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On the spatial variability of the hyporheic zone: in-situ investigation of porosity and grain size using diving bells and 3D photogrammetry

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In order to improve the ecological status of rivers, lakes and other water bodies, recent legislation, such as the European Water Framework Directive, requires for each water body an assessment of its suitability as habitat for organisms. Such an assessment, though, is not easy. This is especially true for the lowest part of the water body: the substrate or hyporheic zone. Even if it is known which kind of hyporheic zone is preferred by an organism, it remains difficult to determine where it can be found, because it is often impossible to observe the hyporheic zone from the banks or shores. It has become common to classify an entire water body as suitable or unsuitable as habitat, using only limited field observations of the hyporheic zone. This is a doubtful practice, which disregards the huge spatial variability of this zone.

The objective of this study was to quantify the spatial variability in hyporheic-zone characteristics in the river Rhine. We focused on two basic characteristics: grain size and porosity, the latter being a primary control on the transport of nutrients, heat, oxygen and organic matter. A diving bell (caisson) was used to obtain access to the river bed, which enabled undisturbed sampling of the hyporheic zone. Between 1968 and 2009 6436 sediment samples were taken and sieved to determine their grain size distribution. Furthermore, in 2009 and 2011 about 100 porosity measurements were carried out, using a novel technique based on a combination of field measurements using three-dimensional photogrammetry and laboratory measurements using the water displacement method.

The measurements revealed a strong cross-sectional variability in porosity and grain size. Each river cross-section contains spots with high porosity (order 0.40) and spots with low porosity (order 0.10). The large cross-sectional variability made it impossible to recognize systematic streamwise porosity trends from the data. Therefore we investigated if porosity was correlated to grain size. This appeared true: porosity depended on grain-size-distribution width, but, in contrast to previous studies, not on median grain size. We used the observed relation between porosity and distribution width to predict the porosity for each of the grain size measurements mentioned above. This confirmed the large spatial variation in porosity, but also revealed systematic downstream trends. Cross-section averaged porosity was relatively high (>0.30) in the upper part of the 600 km long study area, where the river bed consists of nearly uniform gravel. In the central part of the study area, where the river bed consists of a bimodal sand-gravel mixture, porosity was much lower (about 0.10-0.20) and in the downstream part of the study area with a sandy river bed porosity was high (>0.30). Especially remarkable is the sudden streamwise increase in porosity between the latter two areas.

This study also revealed the hyporheic zone to be very dynamic over time. Even over short time scales of 10-20 years significant structural changes in grain size and porosity occurred. The common practice to infer the natural state of modified water bodies from present-day data only, therefore might be unwise.