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Hyporheic Zone Testing on the River Tame, UK

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The hyporheic zone (HZ), the zone of groundwater – surface-water mixing beneath a river, represents an important natural system for water self purification. Field based collection of flow and water quality data under a range of natural and imposed hydraulic conditions has been performed to better understand and exploit the urban HZ system as part of *SWITCH* WP 5.3. The research is set within the *SWITCH Demonstration City* of Birmingham and also forms part of the Environment Agency (for England & Wales) (EA) hyporheic zone research programme. The aim has been to learn enough about the dynamic behaviour of the urban HZ to confirm its continuous spatial and temporal attenuation capacity and to develop appropriate concepts that can be employed as part of any urban river restoration project for the purpose of minimising future potential risks from contaminated groundwater discharges to the river.

Key objectives of the field data collection have been to investigate groundwater – surface-water mixing processes and their importance within the HZ; provide insights into the dynamic behaviour of the HZ including its temporal persistence; investigate chemical attenuation potential of the HZ and spatial relationships between attenuation capacity and flow patterns. Based on the results of the field campaign, work is underway to establish descriptions of the HZ through modelling that can contribute to river restoration design. The research has been undertaken at the urban hyporheic zone test site (*HZ Site*) on the river Tame, Birmingham (UK) developed under *SWITCH* that traverses the Birmingham aquifer to the north of the City Centre. The Tame river acts as the primary natural drain for the groundwater. It builds upon earlier research on the Birmingham aquifer – river Tame system (Rivett et al., 1990, 2005; Ellis et al., 2004, 2007; Ellis & Rivett, 2007; Shepherd et al., 2006). Other on-going relevant research includes the study of HZ volatile organic compound (VOC) attenuation at a site 3 km upstream (Roche et al., 2008) and a city-wide study of VOCs and water table rebound in the Birmingham aquifer (Botha, 2006; Murcott, 2008). The latter indicates

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groundwater levels are now close to estimated pre-industrialisation levels. Natural groundwater baseflow discharge to the Tame is hence probably greater now than at any time in the past century.

Principal infrastructure installed at the *HZ Site* includes a groundwater extraction borehole 5 m from the river Tame and a network of riverbed monitoring points over the adjacent 200 m reach to measure groundwater – surface-water flow and chemical exchange processes in the HZ. Operation of the extraction borehole was expected to modify the hydraulic gradients across the HZ, leading to perturbed groundwater – surface-water interactions and chemical solute/contaminant attenuation behaviour from which the dynamic behaviour of the hyporheic zone could be determined. Establishment of the *HZ Site* required liaison with land owners and the Environment Agency to obtain regulatory permissions including land access agreements, borehole drilling and extraction consents and a discharge consent to dispose of extracted water to the downstream river. Final permissions were acquired in May 2008 allowing the extraction tests to proceed. Prior to this time, the site infrastructure had been developed and 'baseline data' collect under non-extraction natural flow conditions. Nine transects of cross riverbed monitoring have been installed that each comprise >3 multilevel samplers to measure in-riverbed chemical quality profiles, piezometers to record hydraulic head and pressure transducers to obtain continuous temporal records of river stage and head.

Baseline head and chemical water quality data were obtained in Autumn 2007 and Summer 2008 immediately prior to 'Extraction Test 1' (ET-1) that commenced on 4 July 2008 with the borehole pumping at 78 l/min. The pumping rate was then increased for ET-2 to 145 l/min in December 2009 until the pump was switched off in May 2009. The extraction was expected to reduce riverbed gradients and increase HZ residence time by prompting increased surface-water mixing in the riverbed. Flow reversals in the river reach closest to the borehole should have been observable based on the predictions made using the early hydraulic data collected from the site. Although a small effect was observed both in the hydraulic and temperature data, gradients do not appear to have significantly reduced at the monitored riverbed transects. Groundwater heads generally remain at or close to river level despite significant drawdown (6 m) in the extraction borehole. The preliminary conclusion is that the borehole's influence is partly obscured by the natural variability in river flows and the geological conditions are locally more complex than initially predicted. Discrete flow regimes have been found to exist in the heterogeneous geology (proved by freeze-core sampling) that are not being captured by the monitoring. Mean daily river flows have varied by up to an order of magnitude above baseflows of ~1.5 m^3/s. Prolonged periods of steady baseflow conditions that are best for assessing the extraction borehole influence have been relatively rare since extraction began. Gradient reversals or reductions appear to relate mainly to natural flow variability, the most noticeable occur close to peaks in river stage during rainfall events and may only last a few hours. River water quality then is noted to be highly variably sometimes containing high EC (electrical conductivity) first flush run-off up to 1500 µS/cm that becomes rapidly diluted where upon river ECs may approach 500 µS/cm to be followed by a gradual rebound to more normal 800-1000 µS/cm as lower flows return. The EC of the river is much higher than that of the groundwater that is migrating to the river and provides a convenient indicator of mixing although not of chemical behaviour.

Three baseline water-quality sampling campaigns have been conducted on the riverbed monitoring network followed by a further three during ET-1 and one during ET-2. Although the intent was to sample under sustained low flow conditions, this has not always been possible due to the rainfall frequency. The natural variability in river flow conditions appears to be influencing chemical profiles.

Some profiles appear relatively stable with time, others more dynamic and responsive to the natural hydrological variability. Chemical determinants that show most variability across the riverbed with some distinction between typical groundwater and surface-water end-members are chloride (a conservative solute), nitrate (potentially reactive due to denitrification), phosphate (potentially reactive due to sorption) and TOC (potentially reactive as an electron donor). These are all generally more elevated in the surface water than groundwater with the exception of nitrate that usually shows reverse profiles. Other determinants include some of the trace metals monitored and sulphate. Although there is some similarity in cross channel transects, not surprisingly there is significant spatial variability in behaviour that is reasonably attributed to riverbed sediment physical and geochemical heterogeneity. Similar to water flows, it is presently difficult to unequivocally discern the extraction borehole influence against natural variability in the longer term data. Data obtained suggest there may be an influence in specific locations, however, further data and analysis are required and on-going.

Given the dynamic response of the river to rainfall, a characteristic common for many urbanised catchments, important data collected at the *HZ Site* are the high frequency EC measurements made within the river bed. These data suggest that processes on a range of timescales, down to that of individual storm events, may be controlling the HZ water chemistry, and thus data collected during discrete sampling campaigns are being interpreted in this light. Moreover, significant accumulations of gas have been found in the river bed and it appears that these are impacting the hydraulic response of the HZ, something that has not previously been investigated by other researchers.

Data collection and collation has now come to an end, marked by the publication of an interim data report to be published electronically by the Environment Agency. The project is now in the final stages of analysis, interpretation and modelling with the development of river restoration design aspects of the project to follow.