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# Quantifying spatial and temporal variability of groundwater-surface-water exchange in fluvial settings

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Substantial spatial variability in flow across the sediment-water interface is now generally accepted as ubiquitous in hyporheic settings. A growing body of evidence indicates exchange also varies temporally, including frequent reversals in flow direction, on scales of minutes to hours to days. The extent of this dynamism, and the significance with regard to water chemistry and ecosystem viability and stability, have yet to be determined for many hyporheic settings. Anthropogenic influences create even greater variability through bed disturbance, and manipulation of stream and river flow, sediment supply, and surface-water and groundwater quality.
In-situ measurements of seepage rate and direction were made along two river reaches, one located well downstream of any control structures and where bed mobility was common, and the other located several kilometers downstream of a dam where the bed was immobile nearly all of the time. Seepage meters modified for use in flowing water were used to measure rates of exchange between surface and sub-surface water in a sand-and-gravel-bed river in Colorado, USA (South Platte River, mean annual river discharge = 9.7 m3/s), and in a cobble-bed river in western Pennsylvania, USA (Allegheny River, mean annual river discharge = 188 m3/s). The median value of all seepage measurements at the South Platte River was 0.24 m/day, indicating a small to moderate rate of groundwater discharge to the river. However, substantial local-scale bed topography as well as mobile bedforms in the river resulted in spatial and temporal variability an order of magnitude larger than the median groundwater discharge rate. Both upward and downward seepage were recorded along every transect across the river with rates ranging from +2.37 (upward) to -3.40 (downward) m/day. At the Allegheny River site, moss and algae covered much of the bed and river grass was common, indicating greater bed stability than at the South Platte River site. Median seepage was +0.26 m/day, nearly identical to the South Platte River site. Upward and downward seepage again were about an order of magnitude larger than the median seepage rate, ranging from +2.26 to -3.06 m/day. In spite of the stable bed and reduced variability in river discharge at the Allegheny River site, seepage rate was large and highly variable between measurement locations.
Seepage rate and direction were dependent primarily on measurement position relative to local- and meso-scale bed topography at both rivers. Hydraulic gradients and hydraulic conductivity also were measured at each seepage measurement location. Gradients were small at both river sites, nearly always less than 0.05, and occasionally indicated a direction of seepage opposite that measured with seepage meters. Therefore, measuring hydraulic gradient and hydraulic conductivity at in-stream piezometers may be misleading if used to determine seepage flux across the sediment-water interface. Such a method assumes that flow between the well screen and sediment-water interface is vertical, which appears to be a poor assumption in coarse-grained hyporheic settings.