Discussion by Ian Reid

Seydell et al. provide an interesting analysis of inferred flow within the hyporheus of a gravel bar by using thermal properties of the interstitial water as a 'tracer' to calibrate their model. However, the analysis appears to presume that the properties of the porous media constituting the river bed are isotropic. The stratigraphy of both ancient (e.g., Nemec and Steel, 1984) and modern (e.g., Hassan, 2005; Laronne and Shlomi, 2007) gravel-bed rivers shows us that superjacent beds with significantly different grain-size and, hence, pore-size distributions vary considerably in thickness and 3D geometry at decimetre scale. While other studies of matrices show large variations in the degree to which pores are filled and give a rationale for understanding the vertical juxtaposition of open-framework and matrix-filled interstices even within the same bed (e.g., Frostick et al., 1984; Reid and Frostick, 1985). These studies suggest that gravel-bed rivers are more likely than not to be characterized by anisotropy of hydraulic conductivity, both vertical and horizontal, and this must have significant impact on interstitial flow velocity. Questions arise, therefore, as to whether properties and dimensions of gravel-bed facies need to be taken into account when modelling hyporheic flow nets? or whether abrupt changes in hydraulic conductivity are inconsequential in affecting flows as small as those reported by Seydell et al. (up to $14\,\mu\mathrm{m\,s^{-1}}$), except, presumably, where pores are tightly packed with ingressed clay grains or a clay drape is interdigitated in the microstratigraphy?

References

Frostick, L.E., Lucas, P.M., Reid, I., 1984. The infiltration of fine matrices into coarse-grained alluvial sediments and its implications for stratigraphical interpretation. J. Geol. Soc. London 141, 955–965.

Hassan, M.A., 2005. Characteristics of gravel bars in ephemeral streams. J. Sediment. Res. 75, 203–221.

Laronne, J.B., Shlomi, Y., 2007. Depositional character and preservation potential of coarse grained sediments deposited by flood events in hyper-arid braided channels in the Rift Valley, Arava, Israel. Sediment. Geol. 195(1–2), 21–37.

Nemec, W., Steel, R.J., 1984. Alluvial and coastal conglomerates: their significant features and some comments on gravely mass-flow deposits. In: Koster, E.H. and Steel, R.J. (Eds), Sedimentology of gravels and conglomerates. Memoir Canadian Society Petroleum Geologists 10, 1–31.

Reid, I., Frostick, L.E., 1985. Role of settling, entrainment and dispersive equivalence and of interstice trapping in placer formation. J. Geol. Soc. London 142, 739–746.

Discussion by John M. Buffington[1] & Daniele Tonina[2]

Hyporheic exchange is principally driven by spatial variations of near-bed pressure, which can be sensitive to seasonal changes in discharge, flow depth, and water-surface profile (Tonina and Buffington, 2003, 2007). Simulations of hyporheic exchange across two-dimensional pool-riffle topography show that the strength and spatial extent of the hyporheic exchange vary with discharge (Fig. 5.7). High

