Influence of varying hydraulic conditions on hyporheic exchange and reactions in 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. Solutes that infiltrate into the HZ are transported advectively by hyporheic exchange flux (HEF) and show residence times (RT) that are controlled by stream hydraulics, streambed morphology and permeability, and ambient groundwater flow.

In this study, we investigate how stream discharge and ambient groundwater flow control HEF, RT, solute transport and reactions in the HZ of a natural in-stream gravel bar (ISGB). We use three-dimensional Computational Fluid Dynamics (CFD) simulations coupled to a reactive transport groundwater model.

2 Field site

Natural in-stream gravel bar

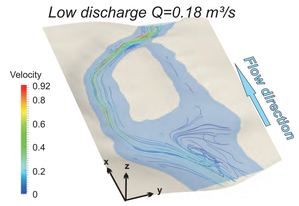
- In-stream gravel bar (ISGB) at the Selke river in central Germany
- Extent: 20 m x 7 m (low discharge)
- GPS-Survey of morphology
- Slug tests, freeze coring for *K*
- Stage / discharge measurements
- Head, EC, O_2 time series in the streambed sediments

3 CFD simulations

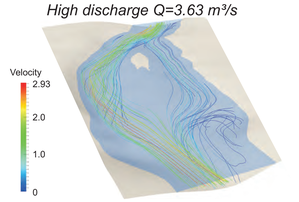
CFD code: OpenFOAM

- Discharge: 0.18 to 5.0 m³/s
- Validation to rating curve

Low discharge Q=0.18 m³/s

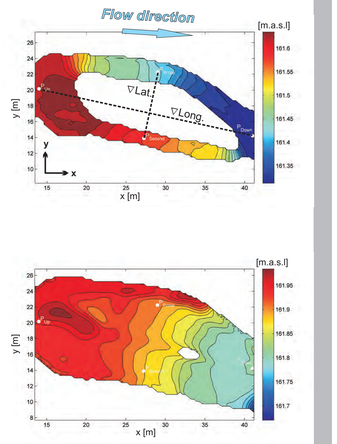


High discharge Q=3.63 m³/s



Hydraulic head distribution

Coupled to groundwater model



4 Reactive transport model - MIN3P

Subsurface flow

- Steady state simulations
- Variation of groundwater heads imply neutral, losing, gaining conditions: Δh= -0.4 to +0.4 m

Solute transport and reactions

Aerobic respiration (AR)

$CH_2O + O_2 \rightarrow CO_2 + H_2O$

Denitrification (DN)

$5CH_2O + 4NO_3^- + 4H^+ \rightarrow 5CO_2 + 2N_2 + 7H_2O$

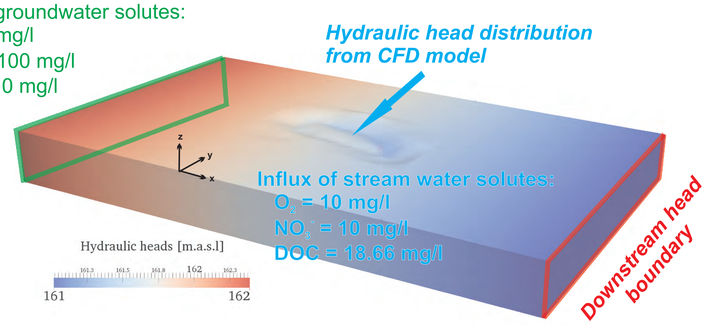
Upstream head boundary

Influx of groundwater solutes:

O_2 = 2 mg/l

NO_3^- = 100 mg/l

DOC = 0 mg/l



5 Spatial patterns of flow and reactions

Hyporheic exchange flux of ISGB

- Stream water infiltrates at small channel and exfiltrates at large channel, forming a hyporheic flow cell (HFC)

Neutral conditions (Δh = 0)

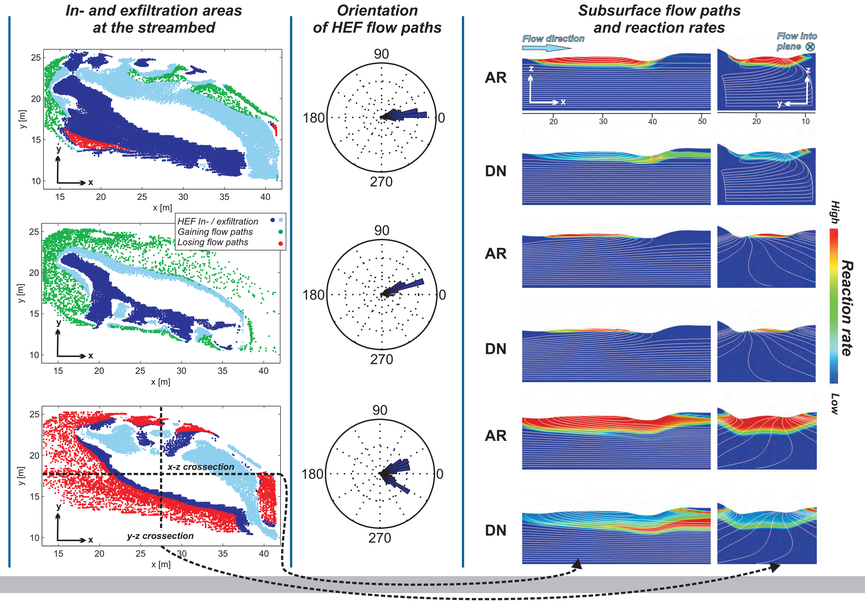
- Large in- and exfiltration areas and HFC extents
- Reactive zones restricted to HFC

Gaining conditions (Δh > 0)

- Upwelling groundwater exfiltrates at the streambed
- Small reactive zones, restricted to the HFC extent

Losing conditions (Δh < 0)

- Stream water infiltrates at the streambed feeding the groundwater
- Large reactive zones exist, also beyond the HFC extent



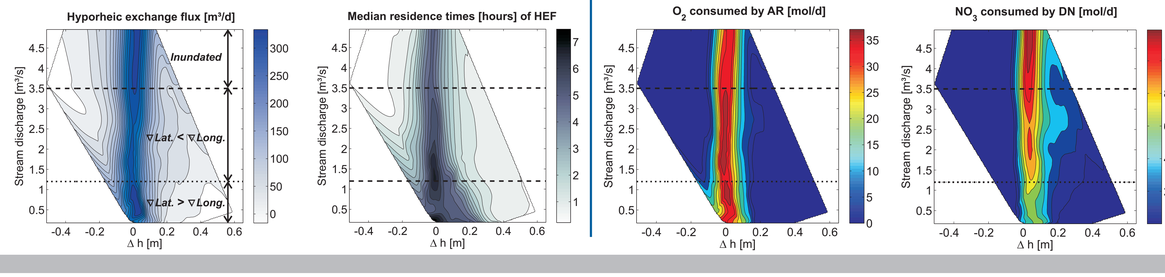
6 Influence of stream discharge and ambient groundwater flow

Hyporheic exchange flux and RT

- Losing and gaining conditions significantly reduce HEF and RT
- Variation with stream discharge: Effect of predominance of lateral or longitudinal head gradients (∇*Lat.* / ∇*Long.*) across the ISGB and the resulting flow-through area.
- Different hydraulic system for completely inundated ISGB

Solute transport and consumption

- Solute influx corresponds to HEF
- Losing and gaining conditions reduce RT and extent of HFC / reactive zones → reduced O_2 and NO_3 consumption
- NO_3 consumption increases with discharge: The higher the discharge, the larger is the HFC and the "reactive fringe" of DN
- Solute consumption correlates with MRT



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References:

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