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Numerical simulation of freshwater/seawater interaction in a dual-permeability karst system with conduits: the development of discrete-continuum VDFST-CFP model

Zexuan Xu and Bill Hu
Department of Earth, Ocean and Atmosphere Science, Florida State University, Florida, United States

Dual-permeability karst aquifers of porous media and conduit networks with significant different hydrological characteristics are widely distributed in the world. Discrete-continuum numerical models, such as MODFLOW-CFP and CFPv2, have been verified as appropriate approaches to simulate groundwater flow and solute transport in numerical modeling of karst hydrogeology. On the other hand, seawater intrusion associated with fresh groundwater resources contamination has been observed and investigated in numbers of coastal aquifers, especially under conditions of sea level rise. Density-dependent numerical models including SEAWAT are able to quantitatively evaluate the seawater/freshwater interaction processes.
A numerical model of variable-density flow and solute transport – conduit flow process (VDFST-CFP) is developed to provide a better description of seawater intrusion and submarine groundwater discharge in a coastal karst aquifer with conduits. The coupling discrete-continuum VDFST-CFP model applies Darcy-Weisbach equation to simulate non-laminar groundwater flow in the conduit system in which is conceptualized and discretized as pipes, while Darcy equation is still used in continuum porous media. Density-dependent groundwater flow and solute transport equations with appropriate density terms in both conduit and porous media systems are derived and numerically solved using standard finite difference method with an implicit iteration procedure. Synthetic horizontal and vertical benchmarks are created to validate the newly developed VDFST-CFP model by comparing with other numerical models such as variable density SEAWAT, couplings of constant density groundwater flow and solute transport MODFLOW/MT3DMS and discrete-continuum CFPv2/UMT3D models. VDFST-CFP model improves the simulation of density dependent seawater/freshwater mixing processes and exchanges between conduit and matrix. Continuum numerical models greatly overestimated the flow rate under turbulent flow condition but discrete-continuum models provide more accurate results. Parameters sensitivities analysis indicates that conduit diameter and friction factor, matrix hydraulic conductivity and porosity are important parameters that significantly affect variable-density flow and solute transport simulation. The pros and cons of model assumptions, conceptual simplifications and numerical techniques in VDFST-CFP are discussed. In general, the development of VDFST-CFP model is an innovation in numerical modeling methodology and could be applied to quantitatively evaluate the seawater/freshwater interaction in coastal karst aquifers.

Keywords: Discrete-continuum numerical model; Variable density flow and transport; Coastal karst aquifer; Non-laminar flow