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Influence of Small Scale Permeability Heterogeneity on Aerobic Respiration and Denitrification in the Streambed: A Stochastic Simulation Approach

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In streams and rivers, streambed permeability heterogeneity is known to increase hyporheic flux and to decrease hyporheic residence time through preferential flow paths. However, the link between permeability and biogeochemical reactions remains poorly understood. Previous studies have come to contradicting conclusions, likely because of the limited number of heterogeneity scenarios considered. In this study we systematically study the influence of permeability heterogeneity on ripple-induced hyporheic exchange, aerobic respiration and denitrification in the streambed.

We simulated and evaluated more than 2000 2D-heterogeneity scenarios by means of Gaussian random fields. The conductivity distributions of those Gaussian fields were transformed to either log-normal or binary distributions with varying variance of hydraulic conductivity in order to investigate both continuous and discrete heterogeneities on a large range of intensities. The results indicate that total aerobic respiration in the domain increases with heterogeneity intensity, expressed as the variance of hydraulic conductivity. In contrast, total denitrification in the domain is minimally influenced by the intensity of heterogeneity, because of the competing effect of increasing solute flux and decreasing reaction time.

These results represent the general trends among the entire range of scenarios. The total solute transformation of single realizations revealed strong deviations from these trends whenever special spatial permeability distributions such as clogging layers occurred. The permeability distribution in the uppermost layer of the domain, at the interface between surface water and sediment, was found to strongly influence the extent of deviation from the general trends.