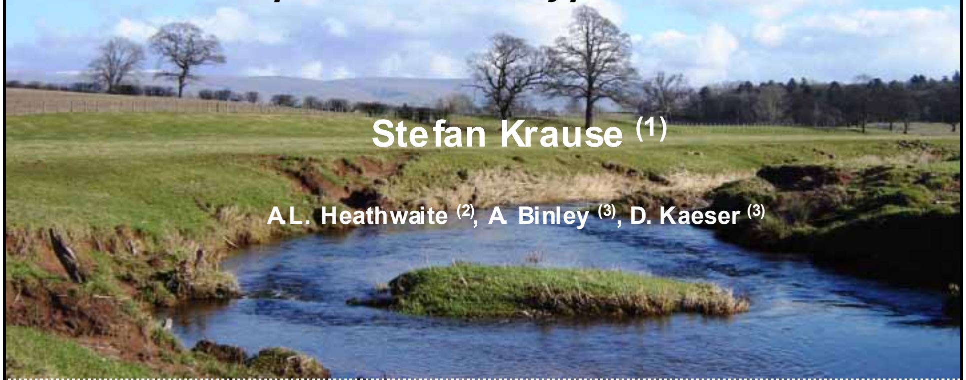
Nitrogen transport and transformation at the groundwater – surface water interface
-
How important is the Hyporheic Zone?



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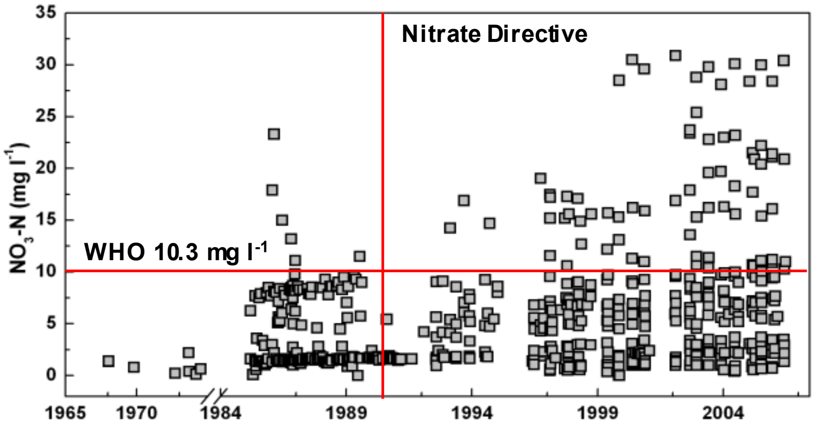
Outline

- **Introduction – Motivation**
- **Efficiency of nitrate attenuation at the groundwater – surface water interface**
- **Transport and transformation of N in the Hyporheic Zone**
  - *- physical streambed controls on transport*
  - *- chemical controls on transformation*
- **Potential implications of HZ nitrogen cycling - upscaling strategies**

Motivation – The Nitrate Time Bomb?

Nitrate Concentrations in 40 Cumbrian GW-Boreholes
1972 - 2007

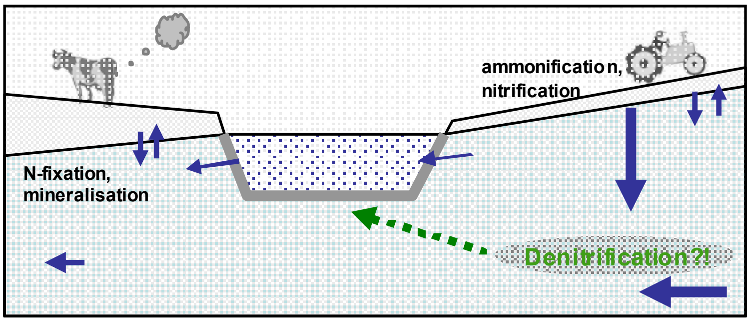


Why are GW Nitrate concentrations still increasing in many aquifers?!

