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A multi-method approach to resolve the dynamics of groundwater flow components in a low-lying karstified limestone aquifer

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Karstified carbonate aquifers are highly heterogeneous systems characterised by multiple porosities and permeabilities formed after deposition of the rocks. The different porosities are associated with different permeabilities commonly interpreted as (fissured) matrix, fractures and conduits (Worthington, et al., 2000), generally associated with a turbulent quick-flow vs. a laminar slow-flow component (Atkinson, 1977, Kiraly, et al., 1995).
Understanding, quantifying and numerically modelling these different flow dynamics is a challenge (Sauter, et al., 2006), yet, relevant since different dynamics can be linked to engineering challenges such as mitigating groundwater flooding (Naughton, et al., 2012) or groundwater source protection schemes for public water supplies.
This research applied a range of different complementary field and desktop methods in order to quantify and model different flow components of the low-lying catchment of Ballindine spring in western Ireland. The catchment was delineated using artificial tracer tests in conjunction with univariate and bivariate statistical methods, continuous wavelet transform and wavelet coherence. The results of these methods reveal an aquifer with a low degree of karstification receiving the majority of groundwater recharge indirectly through a losing stream. Groundwater flow is predominantly slow, as further complemented by the results of a KarstMod reservoir model (Mazzilli, et al., 2017).
Based on the principle that individual flow components may resemble the drainage of linear reservoirs, a novel systematic approach was employed to separate continuous time series of a low-flow component (LFC) from the spring hydrograph, representing drainage of the low permeability domain.
Using the results of the above mentioned methods, a conceptual site model was synthesised and represented in a semi-distributed numerical environment in form of a pipe-network model using InfoWorks ICM® (Innovyze software, Wallingford, version 7.0) (Gill, et al., 2013, Schuler, et al., 2018). The strength of the model lies in its capability of simulating turbulent and open channel flow as well as diffuse laminar flow, while its semi-distributed approach seems to be a reasonable balance to account for the spatial heterogeneity.
The model was run on an hourly time step over a period of eight years (1 year warm-up, 2 years calibration, 5 years validation). The performance of the model was assessed for the total spring discharge and for the LFC using the Kling-Gupta efficiency (KGE), Nash-Sutcliffe efficiency (NSE) and the volume conservation criteria (VCC). The simulated LFC achieves a KGE and NSE of 0.70 and 0.59 during calibration and 0.85 and 0.71 during validation. Further, the total simulated discharge achieves a KGE and NSE of 0.85 and 0.80 during calibration and 0.84 and 0.84 during validation.
Overall, the model performance is considered good, confirming the conceptual site model and the approach of quantifying and modelling the total flow and LFC. Hence, such knowledge can be used to possibly better predict the response of such an aquifer to recharge and as well as potential periods of groundwater flooding.