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Implementation of a 3d numerical model of a folded multilayer carbonate aquifer

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The main objective of this research is to present a case study of the numerical model implementation of a complex carbonate, structurally folded aquifer, with a finite difference, porous equivalent model. The case study aquifer (which extends over 235 km2 in the Apennine chain, Central Italy) provides a long term average of 3.5 m3/s of good quality groundwater to the surface river network, sustaining the minimum vital flow, and it is planned to be exploited in the next years for public water supply. In the downstream part of the river in the study area, a “Site of Community Importance” include the Nera River for its valuable aquatic fauna. However, the possible negative effects of the foreseen exploitation on groundwater dependent ecosystems are a great concern and model grounded scenarios are needed.

This multilayer aquifer was conceptualized as five hydrostratigraphic units: three main aquifers (the uppermost unconfined, the central and the deepest partly confined), are separated by two locally discontinuous aquitards. The Nera river cuts through the two upper aquifers and acts as the main natural sink for groundwater. An equivalent porous medium approach was chosen.

The complex tectonic structure of the aquifer requires several steps in defining the conceptual model; the presence of strongly dipping layers with very heterogeneous hydraulic conductivity, results in different thicknesses of saturated portions. Aquifers can have both unconfined or confined zones; drying and rewetting must be allowed when considering recharge/discharge cycles. All these characteristics can be included in the conceptual and numerical model; however, being the number of flow and head target scarce, the over-parametrization of the model must be avoided. Following the principle of parsimony, three steady state numerical models were developed, starting from a simple model, and then adding complexity: 2D (single layer), QUASI -3D (with leackage term simulating flow through aquitards) and fully-3D (with aquitards simulated explicitly and transient flow represented by 3D governing equations).

At first, steady state simulation were run under average seasonal recharge. To overcome dry-cell problems in the FULL-3D model, the Newton-Raphson formulation for MODFLOW-2005 was invoked. Steady state calibration was achieved mainly using annual average flow along four streambed’s Nera River springs and average water level data available only in two observation wells. Results show that a FULL-3D zoned model was required to match the observed distribution of river base flow.

The FULL-3D model was then run in transient conditions (1990-2013) by using monthly spatially distributed recharge estimated using the Thornthwaite-Mather method based on 60 years of climate data. The monitored flow of one spring, used for public water supply, was used as proxy data for reconstruct Nera River hydrogram; proxy-based hydrogram was used for calibration of storage coefficients and further model’s parameters adjustment. Once calibrated, the model was run under different aquifer management scenario (i.e. pumping wells planned to be active for water supply); the related risk of depletion of spring discharge and groundwater-surface water interaction was evaluated.