Results of diffuse inputs and long residence times - The Nitrate Time Bomb?

Motivation – Riparian Attenuation?

(Potential) impact of riparian nitrate attenuation



Background:

Expectations for potential Nitrate attenuation in riparian groundwaters

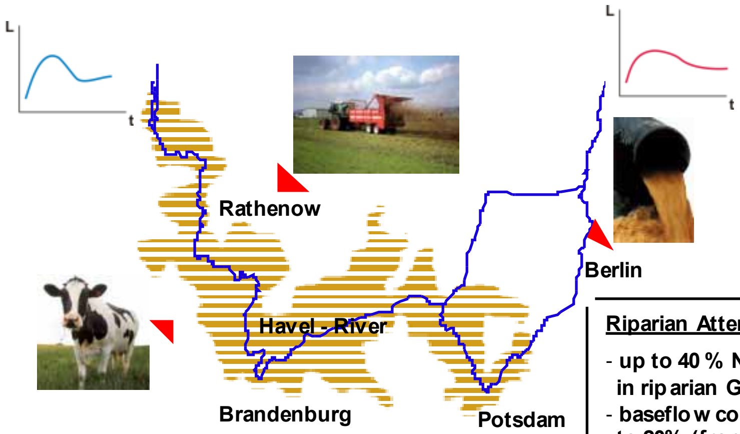
20 yrs of research:

What is the riparian nitrate retention capacity? How much amelioration can be achieved?

Riparian Controls on Nutrient Delivery

Nitrate retention within riparian groundwaters

Model: IWAN: Coupled Groundwater - Surface Water Model



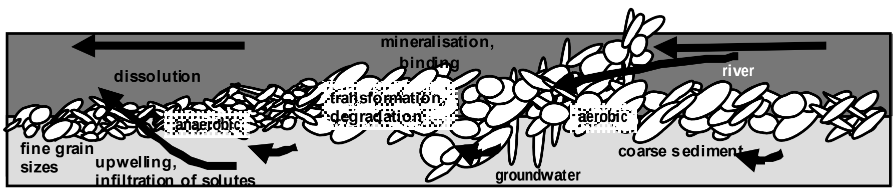
(Krause and Bronstert, 2007, Krause et al. 2007)

Riparian Attenuation:

- up to 40 % NO_3 reduction in riparian GW
- baseflow contributions up to 20% (from 1% of the catchment !)

Motivation – The Hyporheic Panacea?

Hyporheic Transport and Transformation of Nutrients



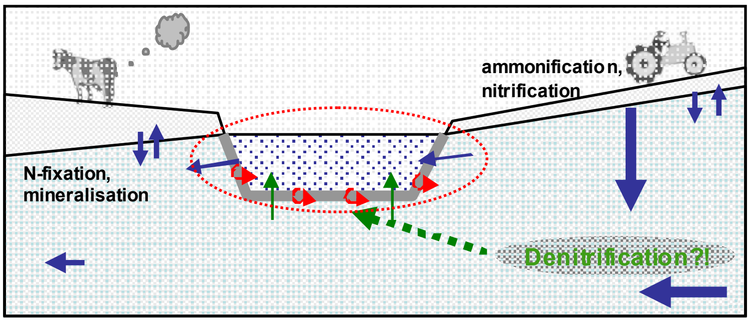
The Hyporheic Zone (HZ) - reactive area of GW-SW mixing (SW> 10%) with strong redox gradients and potential for nutrient transformation in dependence of:

- pattern of transmissivities and fluxes (contact and residence times)
- pattern of redox conditions, nutrient concentrations and availability of reductive agents (FeS_2, Corg)

Previous Studies of HZ processes *(usually accounting for surface water infiltrating and exfiltrating into/from the streambed)* derived evidence for HZ potential to moderately change N transported at GW-SW interface

Motivation – The Hyporheic Panacea?

Hyporheic Transport and Transformation of Nutrients



GW-SW interface potentially controls transport an transformation of nitrogen

How much of the riparian nitrate finally reaches the river?

