A straightforward estimation of the spatial distribution of groundwater transit times in catchments

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Introduction

Quantification of the groundwater transit time distribution is fundamental for the prediction of the fate of diffuse pollution in catchments. We propose a straightforward method to estimate the spatial and statistical distribution groundwater transit time in lowland catchments with homogeneous, horizontal aquifers.

Description of the method

The method is based on the notion that in an isotropic aquifer, the age of a water parcel increases logarithmically with depth. Under this assumption, the groundwater transit time depends on groundwater recharge rate (N), aquifer dimensions (thickness (D) and width (X)) and porosity (n), and distance from the divide. The mean transit time T of groundwater infiltrating in a model gridcell is given by:

$$T = D\frac{n}{N}\left(\frac{x_2}{\Delta x}\ln\left(\frac{X}{x_2}\right) - \frac{x_1}{\Delta x}\ln\left(\frac{X}{x_1}\right) + 1\right)$$

Where x_1 and x_2 are the distances from the divide to the respective upgradient and downgradient cell boundaries and Δx is the gridcell size.

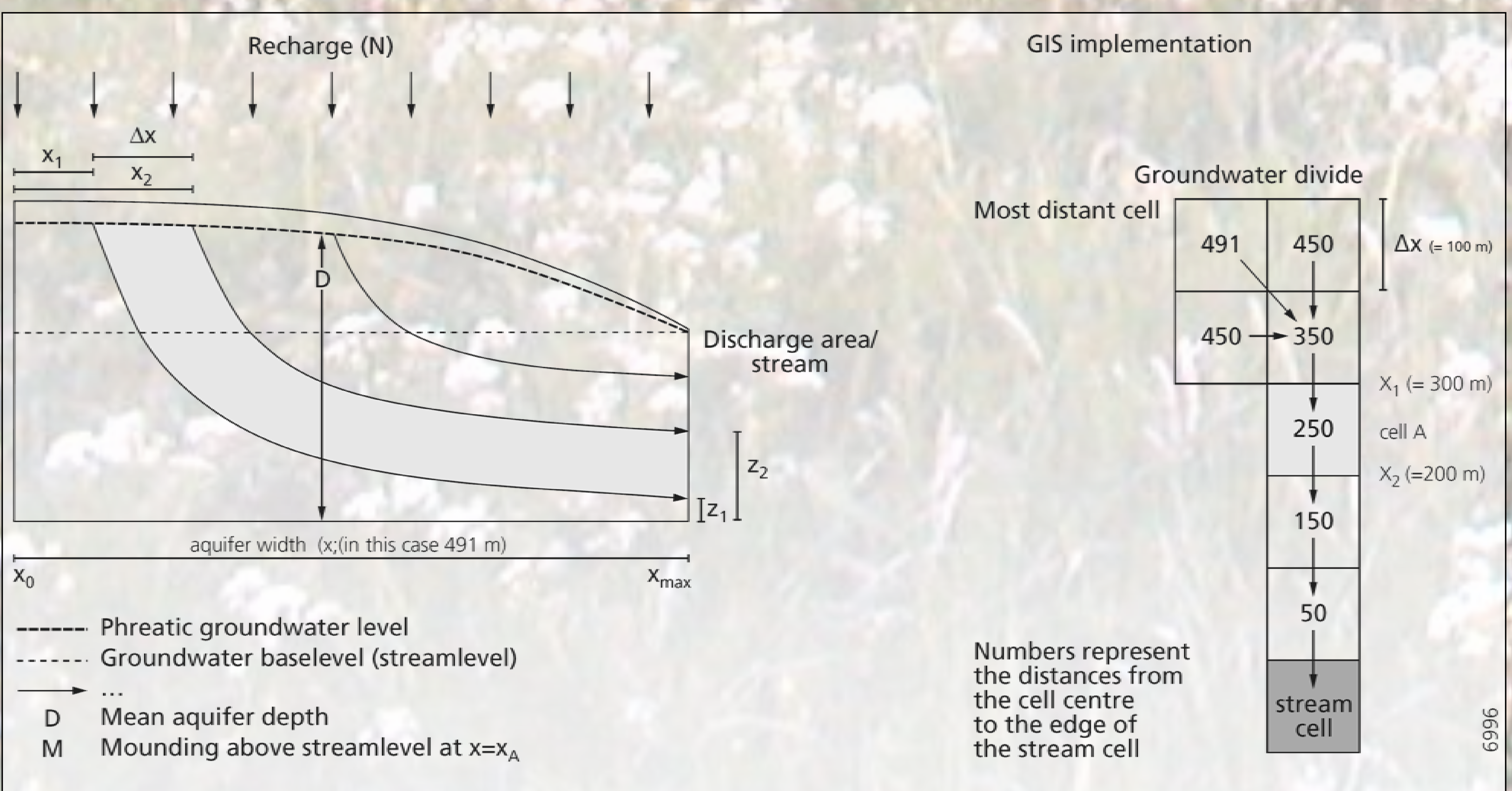

Figure 1 Concept and GIS implementation of estimation of groundwater transit times.

Application

The method was tested and applied to a 901 km2 large Ahja catchment in south-eastern Estonia (Mourad, 2008). Using spatial data on land cover, drainage network and aquifer properties and a simple water balance model to estimate the groundwater recharge rate, we calculated the spatial distribution of groundwater transit time at a spatial resolution of 100 m. For the lower-order streams (Strahler stream order ≤ 3), we related the in-stream logtransformed dissolved inorganic nitrogen (DIN) concentration during baseflow conditions (summer 2002) to the calculated proportion of groundwater from agricultural areas with transit times between 12 and 50 years. The period between 12 and 50 years before 2002 represents the period that fertiliser application in Estonia was considerably more extensive than in the periods before and after.
The relation was positive and statistically significant (n = 37; R2 = 0.49; p-value: 0.000).

