Integrated field experiments and numerical modelling to evaluate the factors controlling water flow and redox conditions in the hyporheic zone

Nico Trauth, Michael Vieweg, Christian Schmidt, and Jan H. Fleckenstein

Helmholtz Centre for Environmental Research - UFZ, Department of Hydrogeology, Leipzig, Germany

1 Introduction

The aim of our study is a quantitative description of hydraulic, morphologic and geochemical controls that govern the magnitude and direction of water flow as well as the redox conditions in the hyporheic zone (HZ).

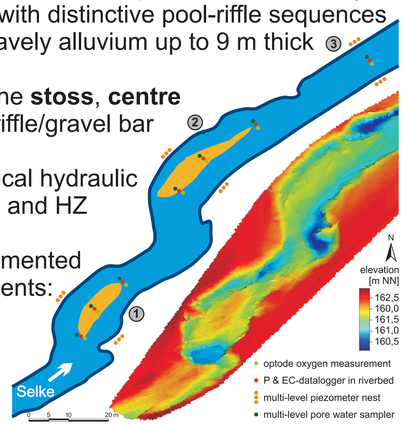
We hypothesize that variable hydraulic conditions and bedform morphology are the key controlling factors for flow, solute transport and reactions in the HZ. The influence of changing hydraulic conditions (such as stream flow velocity, water depth and groundwater discharge) on the extent and the redox-zonation of the HZ is evaluated. Besides varying hydraulic conditions, different setups of periodic bedform structures, described by their wavelengths, amplitudes and frequencies, are considered.

2 Field measurement methods

Study reach at Selke River

a submontane, near natural floodplain at the boundary of the Harz Mountains with distinctive pool-riffle sequences over a sandy and gravely alluvium up to 9 m thick ③

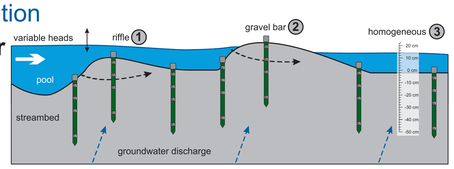
- measurements at the **stoss**, **centre** and **lee** sides of a riffle/gravel bar
- monitoring the vertical hydraulic conditions in banks and HZ
- three equally instrumented sites for measurements:
  ① submerged riffle
  ② gravel bar
  ③ unstructured flat (for manipulation)



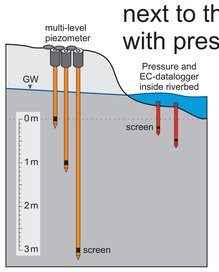
Streambed-adapted instrumentation

multi-level pore water sampler

- redox-sensitive compounds (nitrogen, iron, sulfur)
- biological indicators (ortho-phosphate, DOC, oxygen)



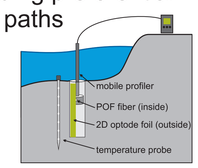
multi-level piezometer nests
next to the instream sites, equipped with pressure datalogger



Pressure and EC-data-logger inside the riverbed
metal rod avoids displacement during readout

- pressure datalogging
- electrical conductivity EC measurement

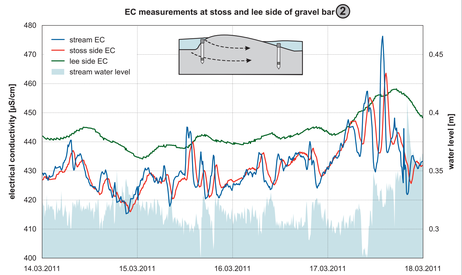
in situ optode oxygen measurements
to obtain continuous O_2 profiles of the HZ while avoiding preferential flow paths



First results

EC-time series of stream water and pore water at gravel bar

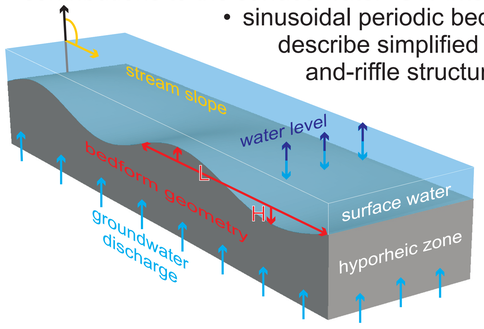
- stream water EC correlates with stream stage reflecting dilution
- time shift of 3-4 h and damped signal between stoss and lee side



3 Numerical Experiments

Experimental setup

- Variation of the hydraulic conditions and bedform configurations to simulate the influence on travel time distributions and (reactive) transport in the HZ
- Evaluation of the hydrostatic and hydrodynamic contributions to the surface water–GW interactions
  - sinusoidal periodic bedforms describe simplified pool-and-riffle structures



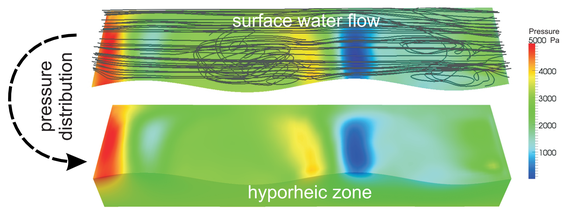
Coupling of surface and subsurface model

1. Simulation of surface water flow

- Computational Fluid Dynamics (CFD), OpenFOAM[1]
- pressure distribution on streambed serves as upper boundary heads for subsurface model

2. Subsurface model

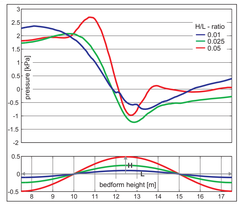
- FD-Code MIN3P[2] for 3D water flow, solute transport and chemical reactions in the HZ



First results

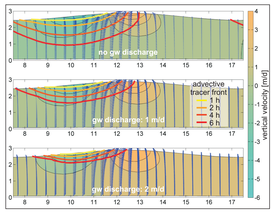
Pressure distribution at stream bed

- depends on eddy extent and the detachment points[3]
- eddy formation is strongly related to bedform morphology
- high H/L-ratio = small distance between max. & min. pressure



Water flow, and conserv. tracer transport in the HZ

- GW discharge reduces extent of the HZ
- vertical infiltration velocity decreases with depth
- GW discharge influences flow path and residence times



4 Perspectives

- simulation of biogeochemical processes, e.g. degradation of oxygen, respiration and denitrification
- model application to natural bedform structures
- by using field data as model input parameters, results of the numerical experiments will be validated in close connection with field measurements
- manipulation of the hydraulic conditions at the unstructured site, e.g. by artificial obstacles or inducing losing conditions by intense GW pumping
- development of concepts to upscale reach scale results to larger scales, e.g. by classification of hyporheic river types, for an assessment of water quality effects

Contact: Nico Trauth
Helmholtz Centre for Environmental Research - UFZ,
Permoserstraße 15, 04318 Leipzig, Germany,
nico.trauth@ufz.de
+49 341 235 1983

References:

[1]OpenFOAM® is licensed under the GNU General Public Licence (GPL) - www.openfoam.com

[2]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 Resour. Res., 38(9), 1174, doi:10.1029/2001WR000862

[3]Cardenas, M. B., and Wilson, J. L., 2007, Dunes, turbulent eddies, and interfacial exchange with permeable sediments, Water Resour. Res., 43, W08412, doi:10.1029/2006WR005787.

WESS
Water & Earth System Science Competence Cluster

HELMHOLTZ CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