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Letter

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Response to "Letter to the Editor Regarding 'Crossing Turbulent Boundaries: Interfacial Flux in Environmental Flows'"

We thank Thibodeaux et al.[1] for their interest in our recent article in *Environmental Science & Technology*.[2] While they touch on numerous topics, their chief criticism of our article can be summarized as follows: hyporheic exchange is an advective process, and therefore cannot be represented by a mass transfer coefficient (or its inverse, the mass transfer resistance).

Thibodeaux et al. fail to differentiate between two distinctly different types of interfacial advection: (1) the net transfer of water into (or out of) an interface (analogous to the many examples they cite involving gravitational sedimentation of particles); and (2) circulation of water across an interface with no net transfer of water. The literature cited by Thibodeaux et al. suggest mass transfer facilitated by the first type of advection cannot be described by a mass transfer coefficient. On the other hand, advection of the second type plays a starring role in two of the three stream-side exchange models (surface renewal model and bed roughness model[3,4]) that appear in our Figure 2 and Thibodeaux et al. conclude are "correctly" described by mass transfer coefficients.

So which type of advection is hyporheic exchange? One hint is in the name—the word "exchange" suggests that water circulates between the bulk stream and the sediment bed, with no net transfer of water. But the devil is in the scale over which the mass flux is averaged. Hyporheic exchange occurs in identifiable upwelling and downwelling zones.[5,6] If the average is taken over one of these upwelling or downwelling zones, hyporheic "exchange" looks more like the first type of advection, and parameterization of mass transfer by a resistance model may be inappropriate. If the average is taken over both downwelling and upwelling zones—as is typically the case in laboratory flume experiments $O(1\ \mathrm{m})$ and reach-scale field studies $O(10\ \mathrm{m})$—hyporheic exchange looks more like the second type of advection, and parameterization by a mass transfer coefficient may be appropriate.

Hyporheic exchange and gravitational sedimentation are very different physical phenomena, and thus theoretical objections to using mass transfer coefficients to parameterize the latter do not automatically apply to the former. As noted in our article, the real challenge associated with parameterizing hyporheic exchange is its intrinsically multiscale nature, in which exchange occurs over at least a million-fold change in length-scales, from single grains to entire catchments. While a universal theory for estimating rates of hyporheic exchange has yet to emerge, we hope the conceptual approach presented in our article contributes to the ongoing discussion of this important topic in environmental science and engineering.

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Notes

The authors declare no competing financial interest.

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