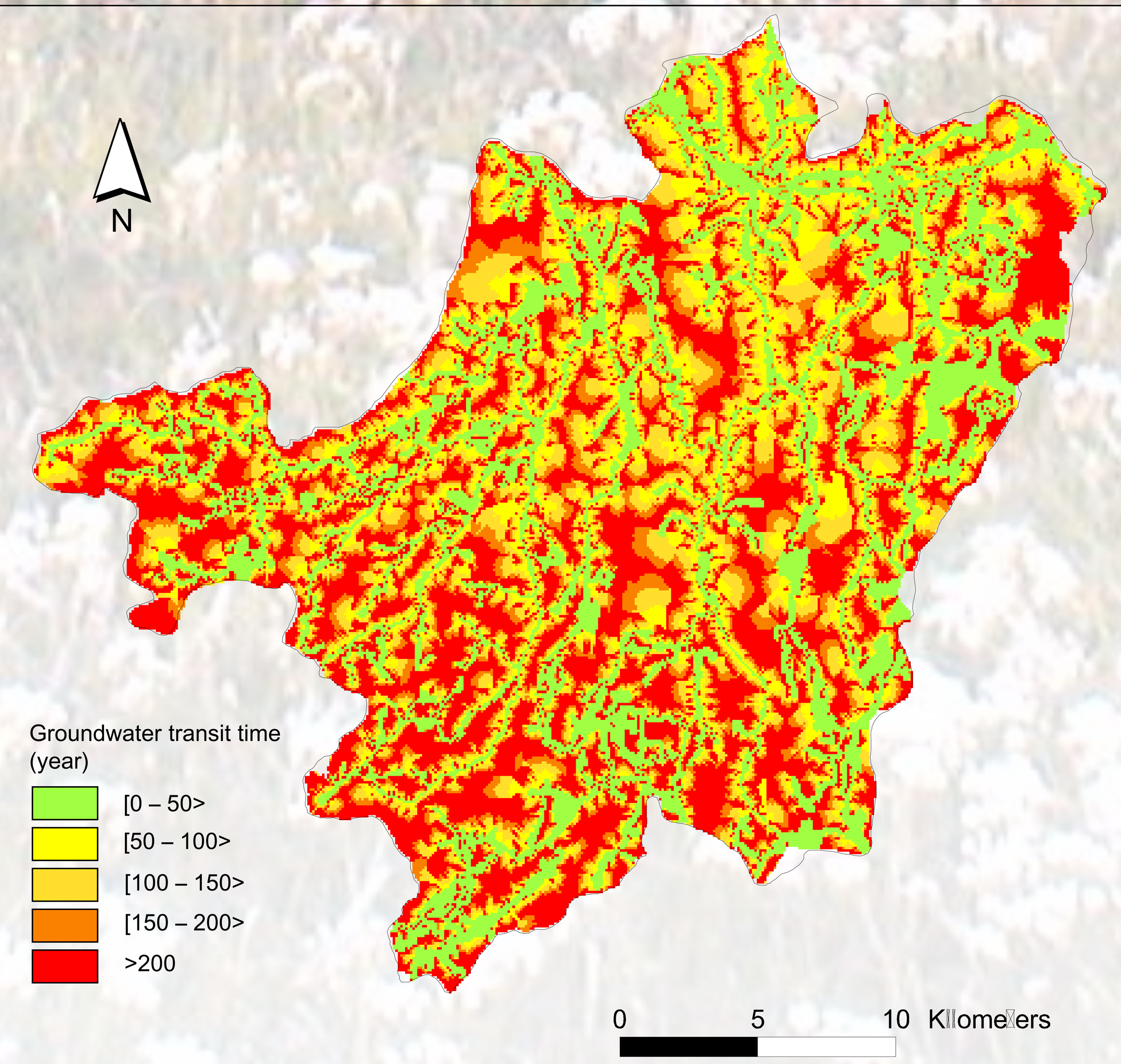

Figure 2 Estimated groundwater transit times in the Ahja catchment (Estonia).

