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Impact of small-scale riverbed topography on stream flow and surface detention of a tracer

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The transitional space between surface water and groundwater also called the hyporheic zone has an important impact on the exchange processes between both compartments through the exchange of water, heat and oxidizing and reducing agents affecting biogeochemical processes and thus the hyporheic zone strongly influences the 'health' of the interacting stream and groundwater. The exchange processes occur on a wide range of spatial and temporal scales, reaching from riverbed topography like ripples to geomorphological features like meanders on the one hand and events like floods to quasi steady state conditions like mean or low flow on the other hand.

This contribution focusses on small-scale high-resolution modelling of stream flow and surface detention of a tracer over a riverbed with ripples. In classical hydraulics, stream and river flow follows the assumption of hydrostatic pressure and in many cases, vertically averaged 1D or 2D approaches are chosen, thus not allowing the occurrence of recirculation zones behind ripples. Therefore, we are applying the 3D computational fluid dynamics (CFD) model OpenFOAM which solves the Navier Stokes equations offering various turbulence models; in our cases, the large eddy simulation (LES) turbulence model was found to be most suitable; we extended the model by a transport equation of a passive tracer. Before applied to the rippled riverbed, we tested the model against experimental data (flow over a 2D ground hill) and an analytical solution (1D tracer transport).

We investigated the impact of the ripple geometry (height, length, spacing) on the hydraulics and transport leading to the following main insights for low to mean flow conditions: (i) we have to apply a two-phase (water, air) flow approach allowing the movement of the free water surface; (ii) the pressure distribution along the rippled riverbed deviates from hydrostatic pressure in large parts; (iii) depending on the ripple geometry recirculation zones occur and (iv) depending on the ripple geometry and the recirculation zones, different surface detention of a tracer was determined. Overall, we found out that the ripple geometry can have a significant impact on the stream flow and the surface detention of a tracer. Therefore, we expect that the flow field as well as the pressure and the tracer distribution at the rippled riverbed, i.e. at the surface water – groundwater interface, will also have a strong impact on the exchange processes between surface and groundwater. For further proof of this speculation, first results of an integral surface water – groundwater model will be presented.