Stream discharge events increase the reaction efficiency of the hyporheic zone of an in-stream gravel bar

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1 Introduction

In the hyporheic zone (HZ) important biogeochemical reactions of stream and groundwater solutes occur with crucial impact on nutrient cycling in fluvial systems.
Prior modelling studies have evaluated the factors which control hyporheic exchange, residence times and biogeochemical processes for mostly steady flow conditions.
In this study, we set up a transient flow and reactive transport model to elucidate the impact of single stream discharge events on water exchange, solute transport and reactions within the hyporheic zone of an in-stream gravel bar.

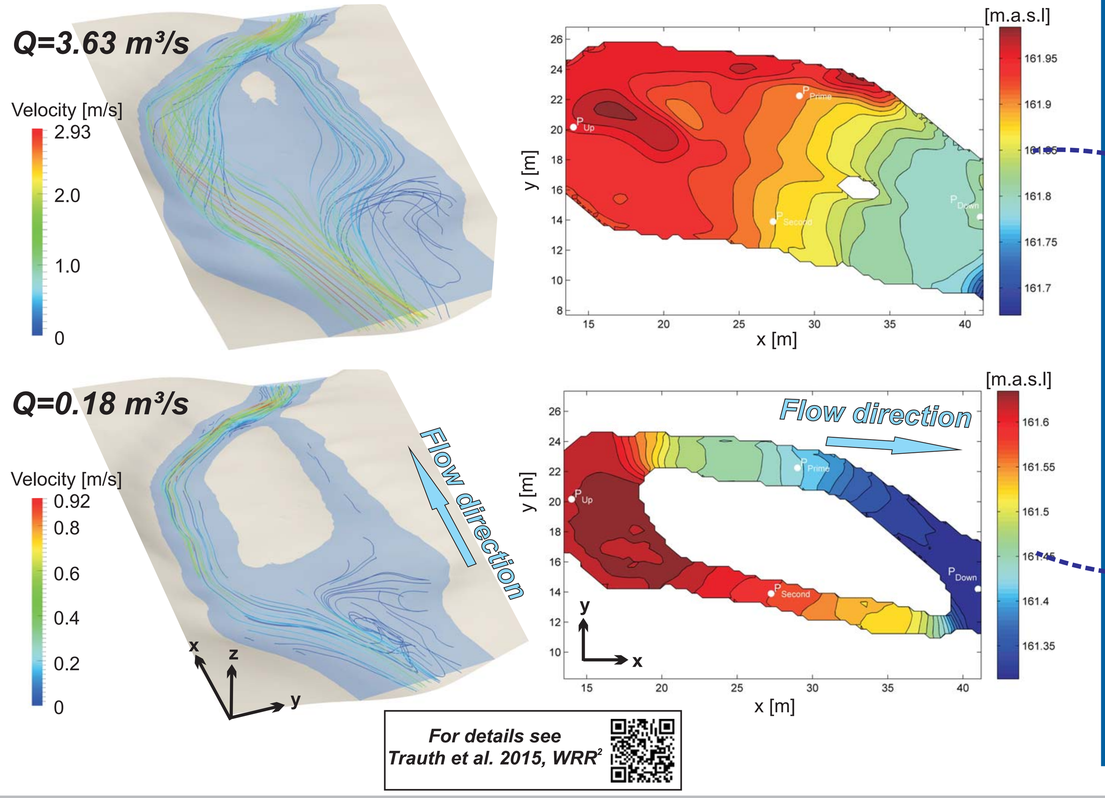
In-stream gravel bar at the Selke River in Germany. Extent: 20 x 7 m

Field site info:

2 Stream flow simulations

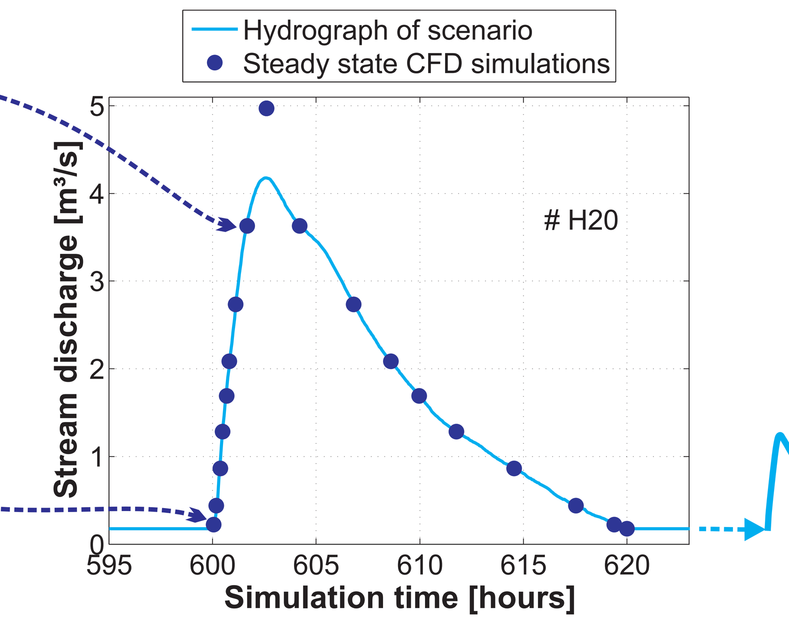
Computational fluid dynamics (CFD)[1]

- Transient flow as sequence of steady states
- Discharge: 0.18 to 5.0 m³/s
- Validation to measured rating curve
- Hydraulic head distribution at the streambed



Transient hydraulic heads

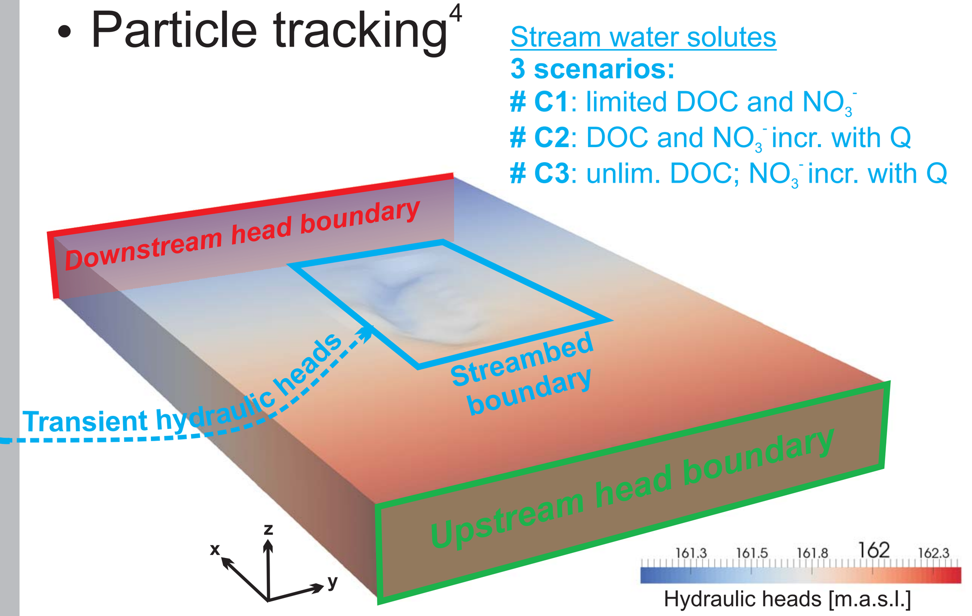
- Interpolation between steady state hydraulic heads from CFD model
- Transient hydraulic heads derived for each mesh cell at the streambed



3 Groundwater model and scenarios

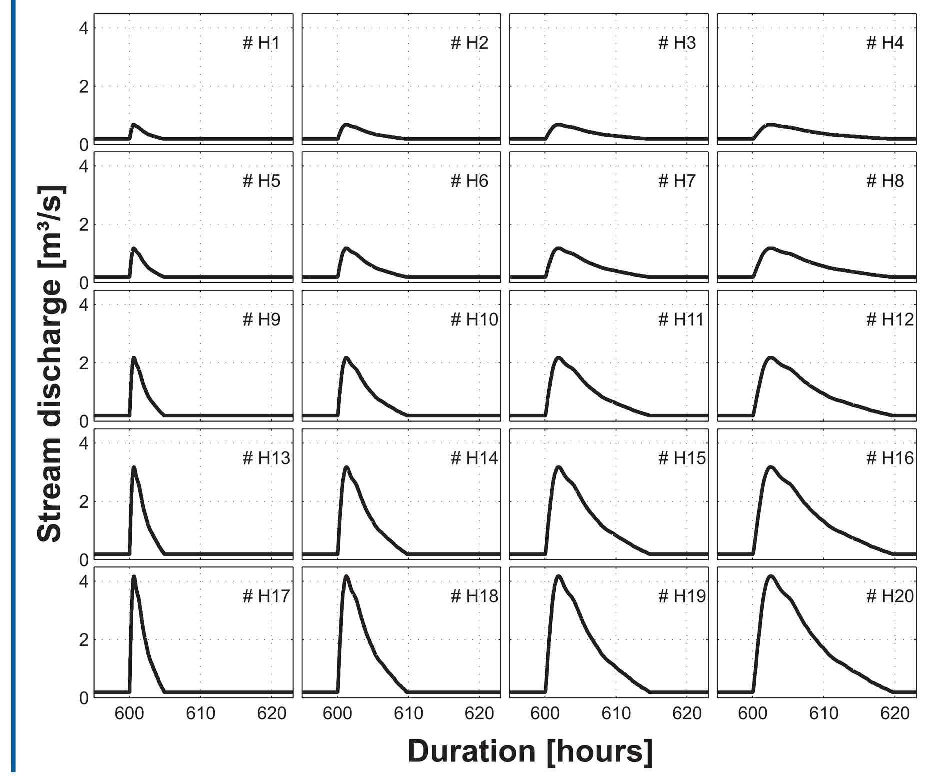
Groundwater model setup (MIN3P[3])

