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Unsteady Mass transfer Across the Sediment-Water Interface

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Fluxes across the sediment-water interface (SWI) are of high ecological significance, as they promote biogeochemical processes that support benthic ecosystems within the hyporheic zone. The SWI marks a boundary between the turbulent water column (typically modelled by Navier Stokes equations) and the interstitial pore fluids in the sediment column, which are typically laminar (and modelled by Darcy's law). Although models of these two flow regimes are generally not coupled, flow in the turbulent boundary layer is affected by the sediment permeability and a slip velocity at the SWI, which decays exponentially into the streambed across a characteristic mixing length. Momentum is transferred across this region (known as the Brinkman layer) through the penetration of coherent structures and turbulent mixing, however, these turbulent structures also promote turbulent mass transfer. Mass transfer within the hyporheic zone can be conceptualised in terms of: (1) the downwelling of solutes from the stream; (2) retention of solutes in the sediment; and (3) the upwelling of solutes back into the stream. Recent work by the authors has shown that a mass transfer coefficient can be defined where a downwelling-upwelling unit cell exists across a concentration gradient. Such unit cells are generated at the SWI by pressure variation from: (1) steady-state influences, such as stream geometry and velocity variation; and (2) unsteady pressure waves produced by coherent turbulent structures. With this definition, mass transfer coefficients can be defined for: steady exchange, by adopting the Elliott and Brooks [1997] advective pumping model; and unsteady exchange, induced by streamwise propagation of upwelling-downwelling unit cells migrating downstream with a characteristic celerity associated with turbulent eddies. We hypothesize that beneath the Brinkman layer (where Laplace equation applies) these mass transfer coefficients can be summed to yield the total mass flux. Although, it does not explicitly deal with momentum transfer, this is a useful tool in modelling hyporheic exchange in turbulent streams.