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A dual approach to compute groundwater flow in karst aquifers using distributive models: example of the Lurbach system (Austria)

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Distributive models of different complexity were applied to the binary Lurbach karst system, which is located 20 km north of Graz (Austria). The upper part of the catchment comprises impermeable schists and is drained by a stream, the Lurbach, towards the lower part, the 8.3 km2 limestone plateau of the Tanneben massif. After it reaches the limestone unit, the Lurbach infiltrates along its course and finally disappears into an inaccessible subterranean sinkhole located in a cave, the Lurgrotte. Then, the water flows through the fissures and conduits of the massif and resurges at two springs, the Hammerbach spring and the Schmelzbach spring, located at the foot of the Peggauer Wand, a 300 m high limestone cliff, at the western border of the catchment.

Two different modelling approaches were used to learn more about the behaviour of the karst system: (A) MODFLOW laminar single-continuum models were implemented using the geological knowledge, tracer results, and spring discharge data. The purpose was to reproduce the response of the two springs under different hydrological conditions. (B) Idealized catchments served to analyse the transfer of an input signal in a conduit with simple geometrical assumptions (such as varying matrix parameters) to learn more about prevailing effects in the system and to evaluate the significance of pressurized- and open-channel flow. Three different numerical models were used for the investigation: the hybrid models CFPM1 (USGS), which couples MODFLOW to a discrete pipe network simulating pressurized flow; ModBraC, which couples MODFLOW to a discrete open-channel flow model adapted for karst conduits; and the modified single-continuum model CFPM2, which is a version of MODFLOW that accounts for turbulent flow by appropriately adjusting the hydraulic conductivity of the model cells.

Results lead to the following conclusions:
(A) The MODFLOW simulations in steady and transient state show good agreement with the discharge data. Transient state should be privileged in the future, because karst aquifers are rarely in steady-state conditions. Even though the behaviour of the system is reproduced, the lack of Schmelzbach data was a problem. Further investigations are needed and should use more data.
(B) Studies with synthetic catchments show that the observed damping of the input signal during recharge events at the Hammerbach spring could be a consequence of strong interaction between conduits and the carbonate matrix when pipe flow is pressurized. The model results with the new hybrid model ModBraC show that damping can also be obtained using open-channel flow. As opposed to CFPM1 and CFPM2, ModBraC displays a time lag between the in- and output signal, which is also observed at the field site. First modelling results with a ModBraC regional model, however, show that open-channel flow alone cannot explain the strongly damped discharge curve and the time lag of up to 26 hours between the in- and output signal at the Hammerbach spring. This means that the recharge signal is obviously influenced by a combination of open-channel flow, pressurized flow, and by the presence of reservoirs along the conduits. However, reasonable results were obtained for the Schmelzbach system using the open-channel flow model.

Finally, results suggest that single-continuum and hybrid models each with turbulent flow representation are adequate to compute spring water discharge in karst aquifers. Nevertheless, information about the conduit geometry and sufficient hydrological data are required.