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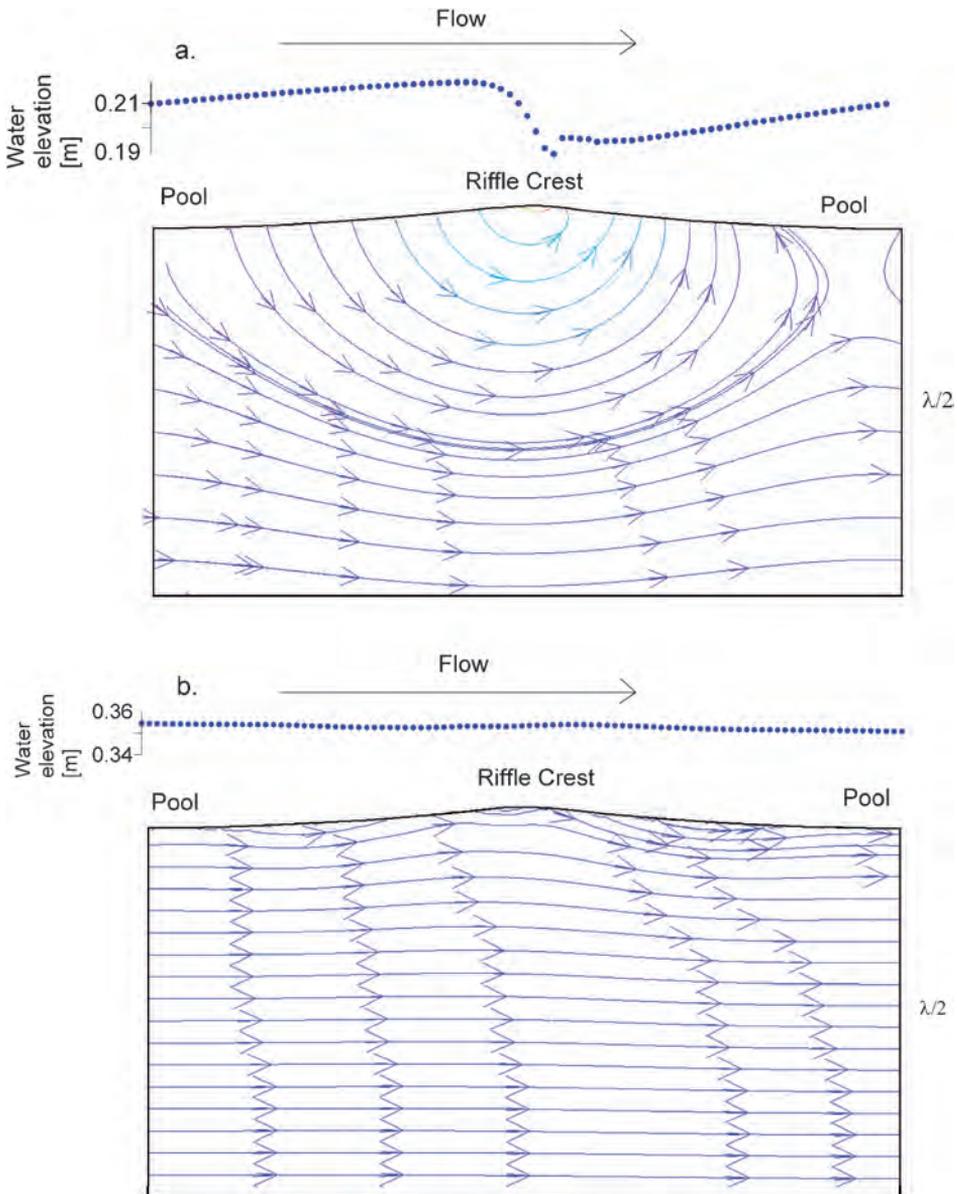
Figure 5.7. Simulated hyporheic pathlines for a synthetic two-dimensional pool-riffle topography with (a) low discharge (8% bankfull flow) and (b) high discharge (100% bankfull flow). Channel characteristics scaled from natural gravel-bed rivers in central Idaho: slope is 0.5% and the ratio of bedform amplitude to wavelength, Δ/λ, is 0.03. Surface and subsurface flow simulated using MD_SWMS 1 (McDonald et al., 2005) and FLUENT 6.0 (FLUENT Inc.), respectively. Predicted water surface profiles are plotted separately above each panel at exaggerated vertical scales to emphasize their differences, but do not indicate flow depths over bed topography. Subsurface flow simulations use a uniform hydraulic conductivity of 0.1 cms^{-1} (sandy gravel), with lighter-coloured hyporheic pathlines indicating faster flow.
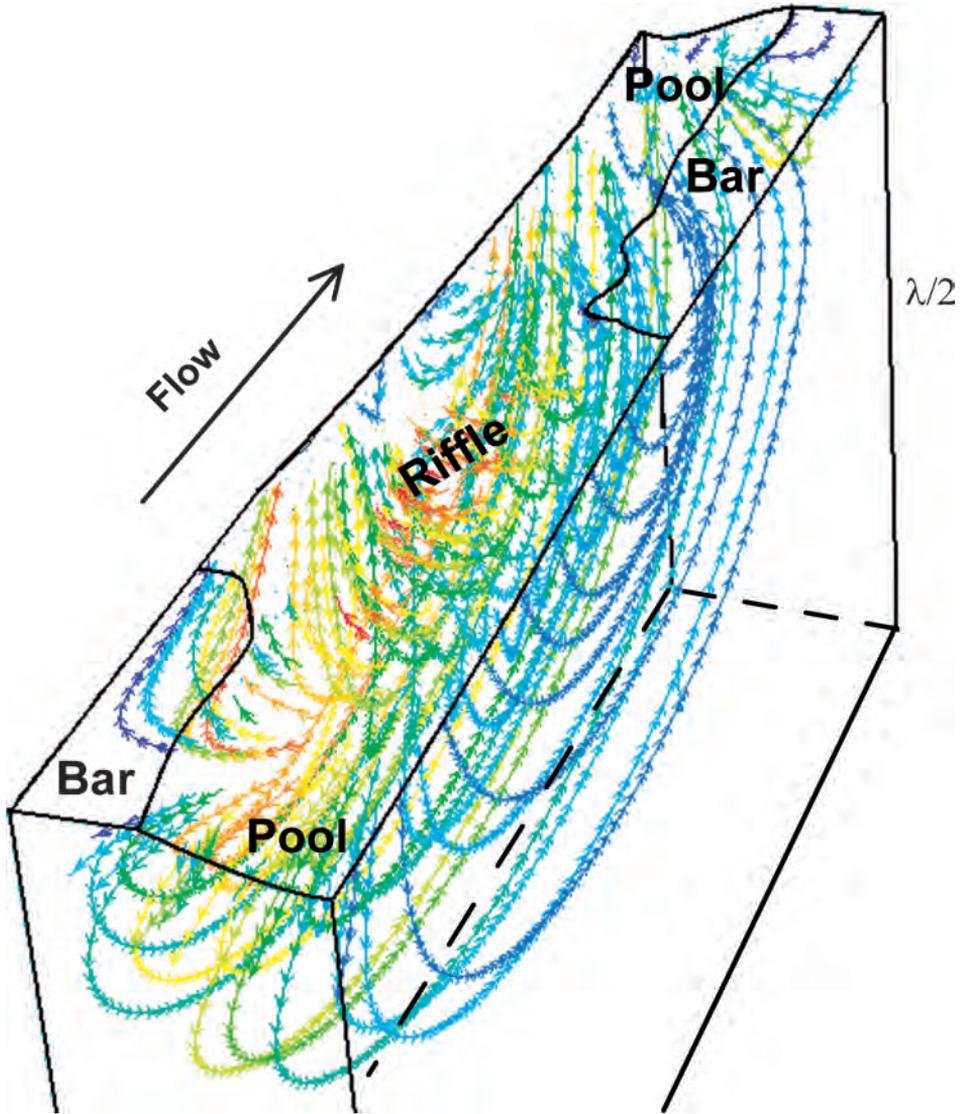
Figure 5.8.   Simulated hyporheic pathlines for a synthetic three-dimensional pool-riffle channel with alternate bar morphology and low discharge (26% bankfull flow). Channel characteristics scaled from natural gravel-bed rivers in central Idaho: slope is 0.41% and the ratio of bedform amplitude to wavelength is 0.022 (Tonina and Buffington, 2007, experiment 1). Surface and subsurface flow simulated using FLUENT 6.0 (FLUENT Inc.), with hyporheic pathlines originating from the surface and coloured by individual trajectory. The simulation uses a groundwater slope of 0.41%, a uniform hydraulic conductivity of $5\,\mathrm{cm\,s^{-1}}$ (Tonina and Buffington, 2007), and an alluvial depth equal to one bedform wavelength (1λ). Deeper groundwater flow paths (those that do not intersect the bed surface) are not shown.

