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Heat transport model within the hyporheic zone

Alessandra Marzadri (1), Daniele Tonina (2), and Alberto Bellin (1)

(1) Department of Civil and Environmental Engineering, Univesrity of Trento, Italy (alessandra.marzadri@ing.unitn.it, alberto.bellin@ing.unitn.it), (2) Center for Ecohydraulics Research, University of Idaho, Boise, Idaho 83702, USA (dtonina@uidaho.edu)

Temperature is a key quantity in controlling water quality, aquatic habitats and the distribution of aquatic invertebrates within the hyporheic zone. Despite its importance in all processes (e.g., biogeochemical reactions and organism metabolism, growth, movement and migration) occurring within the streambed sediment, only few experimental and numerical works analyzed temperature distribution within the hyporheic zone, while little is known on the control that river morphology exerts on temperature dynamics. In the present work, we analyze the effects of river morphology on the thermal regime of the hyporheic zone from a modelling perspective. Our goal is to identify the dominant processes that affect the hyporheic thermal regime and gradients, which influence the rates of microbial and biogeochemical processes. With this objective in mind, we developed a simplified process-based model, which predicts the temperature pattern within the streambed sediment taking into account the external forcing due to the daily temperature variations of the in-stream water and the hyporheic exchange due to streambed morphology. To simplify the analysis the hydraulic conductivity of the streambed sediment is assumed homogeneous and isotropic, and the hyporheic velocity field is obtained analytically by solving the flow equation with the near-bed piezometric head of the stream flow as the linkage between surface and subsurface flows. Furthermore, we solved the heat transport equation with a Lagrangian approach and by neglecting transverse dispersivity. Our model results show a complex near-bed hyporheic temperature distributions, which vary temporally and are strongly related to the in-stream water residence time into the hyporheic zone and consequently to the bed morphology and flow discharge. We compared the temperature dynamics within the hyporheic zone of both large low-gradient and small steep streams to investigate the effect of stream morphology. Results show that the hyporheic mean temperature signal, which is the hyporheic water temperature averaged over the upwelling areas at each time step, has a smaller daily amplitude in the former than in the latter case, because low gradient streams have longer and more diversified residence times than small steep streams. Finally, we quantify the importance of the hyporheic upwelling fluxes in controlling in-stream water temperature.