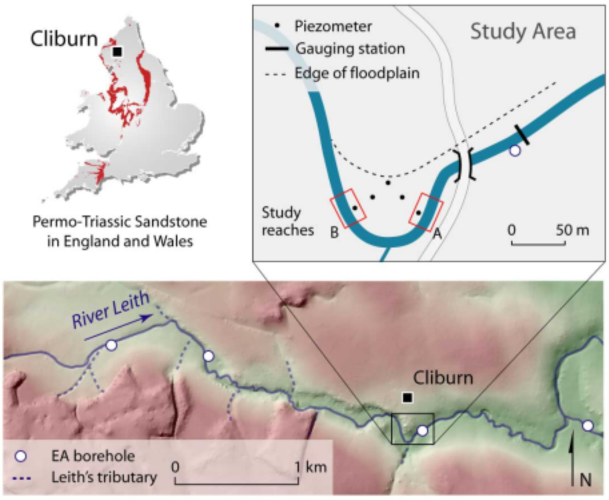
Specific hyporheic process dynamics are not taken into account in modelling approaches

HZ Nitrogen Cycling – the GW Perspective

Investigation of the dynamic controls of physical streambed conditions on hyporheic exchange fluxes and redox chemistry

The Leith field site :

- N - Cumbria
- Tributary of the River Eden
- Gaining section in riparian floodplain (^{222}Rn)
- Baseflow conditions (May to October)
- GW & SW < 10 mg l^{-1} NO_3-N



Geology derived from 1:625k scale BGS Digital Data under Licence 2003/014 British Geological Survey. (NERC)
EA contractor data licence ref. 456

HZ Nitrogen Cycling – the GW Perspective

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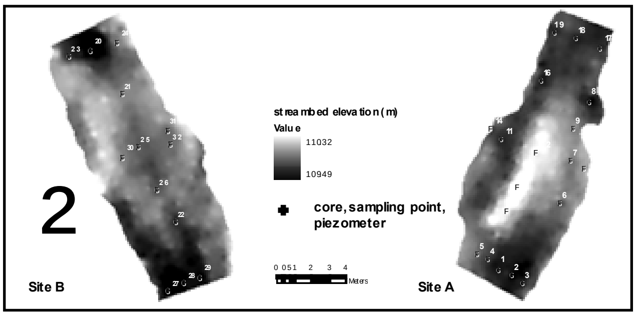
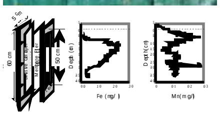
Experimental Setup - River Leith



Two sites - physical and chemical properties:

- 42 cores:
  - porosity, compaction, grain size distribution, hydr. cond.
  - cores: NO_3, NH_4, TN/TON concentrations (foc, CEC (J. Smith))
- ca. 140 piezometer + gw boreholes in riparian floodplain:
  - hydraulic gradients, slug tests, temperature and radon survey
  - NO_3, NH_4, TN/TON, DO, ORP, ph (fortnightly)
- DET probes (sub cm scale)
- *tracer injection: salt, rhodamine – flow velocities, residence times*



