Impacts of contaminated groundwater on urban river quality—Birmingham, UK

P. A. ELLIS, M. O. RIVETT, J. E. HENSTOCK, J. W. DOWLE, R. MACKAY
School of Earth Sciences, University of Birmingham, Birmingham B15 2TT, UK
e-mail: p.a.ellis@bham.ac.uk

R. S. WARD & R. C. HARRIS
Environment Agency, National Groundwater and Contaminated Land Centre, Solihull, West Midlands B92 7HX, UK

Abstract The quality of urban surface waters may be influenced by the quantity and quality of groundwater-baseflow they receive during their passage through conurbations. The generation of contaminated baseflow from "contaminated land" sources is currently being researched through a study of the Birmingham–River Tame system (UK). The study focal point is the 7.4-km Tame reach that crosses the effluent, unconfined Birmingham Triassic sandstone aquifer. Baseflow discharges of dissolved solutes/contaminants to the Tame from the Birmingham aquifer have been observed with the best data obtained from the river-bed piezometer profiles and near-river groundwater monitoring wells. Surface water profiles are difficult to interpret due to elevated solute/contaminant loading from other sources (e.g. pipe discharges) that have significant temporal variability. Continued river-bed piezometer profiling is seen as the primary method to quantify the groundwater-baseflow quality contribution to the overall quality of the River Tame system.

Key words baseflow; Birmingham (UK); groundwater quality; hyporheic zone; river; surface water

INTRODUCTION

The development of conurbations around river systems is common. Such urbanization may cause contamination of land and underlying groundwaters that may pose risks to urban surface waters. Quantification of contaminant fluxes from contaminated land to surface waters via the groundwater pathway is poorly understood and documented. Impetus for the study of contaminated land impacts to baseflow and urban surface water quality comes from several areas, including: site owner or regulatory assessment of liability with respect to local surface water receptors; compliance points being set prior to discharge into rivers; increased importance of the baseflow component as pipe discharge impacts decline due to greater environmental controls or industrial closures; new legislation, e.g. the EC Water Framework Directive (Council of Europe, 2000) providing for integrated water management; and the study of processes occurring in the groundwater—surface water interface (hyporheic zone) that may cause contaminant "natural attenuation" and prevent impacts (Bradley & Chapelle, 1998). Perhaps the most comprehensive study to date on this topic has been the Chesapeake Bay area study in the USA (Ator et al., 1998; Lorah & Olsen, 1999).
The above provides the underlying rationale for our current research to evaluate the impact of potentially contaminated land and associated groundwaters within the Birmingham conurbation (the UK’s second largest city with at least 150 years industrial heritage) on groundwater baseflow and urban surface water quality. The study focuses upon the conurbation’s main surface water drainage feature, the River Tame, and its main underlying aquifer unit, the Birmingham Triassic sandstone. The research is in progress and we present the study setting and preliminary data from surface water surveys, a river-bed piezometer network specifically installed for the study and a shallow groundwater monitoring network in the vicinity of the Tame.

STUDY SETTING

The 7.4 km stretch of the River Tame that flows across the unconfined Birmingham Triassic sandstone aquifer is our primary focus supplemented by data obtained about 8 km up- and downgradient of that reach (Fig. 1; Jackson & Lloyd, 1986). The Tame is typically 3–12 m wide, 0.2–2.0 m deep and comprises natural and engineered sections. Although some of the latter contain impermeable side-walls, the river-bed comprises natural deposits through which baseflow occurs. Towards the Birmingham Fault, weathered Triassic sandstone bedrock is occasionally visible on the river-base and sides. More often than not, however, sandstones are covered by 1–5 m of unconsolidated superficial deposits. These are quite heterogeneously distributed and vary from boulders to gravels to sands and silty-clays, and will exert significant control over groundwater flow and the distribution of baseflow emergence. Due to the steady decline in industrial abstraction from the Birmingham aquifer over the past 50 years,
groundwater has been rising (Knipe et al., 1993) and is now predominantly effluent to the River Tame over the unconfined aquifer with the possible exception of areas near active groundwater abstraction. We estimate baseflow from the unconfined sandstone aquifer to comprise around 20% of total discharge in the Tame. Minimum flow at the downstream end of the 24-km study reach is about 180 Ml day⁻¹.

Surface water quality in the Tame is categorized within the worst classes E/F (poor/bad) under the General Quality Assessment (Stanley, 1998). Reasons include: the Tame source is within an urban area overlying Carboniferous coal measures formations, a significant proportion of its flow is due to industrial and sewage treatment works discharges, untreated runoff, storm-sewer overflows, and, our focus, contaminated baseflow due to contaminated land and groundwater. Past evidence of contamination in the Birmingham aquifer has been obtained from licensed abstraction boreholes that yield an integrated quality measurement (boreholes typically screen ~100 m of sandstone). Groundwater inorganic quality data (Ford et al., 1992; Ford & Tellam, 1994) show increasing acidity, generally high nitrate and barium, and localized high metals and ammonia. Groundwater organic quality data (Rivett et al., 1990) indicate chlorinated solvents to be the main contaminant associated with their use in the metals-related industries historically predominant in Birmingham.

