Predicting mean residence time and exchange velocity in the hyporheic zone of restored streams

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The hyporheic zones of streams and rivers have been identified as hotspots for biogeochemical reactions in the aquatic environment, making the retention time and exchange velocity of the hyporheic zone essential parameters in the modelling of these processes. However, exact site-specific values of those parameters are often missing in stream restoration projects because there are no well-defined scaling relationships linking them to measurable reach characteristics.

In this study we derive semi-analytical solutions for the retention time and exchange velocity in the hyporheic zone. In particular the effect on hyporheic exchange is expressed by the use of physically based models and by superimposing different geomorphologic features of different scales. It is suggested that all exchange phenomena can be modelled as head anomalies expressed with a harmonic distribution along the stream with specific wavelength and head amplitude. The maximum head of an exchange phenomena is either dominated by hydrodynamic or hydrostatic water pressure, depending on the size of the feature causing the exchange. The theory leads to constitutive relationships for exchange velocity and residence time expressed as functions of the distribution of wavelengths, distribution of head amplitude and hydraulic conductivity. In order to validate and evaluate certain empirical coefficients, a number of Rhodamine WT tracer tests were performed in a partly restored agricultural stream in the south of Sweden called the Tullstorps brook. To evaluate the tracer test in sections where remediation actions have been undertaken we used the method of temporal moments. In conjunction with the tracer tests a characterisation of the stream was carried out where hydraulic conductivity of the streambed and stream morphology was measured.

The study verifies that the residence time in the hyporheic zone decreases with the maximum hydraulic head of the largest (dominating) geomorphic feature of the reach, and increases with the length of the feature. It also implies that small superimposed features can have a significant impact on the total residence time and exchange velocity. The conducted field data verifies that there is a difference in residence time and exchange velocity between the reaches which partly can be explained by the existing combination of geomorphologic features.