HZ Nitrogen Cycling – the GW Perspective

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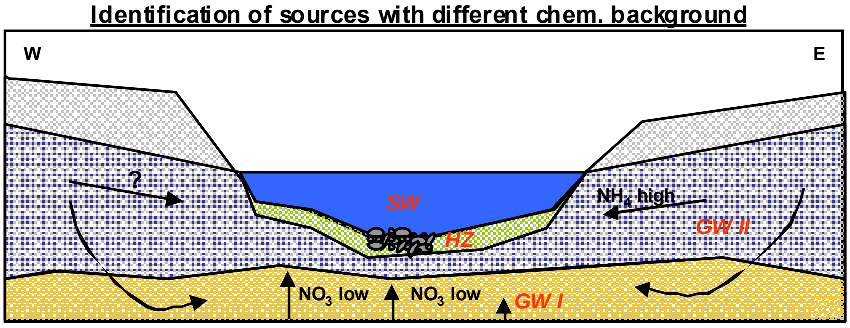
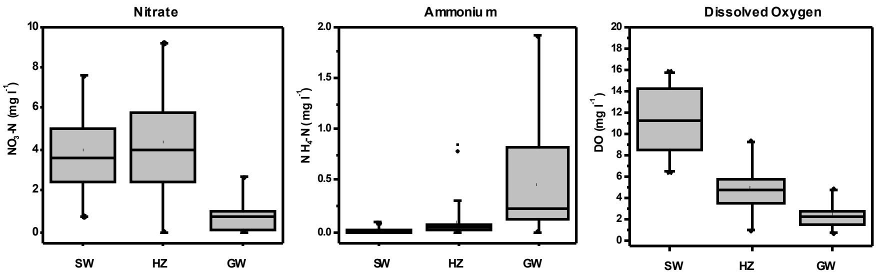
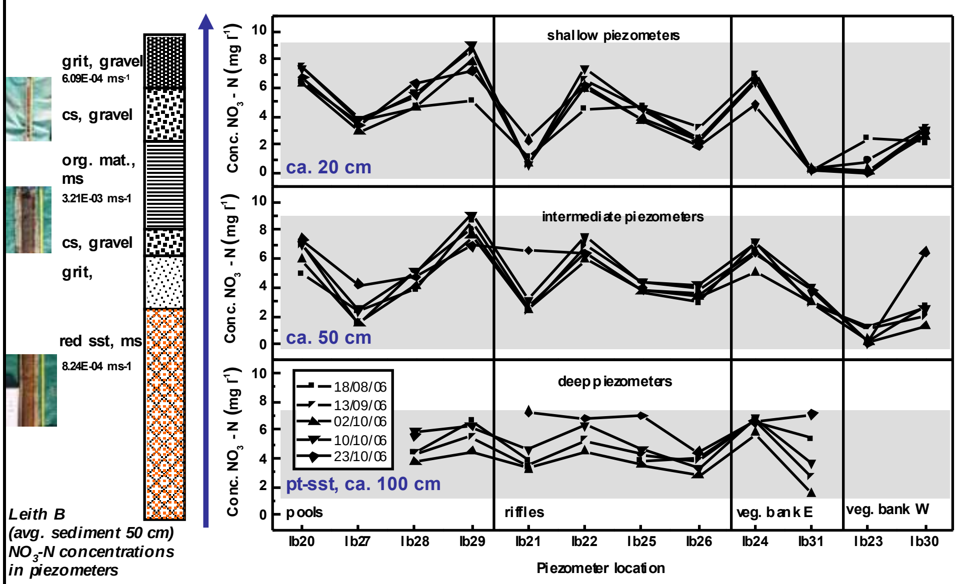
Identification of sources with different chem. background





HZ impact on porewater N along upwelling pathway



Hyporheic Zone – Spatial Extend of Nitrogen Cycling

HZ significantly impacts on nitrate delivery

Highly redox reactive area *(efficient transformations/turnover rates)* exceeds the area usually understood as HZ

