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The dynamics of hyporheic exchange flows during storm events in a strongly gaining urban river.

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There is little published research to date investigating the transient nature of hyporheic exchange flows in strongly gaining rivers. Furthermore, there is a paucity of research describing high temporal frequency river bed water quality variations. This paper addresses both of these research gaps by presenting pressure, electrical conductivity (EC) and temperature data at high temporal frequency (5 minute resolution) collected from within riverbed sediments, the river channel and from the deeper groundwater system, of a well characterised reach of the urban River Tame, Birmingham, UK. The following conclusions have been reached based on data analysis, analytical modelling, and variably saturated numerical flow and transport modelling:

• During storm events, flow reversals observed in the recorded pressure data can lead to substantial changes in EC (>20% in some cases) in the river bed down to depths of greater than 30 cm over periods of tens of hours.

• A variable, but significant, proportion of the 'bank storage' volume during a given storm event comes from the 'backing up' of groundwater that would have been discharged to the river in the absence of the fluctuating river stage. Thus an important control on the extent and dynamics of the reversal is the storage capacity of the riverbank and bed which can be variable and heavily modified in the urban environment.

• Return flows may occur along distinct flowlines in comparison with the path taken by the infiltrating water due to the changing geometry of flows through the storm event. Thus, discharging groundwater may be caused to spiral with each storm event, increasing the dispersion of solutes/contaminants. The magnitude of the exchange flows, and the degree of spiralling is likely to increase with distance away from the centre of the river channel.

• Gas is present within the river bed in quantities up to around 14% by volume, and to at least 0.8 m depth below river bed. Given the indications from hydrochemical data taken from in-bed arrays of multilevel piezometers, it is thought that this gas is predominantly produced by microbial denitrification and, to a lesser extent, methanogenesis.

• By altering the hydraulic conductivity distribution, the gas in the riverbed may lead to an increased proportion of discharge of groundwater from the river banks (relative to river bed) during low flow periods in the river.

• Due to the increased compressible storage of the gas phase in the river bed, during storm events the capacity for flow reversal within the centre of the channel may be greatly increased, by more than 30%. Furthermore, the presence of gas also reduces the water filled porosity, and so the possible depth of such reverse flows may also increase markedly.

• Observed diurnal temperature variations within the gaseous river bed at 0.1 and 0.5 m depth are approximately 1.5 to 6 times larger, respectively, than those predicted for saturated sediments. On an annual basis, fluctuations are seen to be enhanced by around 4 to 20% compared to literature values for saturated sediments. The presence of gas may thus alter the bulk thermal properties to such a degree that the use of heat tracer techniques

becomes subject to a much greater degree of uncertainty.

The study furthers our understanding of the hydraulic and thermal dynamics of the hyporheic zone, and has important implications for it’s biological functioning and capacity for chemical attenuation.