

Simulation of Turbulent Ground-Water Flow with MODFLOW-2005— Overview

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Abstract

The Conduit Flow Process (CFP) is a recently released module for MODFLOW-2005 that can simulate turbulent flow in aquifers with pipe-like (such as karst) features or preferential flow layers. The CFP simulates turbulent flow as a discrete pipe network connected to the MODFLOW cells via head-dependent flux terms using Mode 1 (CFPM1), or as continuous preferential flow layers where flow can transition between laminar and turbulent in the row and column direction using Mode 2 (CFPM2). Additionally, both a pipe network and preferential flow layers can be simulated in the same model, Mode 3 (CFPM3). Preferential flow layers in CFPM2 simulate flow through interconnected pores and vugs more than 0.01 m in diameter, such as those that are present in the carbonate rock making up the Biscayne aquifer in southern Florida. CFPM2 requires less data than CFPM1 or CFPM3 because discrete pipe networks are not simulated. However, CFPM1 is designed to simulate laminar and turbulent flow in large networks of submerged conduits (partially filled conduits can be simulated, but should have almost no slope). CFPM1 is an update of subroutines to MODFLOW-2005 (Harbaugh, 2005) from the Carbonate Aquifer Void Evolution (CAVE) code previously published (Teutsch, 1993; Sauter, 1993; Clemens and others, 1996; Clemens, 1998; Hückinghaus, 1998; Bauer and others, 2000; 2003; Liedl and others, 2003; and Birk, 2002). CFPM2 is a new simple empirical algorithm for simulation of turbulent flow in preferential flow layers modified from Halford (2000). This oral presentation focuses on the theory of the code and the validation of the new algorithm for CFPM2. The code and documentation is public domain and will be available through the U.S. Geological Survey website (Shoemaker and others, 2008):

http://water.usgs.gov/software/ground_water.html

REFERENCES

- Bauer, Sebastian, Liedl, Rudolf, and Sauter, Martin. 2000. Modelling of karst development considering conduit-matrix exchange flow, in Stauffer, F., Kinzelbach, W., Kovar, K., and Hoehn, E., eds., Calibration and reliability in groundwater modelling: Coping with uncertainty—Proceedings of the ModelCARE'99 Conference: International Association of Hydrological Sciences Publication 265, 10-15.
- Bauer, Sebastian, Liedl, Rudolf, and Sauter, Martin. 2003. Modeling of karst aquifer genesis: Influence of exchange flow: Water Resources Research v. 39, no. 10, 1285.
- Birk, Steffen, 2002. Characterization of karst systems by simulating aquifer genesis and spring responses: Model development and application to gypsum karst: Vol. 60 of Tübinger Geowissenschaftliche Arbeiten: Tübingen, Germany, Reihe C. Institut und Museum für Geologie und Paläontologie der Universität Tübingen. Also available at: <http://w210.ub.uni-tuebingen.de/dbt/volltexte/2002/558/>.
- Clemens, T., Hückinghaus, D., Sauter, M., Liedl, R., Teutsch, G. 1996: A combined continuum and discrete network reactive transport model for the simulation of karst development. In: Kovar, K., van der Heijde, P. (eds.), Calibration and reliability in groundwater modelling. IAHS Publication 237: 309-318.
- Clemens, Torsten, 1998. Simulation der Entwicklung von Karstaquiferen: Ph.D. dissertation submitted to Eberhard-Karls Universität Tübingen, Germany.

- Halford, K.J. 2000. Simulation and interpretation of borehole flowmeter results under laminar and turbulent flow conditions: Seventh International Symposium on Logging for Minerals and Geotechnical Applications, Golden, Colorado, October 24-26, 2000, 157-168.
- Harbaugh, A.W. 2005. MODFLOW-2005. the U.S. Geological Survey modular ground-water model -- the Ground-Water Flow Process: USGS Techniques and Methods 6-A16.
- Hückinghaus, Dirk, 1998. Simulation der Aquifergenese und des Wärmetransports in Karstaquiferen: Vol. 42 of Tübinger Geowissenschaftliche Arbeiten: Tübingen, Germany, Reihe C. Institut und Museum für Geologie und Paläontologie der Universität Tübingen. Also available at: <http://w210.ub.uni-tuebingen.de/dbt/volltexte/2005/2030/>.
- Liedl, R., Sauter, M., Hückinghaus D., Clemens T., Teutsch, G. 2003: Simulation of the development of karst aquifers using a coupled continuum pipe flow model. Water Resour. Res., 39 (1), 1057, doi:10.1029/2001WR001206.
- Sauter, Martin, 1993. Double porosity models in karstified limestone aquifers: Field validation and data provision, in Hydrogeological Process in Karst Terranes, International Association of Hydrological Sciences, v. 207, p. 261-279.
- Shoemaker, W.B., Kuniansky, E.L., Birk, Steffen, Bauer, Sebastian, and Swain, E.D., 2008. Documentation of a Conduit Flow Process (CFP) for MODFLOW-2005: U.S. Geological Survey Techniques and Methods 6-A24.
- Teutsch, Georg, 1993. An extended double-porosity concept as a practical modeling approach for a karstified terraine, in Gultekin, Johnson, and Back, eds., Hydrogeological Processes in Karst Terraines, Proceedings of the Antalya Symposium and Field Seminar, October 1990: International Association of Hydrological Sciences, v. 207, 281-292.