Integration of major ion chemistry and stable isotope data with hydrogeological modelling to infer groundwater pathways

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Background
A variety of methods exist to differentiate infiltration zones from seepage zones and to quantify their relationship. We combined hydrogeological modelling and data on major ion chemistry and stable isotopes measured in rainwater, groundwater, and rivers. The analysis aimed at quantifying the connectivity between two aquifers separated by a distinct clay layer several meters thick. The clay layer is believed to play an important role in determining the spatial relationship between infiltration and seepage zones across the hydrogeological landscape.

Hydrogeological model
Hydrostratigraphic units were delineated based on 3D geostatistical analysis of cored boreholes and cone penetration tests. Results consist of an upper aquifer (Mol and Kasterlee Sands) and a lower aquifer (Diest Sands), separated by the poorly permeable Kasterlee Clay layer.

Conceptual and numerical model of groundwater pathways
Groundwater is characterized by local (shallow) and regional (deep) flow paths. Hydrogeologic connectivity between infiltration and seepage zones depends among others on permeability of poorly permeable clay layer(s). Numerical modelling provides insight in such relationships, including age of groundwater(s) and contribution of deep groundwater to seepage and river baseflow. Local flow paths originating from the centre of the catchment had travel times of several tens of years and discharged directly into the nearby Kleine Nete river. Deep flow paths resulted in upwelling groundwater with positive upward gradients across the clay layer in the vicinity of the main river.

Hydrochemical analysis
- Hydrochemical analyses showed distinctly different groundwater compositions for upper and lower aquifers.
- Alkalinity increases with depth while the cations shift from divalent Ca to monovalent Na. A distinct cluster of data points for the upper aquifer (Mol and Kasterlee Formation) was evident, characterised by a strong sulphate component (between 60-80%).
- The water composition in the lower aquifer (Diest Formation) is significantly different compared to the upper aquifer. The anions are dominated by bicarbonate (bicarbonate type groundwater), while Ca becomes the most important cation (calcium type groundwater).
- The river water has a composition inbetween that of both aquifers, suggesting mixing of both waters in the seepage zone.
- Chloride and sulphate concentrations in rainwater are in between rivers and shallow groundwater.

Stable isotope data
- Analysis of stable isotope data reveals two clusters for the hydrostratigraphic units that define the upper and lower aquifer: one for the units above the Kasterlee clay (i.e., Mol and Kasterlee Sands), and one for the Diest Sands.
- The shallower and younger water from the Mol Sands is slightly less depleted in 2H and 18O in comparison with water from the deeper Diest Sands (for the latter aquifer deviations from the meteoric lines are larger both for 18δ and 2δ). These two clusters thus confirm the two water types identified on the basis of geochemical analysis.

Conclusions
Groundwater geochemistry and stable isotope data confirmed the general flow paths obtained from running the groundwater flow model: infiltration zones that are mainly connected with the seepage zones along the Kleine Nete river via shallow groundwater pathways. There is also confirmation from the groundwater geochemistry that the upper and lower aquifers are well separated by the clay aquitard, except in the seepage zones where strong upward hydraulic gradients across the clay exist, resulting in river water with a mixed chemical composition.

References