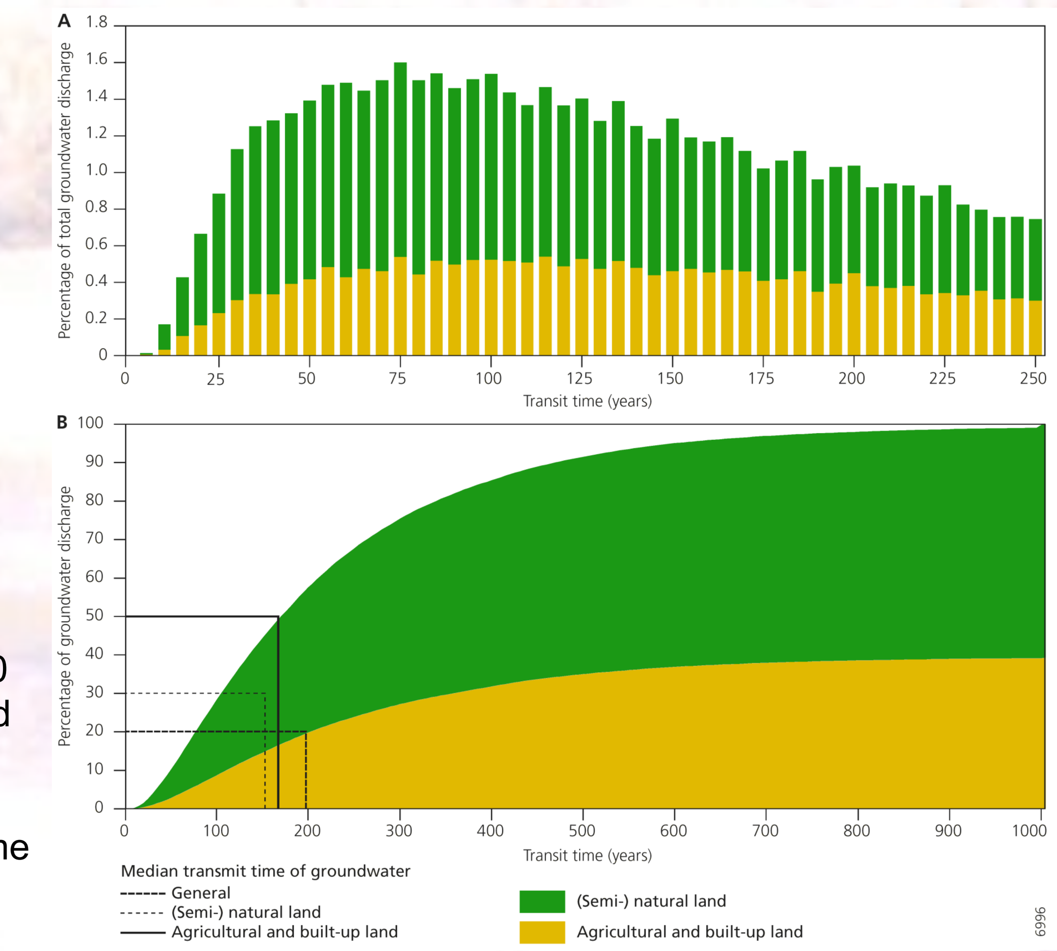

Figure 3 A) groundwater transit time distribution (< 250 y) from agricultural and semi-natural areas; B) cumulative groundwater transit time distribution.

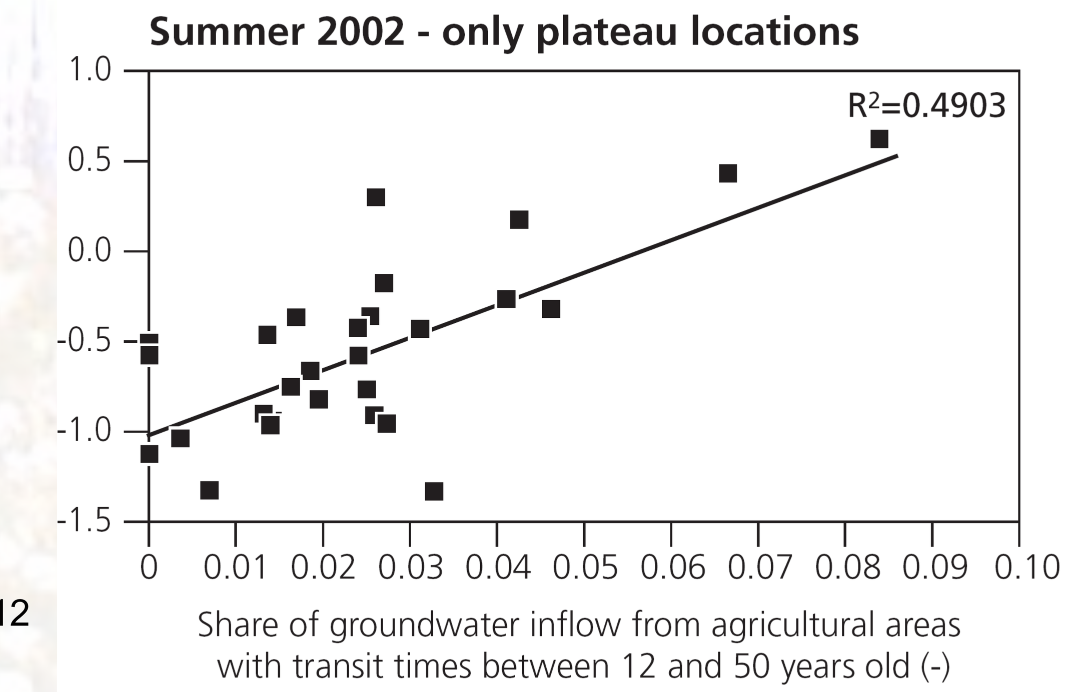

Figure 4 Measured log-transformed DIN concentration against proportion of groundwater from agricultural areas with transit times between 12 and 50 years.

Conclusions and perspectives

This case study demonstrated that the method to quickly assess the spatial distribution of groundwater transit times can readily be implemented in spatio-temporal, hydrology-based models of diffuse pollution at the catchment scale. The described method neglects the transit time of water in the unsaturated zone. If the unsaturated zone thickness is substantially larger than 10 meters, the transit time in the unsaturated zone should be added to the transit time calculated by the method presented here.

References
Mourad, D.S.J. 2008. Patterns of nutrient transfer in lowland catchments – A case study from northeastern Europe. Utrecht: KNAG, Netherlands Geographical Studies 370.