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Advective travel time variability in stream networks

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Catchment-scale nitrogen transport from land to coast, participating considerably in the problem of eutrophication that threatens coastal environmental quality world wide, is of broad significance for the whole society. Although nitrogen is removed along the different pathways of water within the catchment, by denitrification, biological assimilation and mass exchange with relatively immobile water, high riverine loads contribute significantly to coastal ecosystem degradation. Processes of nitrogen in-stream attenuation and delivery to basin outlet need therefore to be better understood and quantified in order to be able to infer efficient management and mitigation measures for reducing coastal nitrogen loading within drainage basins.

A single characteristic in-stream solute travel time is commonly used for representing and quantifying coupled transport-biogeochemical removal conditions in streams for both diffuse and point nitrogen inputs on large stream-reach/sub-catchment scales (e.g., Smith et al., 1997; Alexander et al., 2000; Darracq and Destouni, 2005). Such single travel-time representation neglects actual in-stream travel time variability and distribution, from different nitrogen input points along a stream network to the stream monitoring/outlet location. Thereby it neglects that shorter/longer travel times of diffuse/point nitrogen inputs closer to/further from monitoring locations contribute differently to monitored nitrogen loads, because attenuation/retention kinetics may totally remove nitrogen inputs with long travel times to the monitoring position, whereas most nitrogen inputs with short travel times will reach that position without being attenuated. Previous theoretical study (Lindgren and Destouni, 2004) has shown that such travel time variability neglect may lead to considerable underestimation of model-calibrated in-stream nitrogen attenuation rates, which increases with increasing model aggregation scale and increasing mean value and sub-aggregate variability of solute travel times in the stream system.

In this study, we quantify the advective travel time variability in stream networks of Norrström drainage basin in Sweden, where we also model resulting nitrogen transport and attenuation. We find significant advective travel time variability within sixty sub-catchments of the Norrström drainage basin, and show how this variability increases with sub-catchment area and mean travel time in the sub-catchment stream network. We also compare resulting mean/characteristic travel times for each sub-catchment, with an alternative quantification of characteristic advective travel time as function of sub-catchment area (Alexander et al., 2000; Alexander et al., 2002; Preston and Brakebill, 1999; Smith et al., 1997); in nearly all sub-catchments, the area-function estimates are considerably greater than mean/characteristic advective travel times obtained from resulting stream-network distributions.

Even for perfectly calibrated nitrogen transport-attenuation/retention models on (sub-) catchment scales, misleading estimates of variable physical solute travel times must be compensated by inversely misleading estimates of nitrogen attenuation/retention rates. Such estimate errors may have important practical implications, for instance for predictions of abatement measure effects and nitrogen impacts under changed future conditions.

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