An attempt to bridge the gap between physical and conceptual hydrological models used for transit time determination

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Bottom-up catchment scale distributed hydrological transport models based on physical process descriptions improve our understanding of the hillslope scale in a physically consistent way. They allow for characterization of the flow domain as a multi-continuum, and are amenable to account for biogeochemical processes. However, these models are computationally expensive, and the spatial heterogeneity of the forcings and the boundary conditions are hard to render, which leads to ill posed inverse problems that adversely affect their predictive skill and convenience in real world applications (Hrachowitz et al., 2016).

On the other hand, flexible lumped or semi-distributed modelling approaches based on interplay of conceptual stores have proven their worth in reproducing hydrological responses despite their simplicity. The physical basis of these models is however not well understood – they differentiate between the timescales of hydrological response (governed by wave celerity arising from pressure diffusion) and water quality response (governed by flow velocity and solute dispersion) using passive mixing volumes with zero hydraulic pressure. Being depth based, they're not scalable either. Conceptual models are thus mostly suitable for inverse modelling to compare relatable conceptual parameters in similar catchments.

In this study, we attempted to bridge the gap between these 2 different ideologies for groundwater flow and transport by building a semi-distributed grid-based model which discretizes a catchment based on its hydrodynamic dispersivity. The flow part was based on the concept of Mean Action Times along hillslopes (Simpson et al., 2013) and the transport part was based on solving the pore-scale advection dispersion equation by discretizing the domain as a series of well-mixed reactors to mimic the optimal behavior between the extremes of complete segregation and maximum mixedness for a given catchment. We verified the model with FEFLOW for a synthetic homogenous unconfined aquifer for unsteady flow and in the process established mathematical relationships between physical and conceptual parameters for groundwater flow and solute transport. We then applied the same framework to Kerrien, an agricultural and groundwater dominated headwater catchment located in the French Critical Zone Observatory of Brittany and gained insights on the sensitivity of different parameters on solute breakthrough behavior and
transit time.

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