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Potential for 3-D hyporheic exchange flow along a succession of pool-riffle sequences

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Pool-riffle sequences are key geomorphological features that can influence the ecology of streams by inducing a flow exchange between surface water and groundwater - a process called hyporheic exchange flow (HEF). The objective of this research was to test the suitability of a simple 3-D groundwater model for characterizing HEF induced by pool-riffle sequences that had been the focus of experimental study. Three reaches of 20 m were modelled separately. While the bed topography was surveyed and represented at a high resolution, the permeability distribution referred to a simple conceptual model consisting of two superposed layers. One hypothesis was that, despite its simplicity, the calibrated model would produce an acceptable fit between observed and simulated heads because its permeability structure resembled the natural system. The potential complexity of hyporheic flow patterns is well-known, yet this study highlights the usefulness of a simple conceptual model coupled to mechanistic flow equations for describing HEF in 3-D. The error structure of the calibrated model provides insight into various site-specific features. The root mean square error between computed and observed hydraulic heads (relative to the head drop over the structure) is comparable to other studies with more elaborate permeability structures. After calibration, a sensitivity analysis was conducted in order to determine the influence of permeability contrast between the layers, depth of the permeability interface, and basal flux on three HEF characteristics: residence time, lateral and vertical extent, and total flux. Results indicate that permeability characteristics can affect HEF in different ways. For example, the vertical extent is deepest in homogeneous conditions, whereas the lateral extent is not significantly affected by permeability contrast, or by the depth of the interface between the two layers. Thus bank piezometers may be insufficient to calibrate groundwater models of HEF. One pool-riffle sequence, characterized by large variations of bed elevation, induced a HEF system that was disproportionately small. This shows that, where water depth is variable relative to surface water elevation (as in lowland streams), the curvature of bed topography can be an unreliable indicator of HEF intensity. Finally, simulated flux maps of the sediment-water interface illustrate the importance of lateral variations of flow exchanges. It appears that even a relatively dense network of piezometers can miss areas of high fluxes. Therefore, in terms of habitat, biogeochemical processes, and monitoring strategies, the hyporheic zone of a pool-riffle sequence ought not to be considered as a linear feature only, but as a plan surface and a volume.