- Transient hydraulic heads at streambed
- Ambient groundwater flow field with constant head boundary conditions
- Solute transport of O_2, DOC, NO_3^-
- Redox reactions:
  - Aerobic respiration
  - Denitrification
- Particle tracking[4]



Stream discharge scenarios

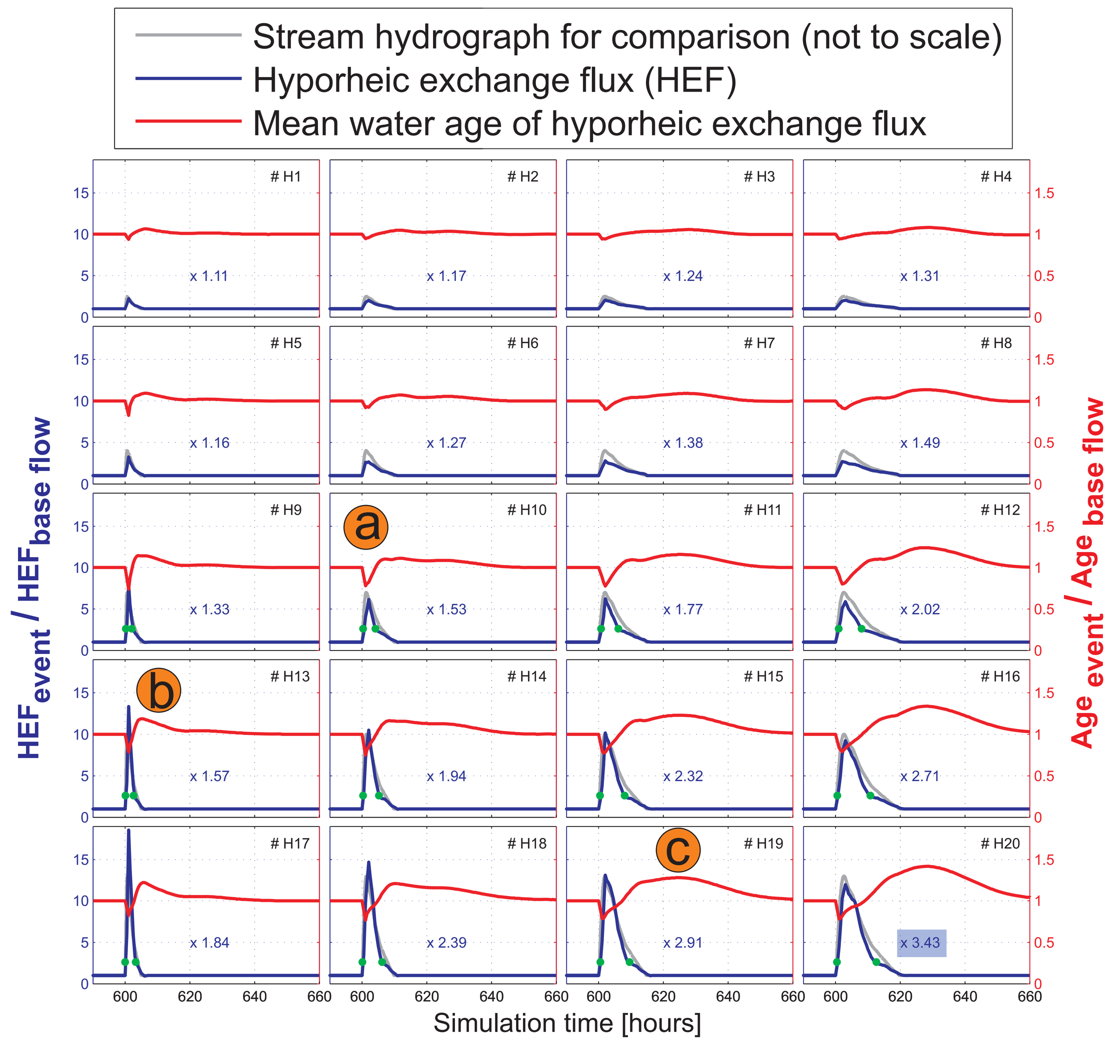
- 20 discharge events
- vary by **duration** and **peak stream discharge**



