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: IWA: Coupled Groundwater - Surface Water Model

Riparian Attenuation:
- up to 40% NO$_3$ reduction in riparian GW
- baseflow contributions up to 20% (from 1% of the catchment)

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

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 and 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 (222Rn)
- Baseflow conditions (May to October)
- GW & SW < 10 mg l⁻¹ NO₃-N
HZ Nitrogen Cycling – the GW Perspective

Experimental Setup - River Leith

Two sites - physical and chemical properties:

- Porosity, compaction, grain size distribution, hydr. cond.
- Cores: NO₃, NH₄, TNTON concentrations (foc. CEC (J. Smith))
- Ca. 140 piezometer + gw boreholes in riparian floodplain:
  - Hydraulic gradients, slug tests, temperature and radon survey
  - NO₃, NH₄, TNTON, DO, ORP, ph (fortnightly)
- DET probes (sub cm scale)
- Tracer injection: salt, rhodamine – flow velocities, residence times

Identification of sources with different chem. background

Nitrate Ammonium Dissolved Oxygen

NO₃-N (mg/l) NH₄-N (mg/l) DO (mg/l)

SW HZ GW SW HZ GW SW HZ GW
HZ impact on porewater N along upwelling pathway

- **Shallow piezometers**: ca. 20 cm
- **Intermediate piezometers**: ca. 50 cm
- **Deep piezometers**: pt-sst, ca. 100 cm

**Piezometer location**
- Leith B (avg. sediment 50 cm)
- NO\textsubscript{3}-N concentrations in piezometers
- HZ: 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

**HZ significantly impacts on nitrate delivery**

- **Hyporheic Zone – Spatial Extend of Nitrogen Cycling**
- **HZ** significantly impacts on nitrate delivery
- **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

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

\[ T_{\text{resd}} = L_{\text{topsed}} k^{-1} \]

- \( L_{\text{topsed}} \) - 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

C SW = 5.0 mg l\(^{-1}\) NO\(_3\)-N

Flow vector
Hyporheic Connectivity

The Principle of Hyporheic Connectivity

Physical connectivity, Riverbed transmissivity

Chemical connectivity, Redox reactivity

HYPORHEIC CONNECTIVITY

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

Sample period 07/2006 - 08/2007
Spontaneous Changes of HZ Conditions

NO₃ conc. changes along upwelling HZ flowpath (due to denitrification, nitrification)

Impact of sediment restructuring after storm events

Concentration alteration disappears

Future Challenges - Model Upscaling

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

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 path ways (exposure to redox reactive zones)
   b) Chemical Reactivity:
      • Redox environment (Reaction type (Nitrification / Denitrification / Anamox...))
      • Reaction efficiency

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

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