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Influence of aquifer geometry on karst hydraulics using different distributive modeling approaches

Sandra Oehlmann (1), Tobias Geyer (1), Tobias Licha (1), and Steffen Birk (2)

(1) Georg-August-Universität Göttingen, Geowissenschaftliches Zentrum, Goldschmidtstraße 3, 37077 Göttingen, Germany,
(2) Karl-Franzens-Universität Graz, Institut für Erdwissenschaften, Heinrichstraße 26, 8010 Graz, Austria

The simulation of flow and transport processes in karst systems is a challenge due to the unknown location of highly conductive karst conduit networks.

In this work, the influence of aquifer geometry, particularly the geometry of highly conductive discrete elements, on three-dimensional groundwater flow in a large-scale aquifer system is examined. The area of investigation comprises several springs on the Western Swabian Alb / Germany and has an area of approximately 150 km^2. The largest spring therein is the Gallusquelle with an annual average discharge of 0.5 m^3/s. Long-term spring hydrographs and hydraulic head measurements, as well as several tracer tests, are available from previous work and are used for model calibration.

Four distributive continuum and discrete flow models with different degrees of complexity were set-up employing the finite element simulation software Comsol Multiphysics®. Stationary groundwater flow equations were implemented for single continuum and hybrid modeling. The aquifer geometry was modeled previously with the software Geological Objects Computer Aided Design® (GoCAD®) and transferred to Comsol® software.

Simulation results show that not only the location of karst conduits but also their geometry has significant impact on the simulated spring discharge and hydraulic head distribution. A constant conduit radius leads to distorted hydraulic head contour lines and a conduit restrained flow regime close to the spring, while a linearly increasing radius towards the spring leads to evenly distributed contour lines. Models with such an increase in conduit diameters allow the simulation of annual discharge for several springs. This result is in agreement with synthetic karst genesis models, which suggest an increase of conduit diameters towards karst springs because of a positive correlation between flow rates and carbonate solution. The software Comsol Multiphysics®, while rarely used for groundwater flow modeling, was found to meet all requirements for karst modeling and thus represents a promising, extendable tool for further modeling studies.