4 Hyporheic exchange flow

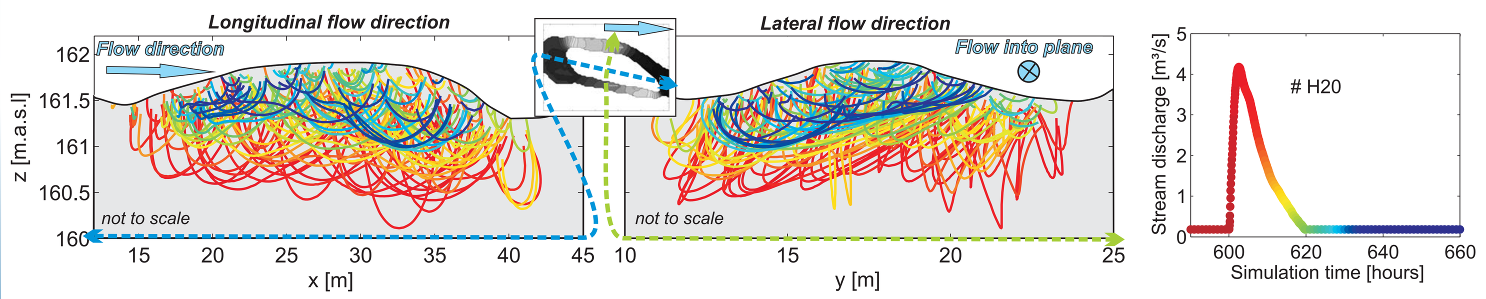
Hyporheic exchange flux (HEF) and water age

- normalized to base flow conditions



Hyporheic flow patterns during an event

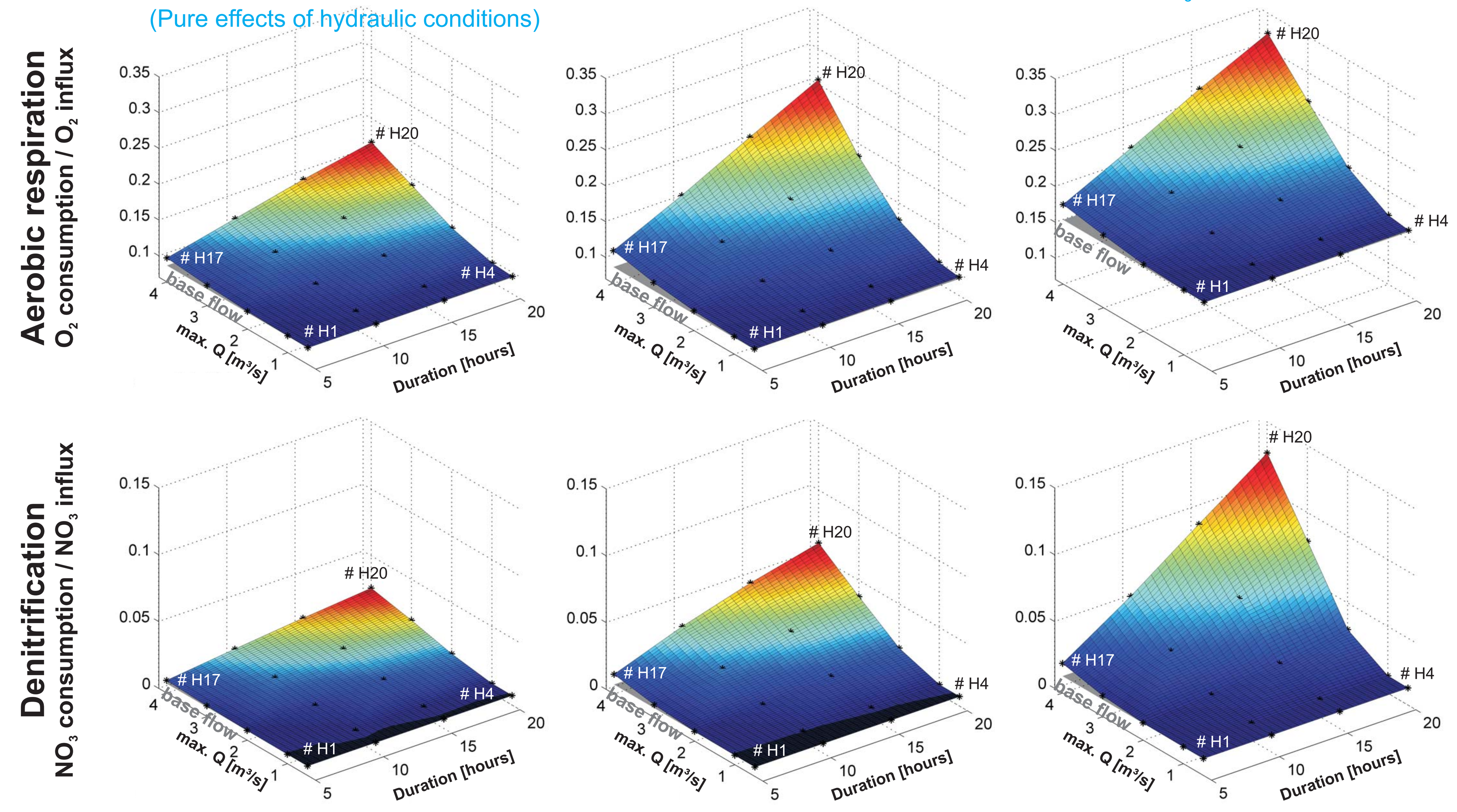
- Colours indicate time of infiltration according to hydrograph
- Deep infiltration during events: Larger extent of the HZ



