Natural attenuation potential of the urban hyporheic zone

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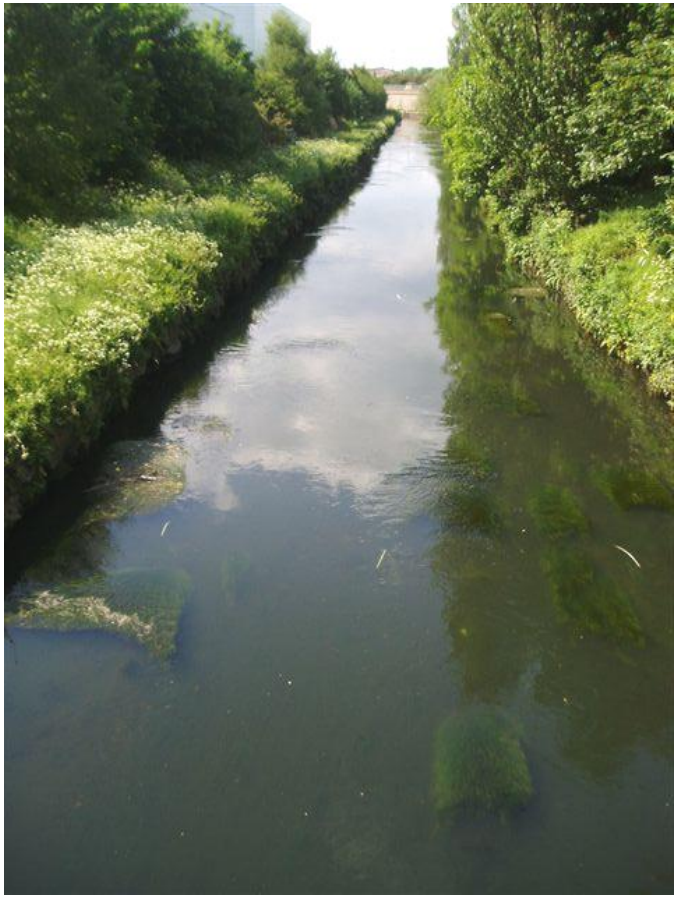
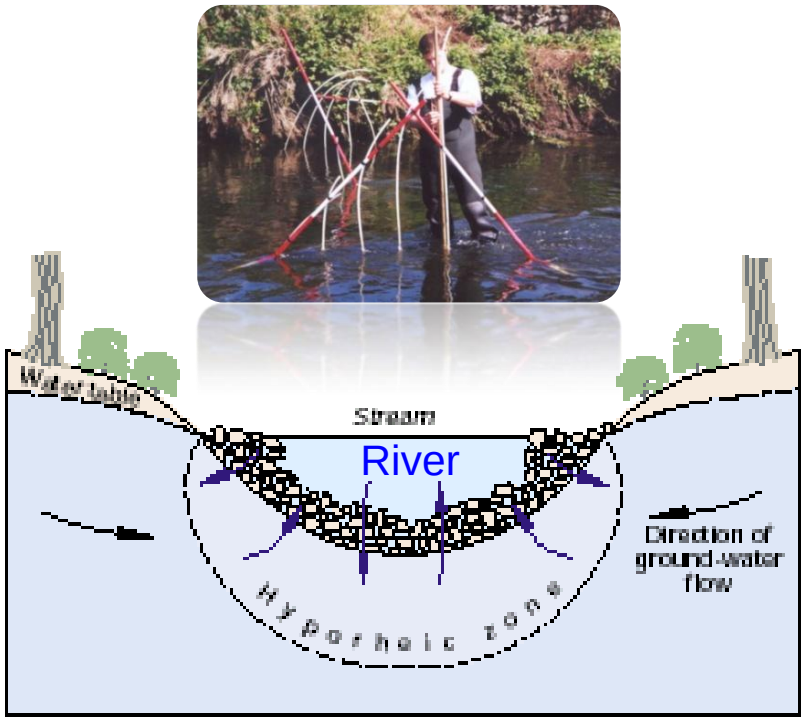
Outline



- Rationale
- Our hyporheic zone sites
  - SWITCH HZ site
- Results
  - Natural attenuation, or not?
- Implications

Rationale

- Why study the natural attenuation potential of the urban HZ ?
- It potentially offers:
  - A natural system for self-purification of the urban water cycle
  - Cost-effective treatment of discharging groundwater plumes in river baseflows



