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Quantification of hyporheic exchange depths using water temperature time-series and a multi-model approach

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Quantifying exchange fluxes between surface water and groundwater remains an important challenge, which is relevant for a better understanding of the processes governing water quality dynamics in the aquatic environment. Based on water temperature time-series, there exist several methods to quantify hyporheic exchange fluxes. However, for alternating hydraulic boundary conditions (up- and down-welling water fluxes) the accuracy and the uncertainty of these methods remain precarious.

The aim of this study was to determine the depths below the stream bed until which hyporheic exchange fluxes can be quantified and how these depths vary with time, space and hydraulic boundary conditions. The study area is located at the "Olewiger Bach" a 15.6 km long tributary to the river Mosel, with a catchment area of about 24 km^2 and an annual mean discharge of 302 L s^{-1}. Within the lower stretch of the stream, we find a high seasonal variation of groundwater tables and therefore an alternation between gaining and loosing stream conditions. For 6 years (since 2011 – today), we measured vertical water temperature profiles (7 depths, 0.02 m – 0.65 m) at 3 locations in the alluvium below the river. In parallel, we observed groundwater table fluctuations as well as surface water levels and associated discharges. For the 3 profiles up- and down-welling water fluxes were calculated using the Vertical Fluid Heat Transfer Solver (Vflux) which includes several analytical solutions of the one-dimensional conduction-advection dispersion equation. Within the model, hyporheic flux calculations are based on either both the amplitude difference and the phase shift of the diurnal temperature signal with depth or only one of both signals, respectively. We simulated the direction and intensity of vertical fluxes for 20 different depth combinations at each temperature lance, ranging from 0.035 m to 0.55 m mean depths below the stream bed. Comparing long term dynamics of the resulting flux directions to observed hydraulic gradients between groundwater and surface water levels with a binary logistic regression model we were able to determine threshold values for seasonal groundwater levels, where down-welling conditions shift to up-welling conditions, as well as mean boundary depths for hyporheic exchange fluxes. These boundary depths vary between the 3 profile locations from 0.06 m to 0.25 m below the stream bed and are strongly affected by seasonal variation. These results have implications for quantifying the long-term dynamics of residence times and associated matter turnover within the hyporheic zone.