RESULTS

To date, the influence of some groundwater solutes/contaminants on surface water quality has been difficult to discern due to the effect of in-river dilution and variable inputs from upstream sewage treatment works (up to 50% of total flow) and other urban/industrial sources. The existence of high and low calcium groundwater types can be seen in Fig. 2(a), however, only limited variation in the surface water profile (taken at low river flows) is apparent. In relation to chloride, sewage treatment works discharges caused greater concentrations in surface water relative to groundwater except at specific sites of hot-spot chloride contamination (Fig. 2(b)). For example, a chloride peak in the shallow groundwater of 1570 mg l⁻¹ may be responsible for chloride increases around the 12 km point of the surface water profile. However, interpretation of the surface water profile is complicated by changes in the chloride quality over the two-day sampling period apparently due to a gradual increase in chloride discharge from the upstream sewage treatment works. Repeat sampling is on-going to evaluate if increased concentration trends in surface water profiles are due to specific groundwater sources or temporal trends in pipe discharges. The sharp decline in concentration near the Mercia Mudstone boundary is ascribed to dilution by the River Rea tributary.

Individual, localized contaminant plumes in groundwater are potentially difficult to identify from the surface water profiles. Fluoride values (Fig. 2(c)) show generally low values in both groundwater and surface water, but with occasional peaks. An obvious peak of 6 mg l⁻¹ in the surface water (~12 km) is associated with an unidentified source. The reverse situation also arises, a fluoride plume has been identified by the river-bed piezometers (Fig. 3(a)), but apparently makes an inconclusive impact on the surface water profile. Trichloroethene (TCE) (Fig. 2(d)) shows a general increase along the surface water profile that peaks and persists across the unconfined aquifer. As this contaminant may be lost by volatilization, dilution and possibly
Fig. 2 Water quality data for Tame reach in Fig. 1. (Fig. 2(d) after Hogan (1999)).
biodegradation, data infer TCE continues to enter the river via baseflow (occasional pipe discharges are probably not responsible). Such inputs are not unexpected as chlorinated solvents have been observed in previous groundwater surveys of the Tame valley (Rivett et al., 1990).

**Fig. 3** River-bed piezometer cross-section profiles for the River Tame, Birmingham.
An example of cross-section profiles obtained from river-bed piezometers is depicted in Fig. 3. The fluoride plume shown (Fig. 3(a)) is relatively discrete emerging from one bankside and is not detected in other profiles located 200 m upstream and downstream. The calcium profile (Fig. 3(b)) shows elevated concentrations in the groundwater relative to the surface water but variations are less distinct than fluoride probably due to its significant contribution from many aquifer strata. Calcium and other major ion variations are currently being examined to assess the varying water types expected to be present in profiles due to convergence of shallow and deep groundwater flowpaths at the river-bed and also mixing of influent surface water with groundwater during high river flows. The chloride profile (Fig. 3(c)) shows more lateral variation. High chloride is present in both surface water and groundwater, but with low concentrations also present in the latter. Piezometric measurements indicate groundwater is currently discharging to the river around the central and right hand profile sections where chloride is high. Elevated chloride is probably from a variety of industrial processes or road salting, and perhaps dechlorination of organochlorines.

Interestingly, high aluminium concentrations are coincident with the elevated fluoride (Figs 3(a) and 3(d)). Preliminary modelling suggests transport of aluminium is occurring due to its complexation with fluoride. Limited sampling has detected TCE (Fig. 3(c)) that has a similar distribution to the fluoride suggesting perhaps a similar source area. TCE occurrence is expected from the surface water profile (Fig. 2(d)). Further work is in progress to assess its distribution and the presence of dechlorination products observed in other studies (Lorah & Olsen, 1999) anticipated from biodegradation in the hyporheic zone. River-bed profiles to date (not shown) indicate that significant electron acceptor variability and aerobic–anaerobic zones are present.

CONCLUSIONS

Understanding spatial and temporal chemical quality distributions within urban river systems is a complex proposition. Assessing the contribution of contaminated groundwater baseflow arising from contaminated land sources is particularly challenging. Discharges of dissolved solutes/contaminants to the River Tame from the Birmingham aquifer system have been observed with the best data afforded by the river-bed piezometer profiles and near-river groundwater monitoring wells. Surface water profiles are difficult to interpret due to elevated solute/contaminant loading from other sources (e.g. pipe discharges) that have significant temporal variability. Continued river-bed piezometer profiling is being undertaken to further resolve groundwater quality contributions to the River Tame system.

Acknowledgements This work is jointly funded by the Environment Agency and the School of Earth Sciences, University of Birmingham.

REFERENCES


