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Dimensionless Numbers For Morphological, Thermal And Biogeochemical Controls Of Hyporheic Processes

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Transport of solutes and heat within the hyporheic zone are interface processes that gained growing attention in the last decade, when several modelling strategies have been proposed, mainly at the local or reach scale. We propose to upscale local hyporheic biogeochemical processes to reach and network scales by means of a Lagrangian modelling framework, which allows to consider the impact of the flow structure on the processes modelled. This analysis shows that geochemical processes can be parametrized through two new Damköhler numbers, Da_O, and Da_T. $Da_O = \tau_{up,50}/\tau_{lim}$ is defined as the ratio between the median hyporheic residence time, $\tau_{up,50}$ and the time of consuming dissolved oxygen to a prescribed threshold concentration, τ_{lim}, below which reductive reactions are activated. It quantifies the biogeochemical status of the hyporheic zone and could be a metric for upscaling local hyporheic biogeochemical processes to reach and river-network scale processes. In addition, $\tau_{up,50}$ is the time scale of hyporheic advection; while τ_{lim} is the representative time scale of biogeochemical reactions and indicates the distance along the streamline, measured as the time needed to travel that distance, that a particle of water travels before the dissolved oxygen concentration declines to $[DO]_{lim}$, the value at which denitrification is activated. We show that Da_O is representative of the redox status and indicates whether the hyporheic zone is a source or a sink of nitrate. Values of Da_O larger than 1 indicate prevailing anaerobic conditions, whereas values smaller than 1 prevailing aerobic conditions. Similarly, Da_T quantifies the importance of the temperature daily oscillations of the stream water on the hyporheic environment. It is defined as the ratio between $\tau_{up,50}$, and the time limit at which the ratio between the amplitude of the temperature oscillation within the hyporheic zone (evaluated along the streamline) and in the stream water is smaller than e^{-1}. We show that values of $Da_T > 1$ indicate a thermally stable hyporheic zone, where organism metabolism is not influenced by surface water thermal oscillations and biogeochemical reaction rates depend on the mean daily stream water temperature. Values smaller than 1 suggest that organisms need to adapt to the daily thermal variations and biogeochemical reaction rates will depend on the daily fluctuations induced by stream water.