Variability of hyporheic exchange in an experimental gravel bed

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1. Introduction

Most existing models of hyporheic exchange implicitly or explicitly assume that hyporheic transfer between the streambed sediments and the overlying stream water occur at a constant rate.

To examine the tenability of this assumption, the variability of hyporheic exchange rates and patterns was measured in a flat experimental gravel bed in a large outdoor flume.

2. Experimental set-up

An 18 m long section of a 2 m wide flume was filled with a 30 cm thick layer of well-sorted gravel layer (porosity = 0.39; d_{50} decraases from 37 mm in the top gravel layer to 11 mm in the deeper layer. A water layer of 20 cm depth over the gravel bed was established (Fig. 1).

The experiments included a flush-out experiment and instantaneous injection experiments using a salt tracer at various water discharge rates. During the experiments, the breakthrough curves of local groundwater was monitored using small electrical conductivity (EC) probes in the water layer and at three gravel depths (-5 cm, -10 cm, and -20 cm) at four locations downstream of the flume inlet.

In addition, dye tracer experiments were performed to investigate the patterns of exfiltration relative to the point of infiltration by injecting uranine dye tracer in a pore at the sediment-water interface.

a. b.

Fig. 1 a. Experimental flume; b. EC meters installed in clusters (O) at approximately 8 m downstream from the flume inlet. Inset: EC probe.

3. Breakthrough curves

Fig. 2 depicts typical breakthrough curves of the local groundwater a measured in the water layer and at the different depths in the gravel layer.

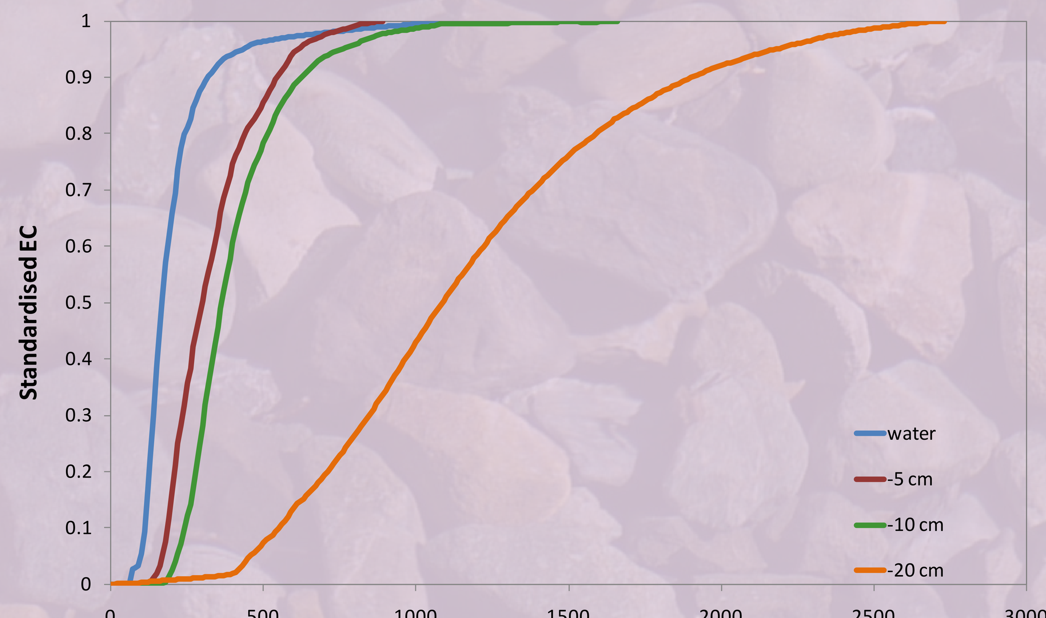

Fig. 2 Typical breakthrough curves at location 2 (8 m from the flume inlet) (Q_{flume} = 0.039 m³ s⁻¹; $\bar{v}$ = 0.087 m s⁻¹).

The time to breakthrough (i.e. the time that the standardised EC reaches the value of 0.5) is a measure for the hyporheic exchange rate. Figure 3 shows the differences between the times to breakthrough in the water layer and the times to breakthrough measured at the different depths in the gravel bed.

The times to breakthrough exhibit a considereable variation in local hyporheic exchange rates, both between the repetitive experiments and between the locations. The variation increases with depth.

