be performed related to Beavers and Joseph (BJ) analysis consisting of three coupling interface conditions: 1) continuity of interface flux normal component, 2) appropriate pressure condition enabling its discontinuity between two flow domains and 3) condition postulating that the difference between the slip velocity of the free fluid and the tangential component of the velocity through the porous medium is proportional to the shear rate of the free fluid introducing unknown (calibration) parameter. If we consider mentioned simplifications of NSE for conduits, the coupling between two flow domains is established via a first-order exchange term governed by the conduit-matrix head difference and also unknown (calibration) exchange parameter. Crucial problem is sensitivity of exchange parameter and its physical meaning. Some other options used Peaceman well index or pressure continuities. Since realistic verification of the karst flow models is an extremely difficult task, the consequences of mentioned different coupling strategies will be shown on 2-D [2] and 3D [3] physical laboratory flow models. Special attention will be devoted to the exchange parameter, its sensitivity as well as temporal and spatial distribution.

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