Geophysical Research Abstracts
Vol. 19, EGU2017-3332, 2017
EGU General Assembly 2017

Development of a discrete-continuum VDFST-CFP numerical model for simulating seawater intrusion to a coastal karst aquifer with a conduit system

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A hybrid discrete-continuum numerical model, Variable-Density Flow and Solute Transport - Conduit Flow Process (VDFST-CFP), is developed to simulate seawater intrusion to a coastal karst aquifer with a conduit network. The Darcy-Weisbach equation is applied to simulate the non-laminar groundwater flow in the conduit system that is conceptualized as pipes, while the Darcy equation is used for laminar groundwater flow in the continuum porous medium. Density-dependent groundwater flow with appropriate additional density terms in the conduit is analytically derived. The flow equations are coupled with transport equations, and numerically solved by the finite difference method with an implicit iteration procedure. Two synthetic benchmarks are developed to compare the VDFST-CFP model results with other numerical models, such as the variable-density SEAWAT, constant-density continuum MODFLOW/MT3DMS and constant-density discrete-continuum CFPv2/UMT3D models. The VDFST-CFP model compares reasonably well with the other model results in both conduit and porous medium domains, and well describes water and salt exchanges between the two systems. Under turbulent flow conditions within the conduit, the Darcy-Weisbach equation calculates the flow rate more accurately without the overestimation by the Darcy equation . Sensitivity analysis indicates that conduit diameter, friction factor, matrix hydraulic conductivity, and effective porosity are important parameters in the VDFST-CFP model. The pros and cons of the VDFST-CFP model are discussed, including the model assumptions and simplifications, limitations of the discrete-continuum modeling method, and the convergence criteria. In general, the newly developed VDFST-CFP model provides a new numerical modeling method for simulating seawater intrusion in a coastal karst aquifer with conduits.