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What function tells about structure in heterogeneous aquifers

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Hydogeologists and water resources managers are interested in the functional aspects of groundwater systems, that is, the temporal behaviour of groundwater head, patterns of groundwater flow pathways or residence time distribution. These functional aspects highly depend on the structure of the respective aquifer, e.g., on the extent and inclination of confining layers or on the geometry of fissures in hardrock aquifers. Thus a sound knowledge of the prevailing features of the aquifer's structure is a necessary prerequisite for groundwater resources management and application of groundwater models.

There is urgent need for efficient ways to extract relevant information from easily available data. When certain structures in the subsurface have a major effect on the functioning of a groundwater system sophisticated analysis of the latter might be used to infer the former in an inverse approach. Then in a next step this information could be used, e.g., for constraining groundwater models. Unless, e.g., for a naïve implementation of geophysical data in groundwater models, the approach outlined here ensures that only structures relevant for hydrogeological functioning are considered, thus minimizing the model structure uncertainty.

This approach has been applied in the Quillow catchment in Northeast Germany, a region with a very complex setting of pleistocenic unconsolidated sediments of 200 m thickness, where numerous layers of varying permeability intersect to unknown numbers and extent. Here the key problem is the identification of confining layers that effectively separate different aquifers. Different approaches were combined.

Firstly, a principal component analysis was applied to time series of groundwater head from 10 groundwater wells in the study region, allowing to differentiate between different effects on groundwater dynamics. Corresponding to other studies published recently, groundwater head dynamics in the first place depended on the degree of transformation of the input signal, that is, the temporal structure of the seepage flux in the vadose zone. In the uppermost unconfined aquifer the degree of that transformation linearly increased with the thickness of the overlying vadose zone, whereas there was no clear relationship for wells screened in the underlying confined aquifer. Scores of that principal component could even be used to assess the thickness of the vadose zone in the respective recharge area for the confined aquifer.

Secondly, longitudinal discharge measurements of the catchment's main stream during baseflow conditions were used to identify gaining or loosing reaches, giving indirect evidence for major aquifer and aquitard layers. Thirdly, water level data from about 1100 small lakes as well as from the streams derived from a high-resolution airborne laser scan survey were used for setting up a map of groundwater head of the uppermost aquifer. Comparison with groundwater head data from deeper wells revealed substantial deviations in certain parts of the catchment, confirming the existence of a separate deeper aquifer. Last but not least, additional evidence was provided by groundwater quality data. Findings from the different approaches were merged. This resulted in a consistent conceptual model which will be tested in next step by a distributed hydrological model.