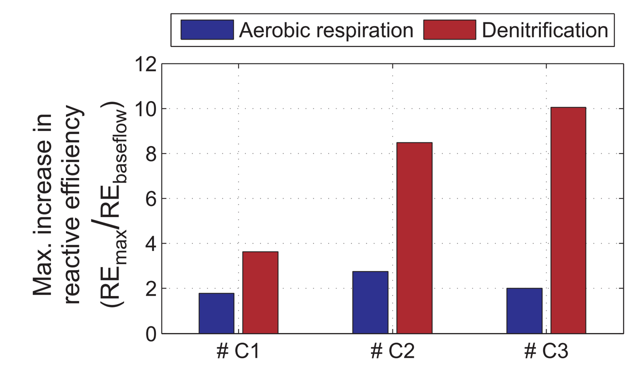
- Total HEF increases by events (up to 3.4 times of $HEF_{base\ flow}$)
- Slope of falling HEF limb changes at neutral conditions (●)
- Water age peaks:
  - (a) Age minimum: Rising limb creates larger degree of submergence, a lot of fresh water infiltrates into the domain
  - (b) 1st age maximum after Q-peak: Less fresh water infiltrates and old water from (a) still exists in the domain
  - (c) 2nd age maximum after event: During falling limb hydraulic head gradients decline and flow velocity decreases leading to older water ages

5 Reactive efficiency of the hyporheic zone during events

Reactive efficiency (RE) = Total solute consumption as a fraction of total solute influx



- RE increases with event duration and maximum discharge (larger HZ extent and longer residence times) and DOC availability
- Higher DOC availability fuels denitrification RE more strongly than aerobic respiration RE, which is close to the maximum



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References:
[1] **OpenFOAM**® is licensed under the GNU General Public Licence (GPL) - www.openfoam.com
[2] **Trauth, N.**, C. Schmidt, M. Vieweg, S.E. Oswald, and J. H. Fleckenstein (2015), Hydraulic controls of in-stream gravel bar hyporheic exchange and reactions, Water Resources Research, 51, doi:10.1002/2014WR015857
[3] **Mayer, K. U.**, Frind, E. O., and Blowes, D. W., (2002), Multicomponent reactive transport modeling in variably saturated porous media using a generalized formulation for kinetically controlled reactions. Water Resources Research, 38(9), 1174, doi:10.1029/2001WR000862
[4] **Henderson, A.**, Ahrens, J., and Law, C. (2004). *The ParaView Guide*. Kitware Inc., Clifton Park, New York.

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