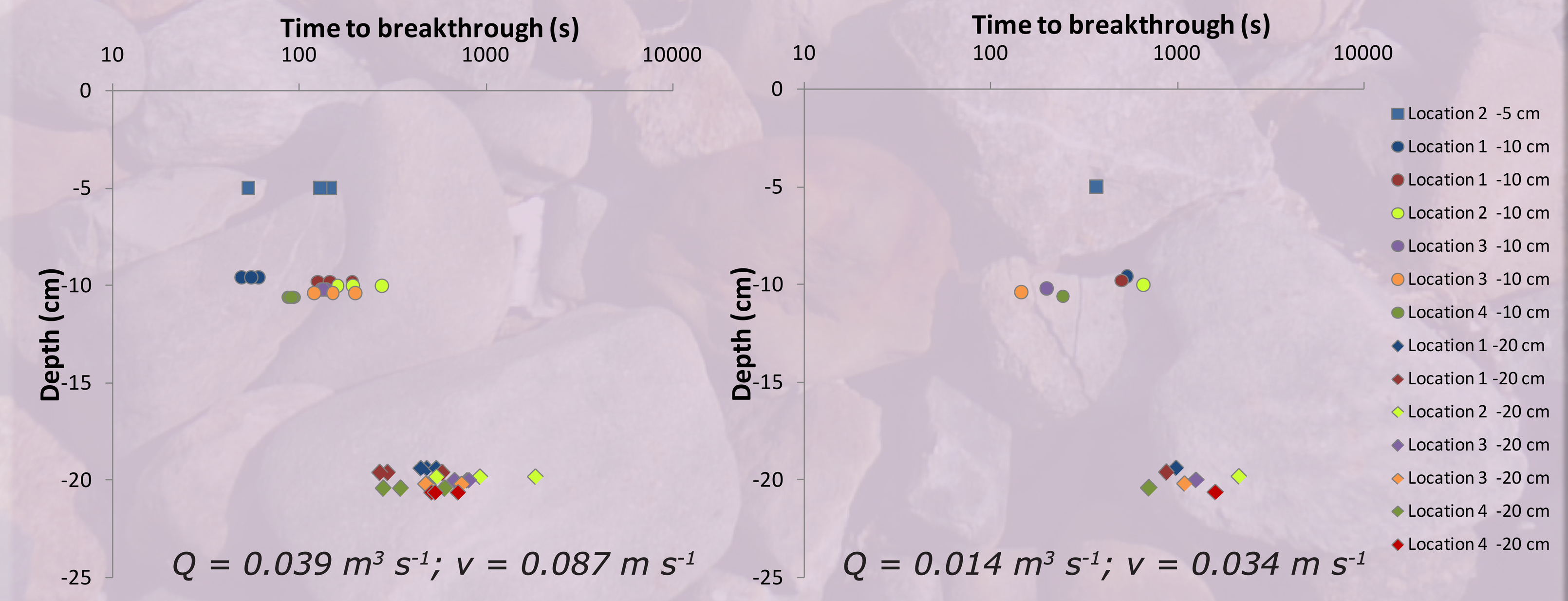

Fig. 3 Time to breakthrough at different depths in the gravel bed (difference with time to breakthrough in the water layer). (Note the logarithmic scale of the horizontal axis).

4. Hyporheic flow patterns

The dye tracer experiments (see Fig. 4 for an example) show that the locations of exfiltration are temporally stable and occur mostly within 0.5 m downstream from the point of dye injection (Fig. 5). On a few rare occasions the water exfiltrates upstream from the point of infiltration.

Fig. 4 Uranine dye tracer experiment showing the location of exfiltration in relation to the point of injection

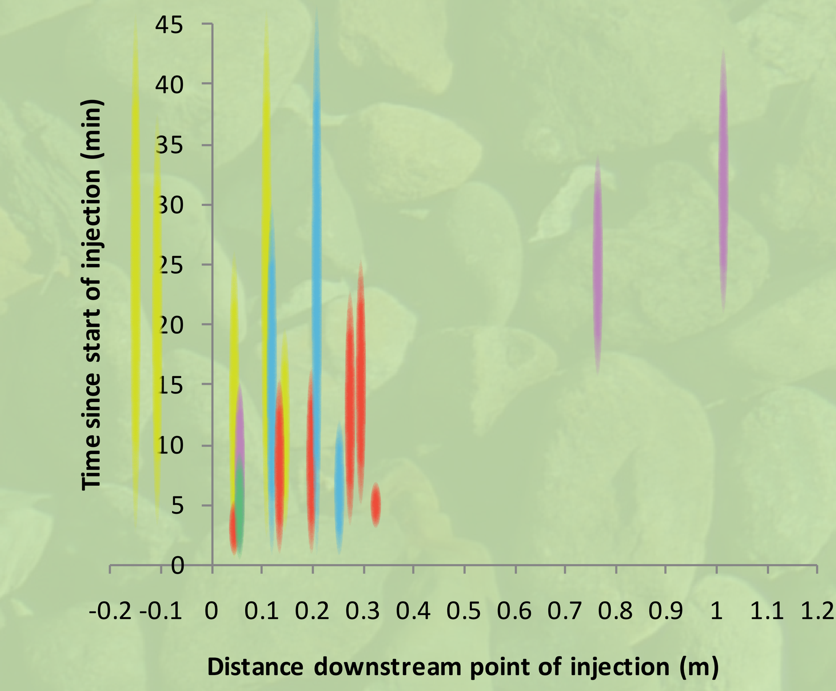

Fig. 5 Locations of exfiltration (colours represent consecutive experiments at different locations)

5. Conclusions and implications

Despite that the gravel was relatively homogeneous, the hyporheic exchange rate and waiting time distribution vary considerably locally depending on local pore space configurations and accompanying hyporheic flow patterns. This implies that parameters of hyporheic exchange models should be estimated based on measurements at multiple locations.

The hyporheic flow patterns during each experiment were temporally stable. Exfiltration occurs at relative short distances from the point of infiltration. This suggests that hyporheic transfer at the river reach scale can be simulated a vertical exchange process.