discharges decrease the magnitude of hyporheic exchange in pool-riffle channels by smoothing the water-surface profile and decreasing the spatial variation of near-bed pressure (Fig. 5.7) (Tonina and Buffington, 2007). Furthermore, the direction of hyporheic flow (up-welling vs. down-welling) can change with discharge. For example, just downstream of the riffle crest, hyporheic flow is predicted to up-well at low discharge, but down-well at high discharge (Fig. 5.7). These changing patterns and magnitudes of hyporheic exchange together with the authors' limited number of fixed sample sites may partially explain the seasonal variations in hyporheic flow observed at their study site (their Fig. 5.6). Furthermore, hyporheic flow paths are even more complex and strongly three dimensional in pool-riffle channels with alternate bar morphology (Fig. 5.8). Interactions between flow and bedform topography induce lateral hyporheic flow in these channels that can change with discharge and may contribute to the lateral flow observed by the authors.

References

McDonald, R.R., Nelson, J.M., Bennett, J.P. 2005. Multi-dimensional surface-water modeling system user's guide. U.S. Geological Survey Techniques and Methods, 6-B2, 136pp. (http://wwwbrr.cr.usgs.gov/projects/SW_Math_mod/OpModels/MD_SWMS/index.htm)

Tonina, D., Buffington, J.M., 2003. Effects of discharge on hyporheic flow in a pool-riffle channel: Implications for aquatic habitat. EOS Trans. Am. Geophys. Union 84 (46), Fall Meeting Supplement, Abstract H52A-1154.

Tonina, D., J.M. Buffington., 2007. Hyporheic exchange in gravel-bed rivers with pool-riffle morphology: Laboratory experiments and three-dimensional modeling. Water Resources Research, 43, W01421.

Reply by the authors

We thank the discussants for highlighting important points. The described changes in hyporheic flow are greatly attributed to in channel flow and do not reflect necessarily seasons but different flow conditions. In the Lahn field site one interesting finding was the change from seemingly up-welling in the upper 50 cm of sediment, to down-welling at 100 cm depth during September 2000. Here the additional influence of ground water level and, in the investigated case the induced strong lateral velocity component is visible.

This points out the limitation of the one-dimensional approach main aim of which is to provide an simple method for research interested in only limited information on vertical exchange between the stream and the pore water.

Beyond this it is most desirable to have a 3D model as described by the Discussants with additional temperature data for a natural river bed, to determine spatial heterogeneity with greater reliability. This is currently done by the Department of Hydrogeology, UFZ Centre for Environmental Research, Leipzig-Halle, Germany.