HZ: rather static + arbitrary definition of SW-GW mixing with ≥ 10% SW

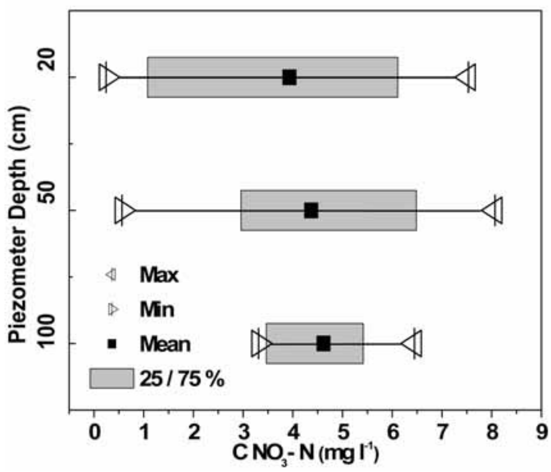
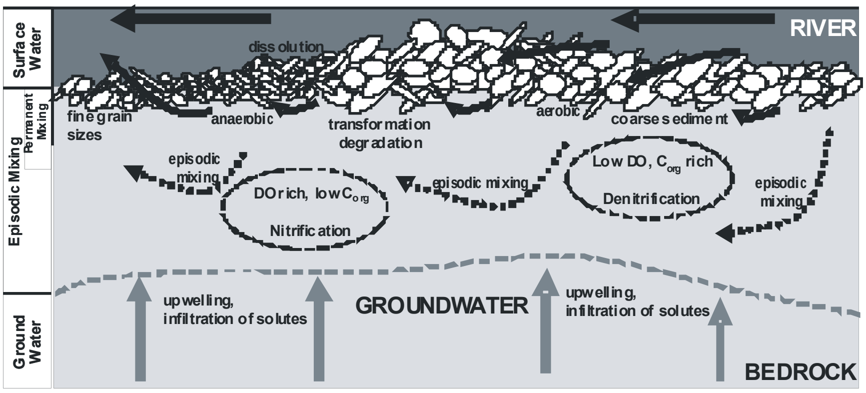


Fig. Alteration of Nitrate concentrations in the upwelling GW of 30 streambed piezometers

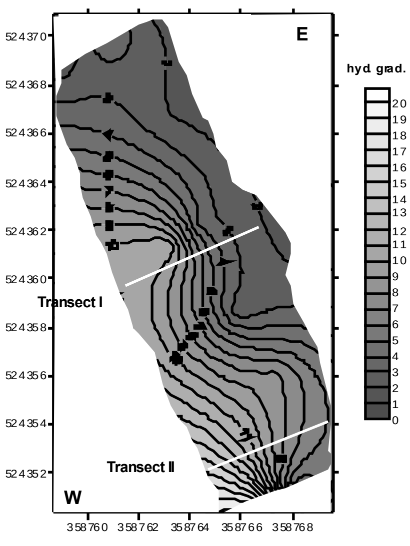
Hyporheic Zone – Revising static concepts

Revised Concept of Hyporheic Zone Impacts on Nutrient Cycling

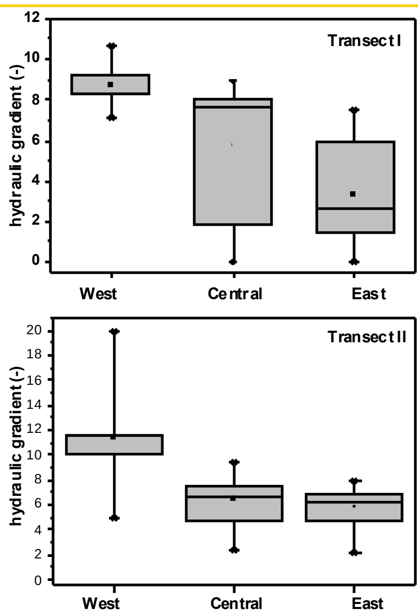


Considering episodic mixing as sufficient source for organic matter and dissolved oxygen

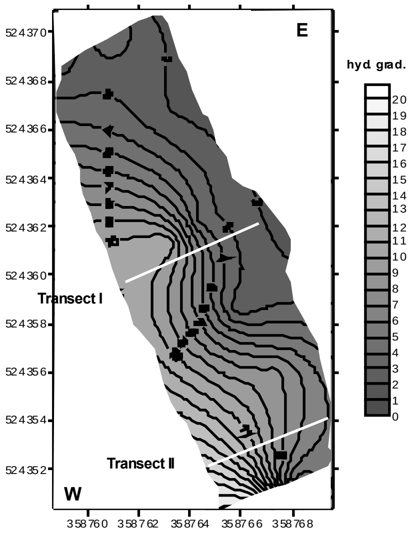
Hyporheic Nitrogen Cycling - Impact of Mixing



