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Using Isomap to differentiate between anthropogenic and natural effects on groundwater dynamics in a complex geological setting

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The water budget of many catchments has vastly changed throughout the last decades. Intensified land use and increased water withdrawal for drinking water production and irrigation are likely to intensify pressure on water resources. According to model predictions, changing rainfall intensity, duration and spatial distribution in conjunction with increasing temperatures will worsen the situation in the future.

The current water resources management has to adapt to these negative developments and to account for competing demands and threats. Essential for successful management applications is the identification and the quantification of the cause-and-effect chains driving the hydrological behavior of a catchment on the scale of management. It needs to check direction and magnitude of intended effects of measures taken as well as to identify unintended side effects that interact with natural effects in heterogeneous environments (Wood et al., 1988; Bloschl and Sivapalan, 1995). Therefore, these tools have to be able to distinguish between natural and anthropogenic driven impacts, even in complex geological settings like the Pleistocene landscape of North-East Germany.

This study presents an approach that utilizes monitoring data to detect and quantitatively describe the predominant processes or factors of an observed hydrological system. The multivariate data analysis involves a non-linear dimension reduction method called Isometric Feature Mapping (Isomap, Tenenbaum et al., 2000) to extract information about the causes for the observed dynamics. Ordination methods like Isomap are used to derive a meaningful low-dimensional representation of a complex, high-dimensional data set. The approach is based on the hypothesis, that the number of processes which explain the variance of the data is relative low although the intensity of the processes varies in time and space. Therefore, the results can be interpreted in reference to the effective hydrological processes which control the system.

The method was applied on a data set of groundwater head and lake water level. Two factors explaining more than 95 percent of the observed spatial variations were identified: (1) the anthropogenic impact of a waterworks in the study area and (2) natural groundwater recharge dynamics of different degrees of dampening at the respective sites of observation. The spatial variation of the identified processes revealed previously unknown hydraulic connections between two aquifers and between surface water bodies and groundwater. The obtained information can be used to reduce model structure uncertainty and a more efficient process-based modeling of hydraulic system behavior. Thus, the approach provides essential information to evaluate and adapt strategies for an integrated water resources management in complex landscapes.

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