Simulation of reach-scale water and heat fluxes across the river-groundwater interface for retrieving hyporheic residence times and temperature dynamics

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1. Introduction
Flow patterns in conjunction with seasonal and diurnal temperature variations control ecological and biogeochemical conditions in hyporheic sediments. In particular, hyporheic temperatures have a great impact on many temperature-sensitive microbial processes. In this study, we used 3D coupled water flow and heat transport simulations applying the HydroGeoSphere code in combination with high resolution observations of hydraulic heads and temperatures to quantify reach-scale water and heat flux across the river-groundwater interface and hyporheic temperature dynamics of a lowland gravel-bed river. Based on the simulation results we derived a general empirical relationship, estimating the influence of hyporheic flow path residence time on hyporheic flow path temperature. Furthermore we used an empirical temperature relationship between effective temperature and flow path temperature and incoming short and long wave solar radiation.

2. Study side and data collection

3. HydroGeoSphere model setup

3.1 Discretisation
The dimensions of the model domain were 80 m x 160 m x 13 m (length, width, thickness, Fig. 2). Element size was set to 10 m in the floodplain, but subsequently refined to 0.25 m in the riverbed.

4. Boundary condition
- Prescribed hydraulic head and groundwater temperature at the sides of the model domain,
- Prescribed water flux and river temperature at the river inlet
- Critical-depth boundary is applied at the river outlet
- Atmospheric energy input calculated by means of the ambient air temperature and incoming short and long wave solar radiation

4.1 Parameterisation
Hydraulic conductivity ($K_n$) was generated by Sequential Gaussian Simulation. In the simulations, the mean hydraulic conductivity was chosen as $K_n = 5.1 \times 10^{-10} m/s$. Values for porosity ($n$) and specific storage ($S_s$) were chosen as $n = 0.36$ and $S_s = 2.1\times10^{-7}$ m$^{-1}$, respectively. The Kriging parameter $b$ was chosen as 1 for the first order moments of the hydraulic conductivity. A semi-variogram with anisotropy of 1.5 was used to model the spatial variability of the hydraulic conductivity.

4.2 Flow Path Residence Time
Table 1: Flow path temperature (°C) for different discharge conditions and residence times (log(hours)).

<table>
<thead>
<tr>
<th>Residence Time (log(hours))</th>
<th>Flow Path Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>9.03</td>
</tr>
<tr>
<td>0.2</td>
<td>9.03</td>
</tr>
<tr>
<td>0.3</td>
<td>9.03</td>
</tr>
<tr>
<td>0.4</td>
<td>9.03</td>
</tr>
<tr>
<td>0.5</td>
<td>9.03</td>
</tr>
</tbody>
</table>

4.3 Simulation of reach-scale water and heat fluxes across the river-groundwater interface for retrieving hyporheic residence times and temperature dynamics

5. Implications of hyporheic residence time and temperature for biogeochemical processes in the streamed

6. Summary and conclusions
The calibrated and validated 3D fully-integrated model of reach-scale water and heat fluxes across the river-groundwater interface was able to accurately represent the real system. The simulation results showed that non submerged streambed structures caused significant thermal heterogeneity within the saturated sediment at the reach scale. The average hyporheic flow path temperature was found to strongly correlate with the flow path residence time (flow path length) and the temperature gradient between river and groundwater. Despite the complexity of these processes, the simulation results allowed the derivation of a general empirical relationship between the hyporheic residence times and temperature patterns (eq. 1). Based on this empirical relation we furthermore quantified the influence of hyporheic flow path residence time and temperature on oxygen consumption (Fig. 7).