Hydraulic gradient in the superficial bed sediments at 18/08/2006



Hyporheic Nitrogen Cycling - Impact of Mixing



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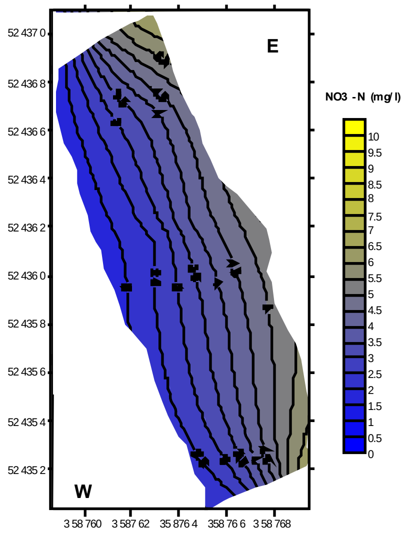
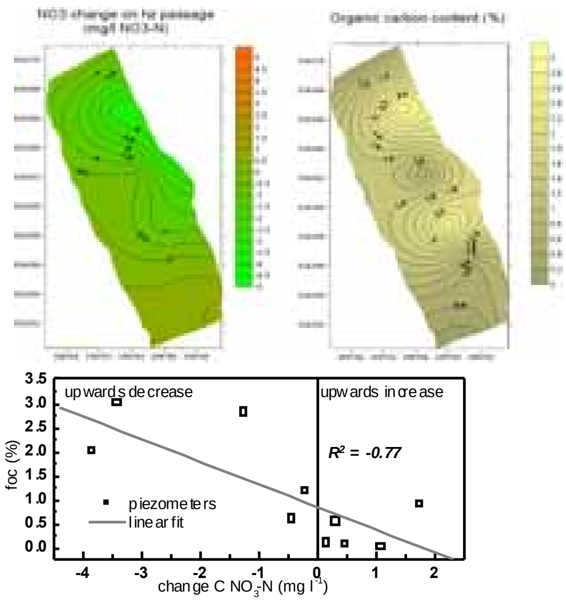


NO_3 – N concentrations 0.5 – 1.0 m
18/08/2006

Hyporheic Nitrogen Cycling - Redox Conditions



Nitrate concentration change along the upwelling groundwater passage:

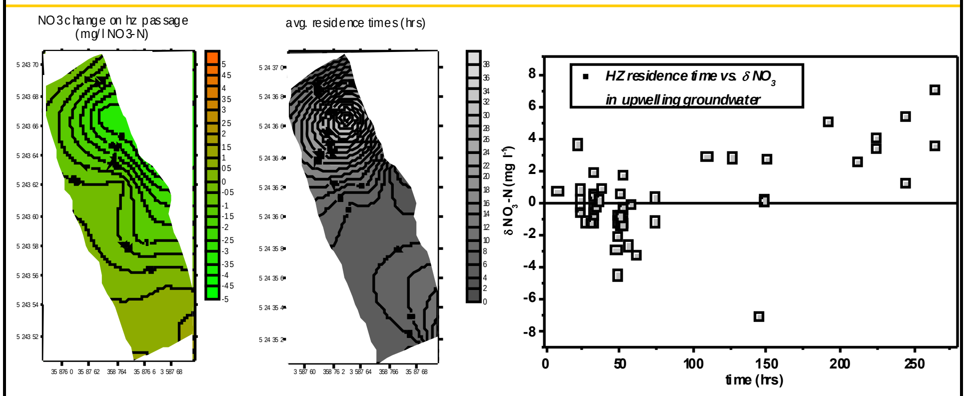
High foc:

upwards decrease

Low foc:

upwards increase or no concentration changes

Hyporheic Nitrogen Cycling - Retention Time



$$T_{resd} = L_{topsed}\, k^{-1}$$

L_{topsed} - *coring, geoph. exploration*

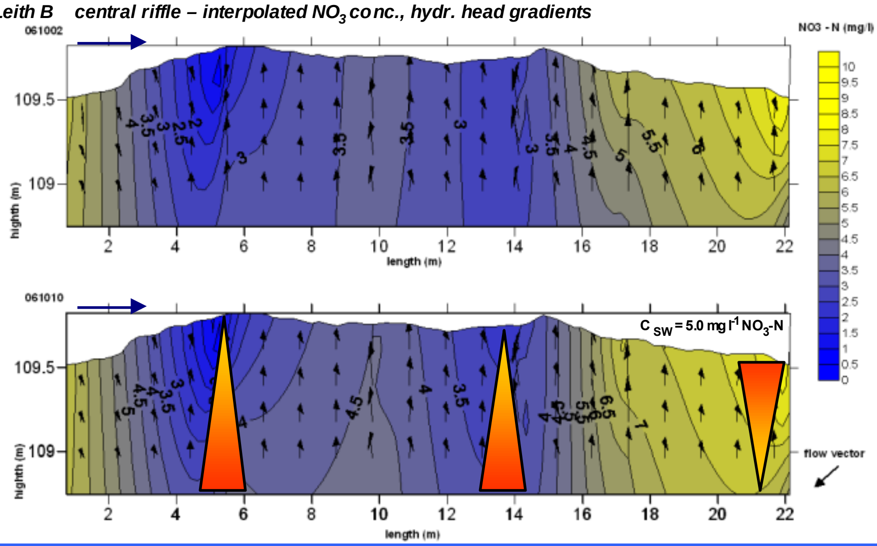
k - *derived by slug tests*

Longer residence times increase the efficiency of redox reactions – for both nitrification / denitrification

Streambed Geomorphology - Parameterisation Proxy

Geomorphic controls on transport and transformation

Leith B central riffle – interpolated NO_3 conc., hydr. head gradients



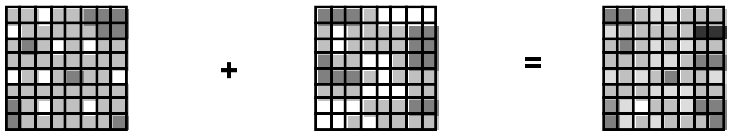
Hyporheic Connectivity

The Principle of Hyporheic Connectivity

Physical connectivity, Riverbed transmissivity

Chemical connectivity, Redox reactivity

HYPORHEIC CONNECTIVITY



High — moderate — low

controlling

- *Exchange flow rates*
- *Mixing intensities*
- *Pathways and residence, reaction times*

controlling:

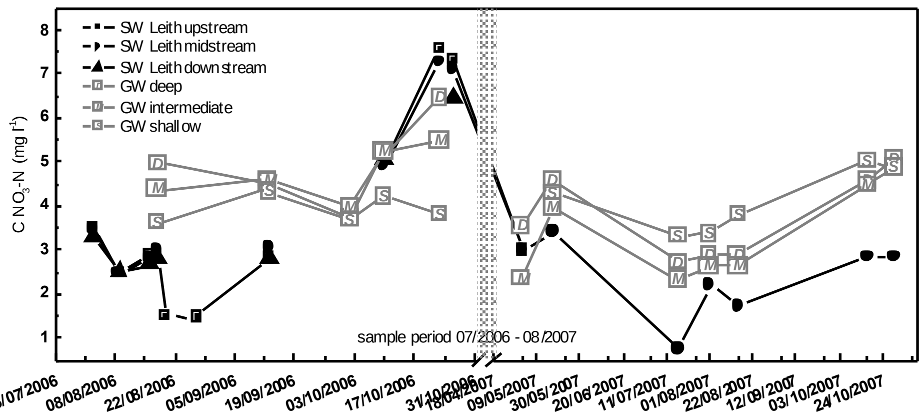
- *Redox environment*
- *Transformation types (Nitrification/Denitrification)*
- *Reaction rates*

controlling:

- *Efficiency of transport, exchange and transformation rates*

Seasonally Variable HZ Implications

Temporally variable implications of nitrate contributions from hyporheic groundwater

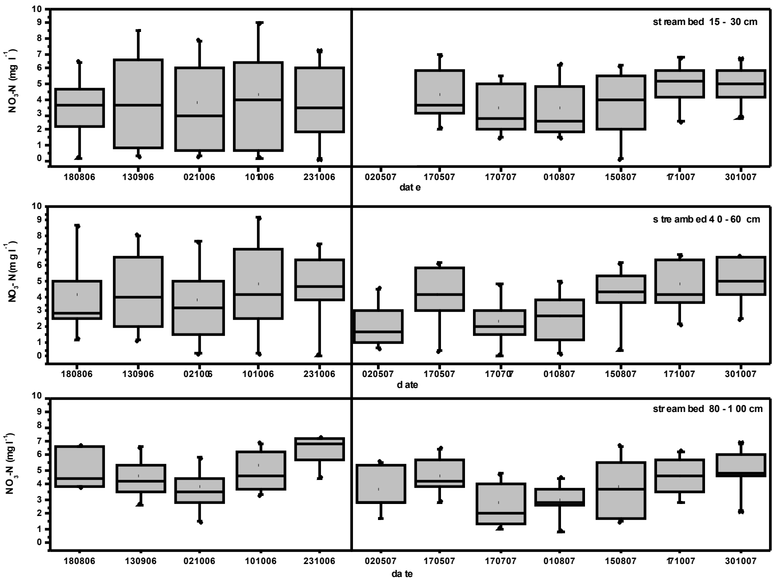


Spontaneous Changes of HZ Conditions

NO_3 conc. changes along upwelling HZ flowpath (due to denitrification, nitrification)

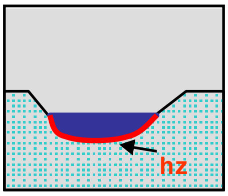
Impact of sediment restructuring after storm events

Concentration alteration disappears



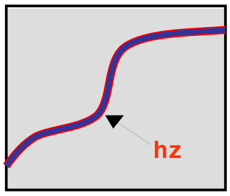
Future Challenges - Model Upscaling

plot scale



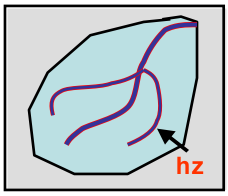
cross section

local scale

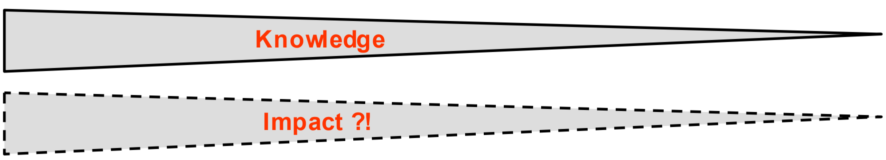


stream reach

regional scale



catchment



How does the impact of hyporheic connectivity controls on exchange fluxes and nutrient amelioration change with scale?

Conclusions

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i. **The hyporheic flow path can have a significant impact on the GW nitrate concentrations (attenuation + enrichment) – effect can be lost due to HZ disturbance**

ii. **Pattern of groundwater nitrate transformations and contributions to surface water are controlled by Hyporheic Connectivity:**

   a) **Physical Riverbed Connectivity:**
      - **Mixing** *(sources of different chem. signature)*
      - **Residence/reaction time** *(active/non-active areas)*
      - **Flow pathways** *(exposure to redox reactive zones)*

   b) **Chemical Reactivity:**
      - **Redox environment** *(Reaction type (Nitrification / Denitrification / Annamox….)*
      - **Reaction efficiency**

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iii. **River(basin) management requires assessment of HZ impact on at least sub-catchment scale - Model based upscaling of experimental small scale knowledge**