(USGS Circular 1139, 2001)

- Availability of oxygen, organic carbon, nutrients, bacteria
- Steep redox, pH, chemical gradients
- Biogeochemical reactivity
- Dynamic flows

Urban hyporheic zone sites, Birmingham

SWITCH HZ site

7 km city-scale reach

VOC plume site

Motorway run-off site

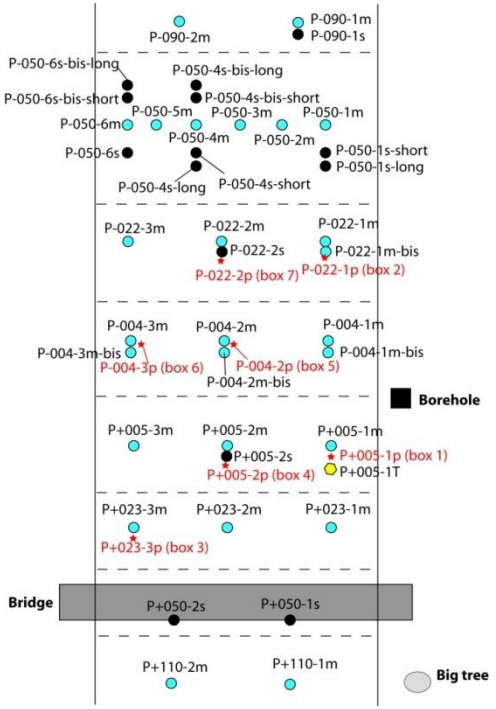
SWITCH HZ site

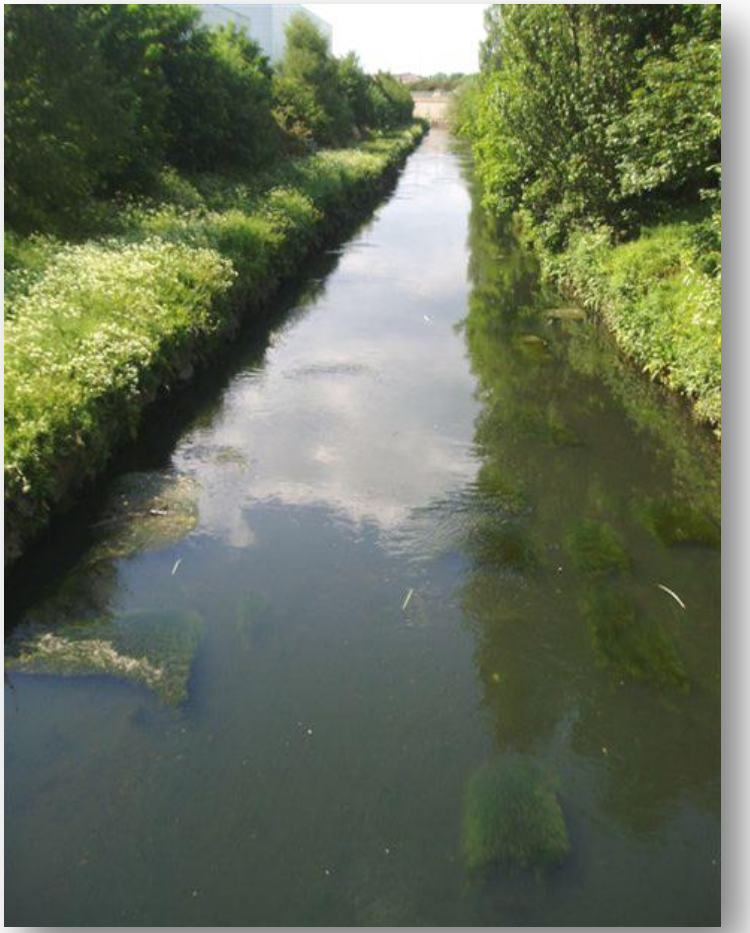
River Tame, Birmingham, UK

UNIVERSITY OF BIRMINGHAM

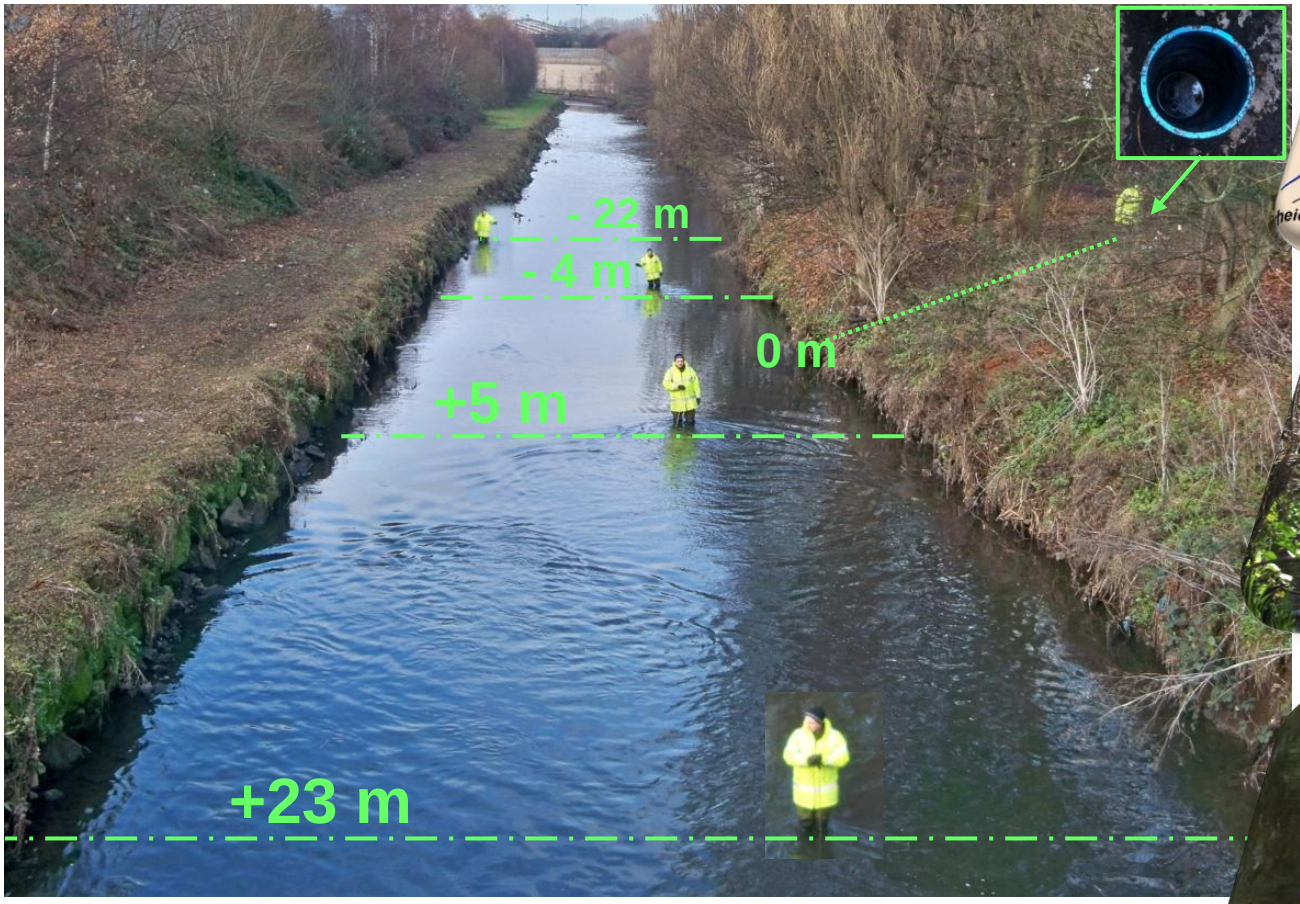
SWITCH

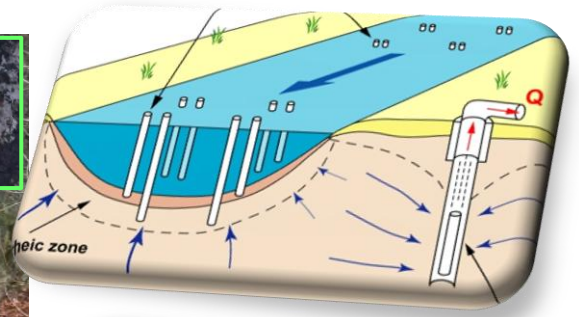
Environment Agency





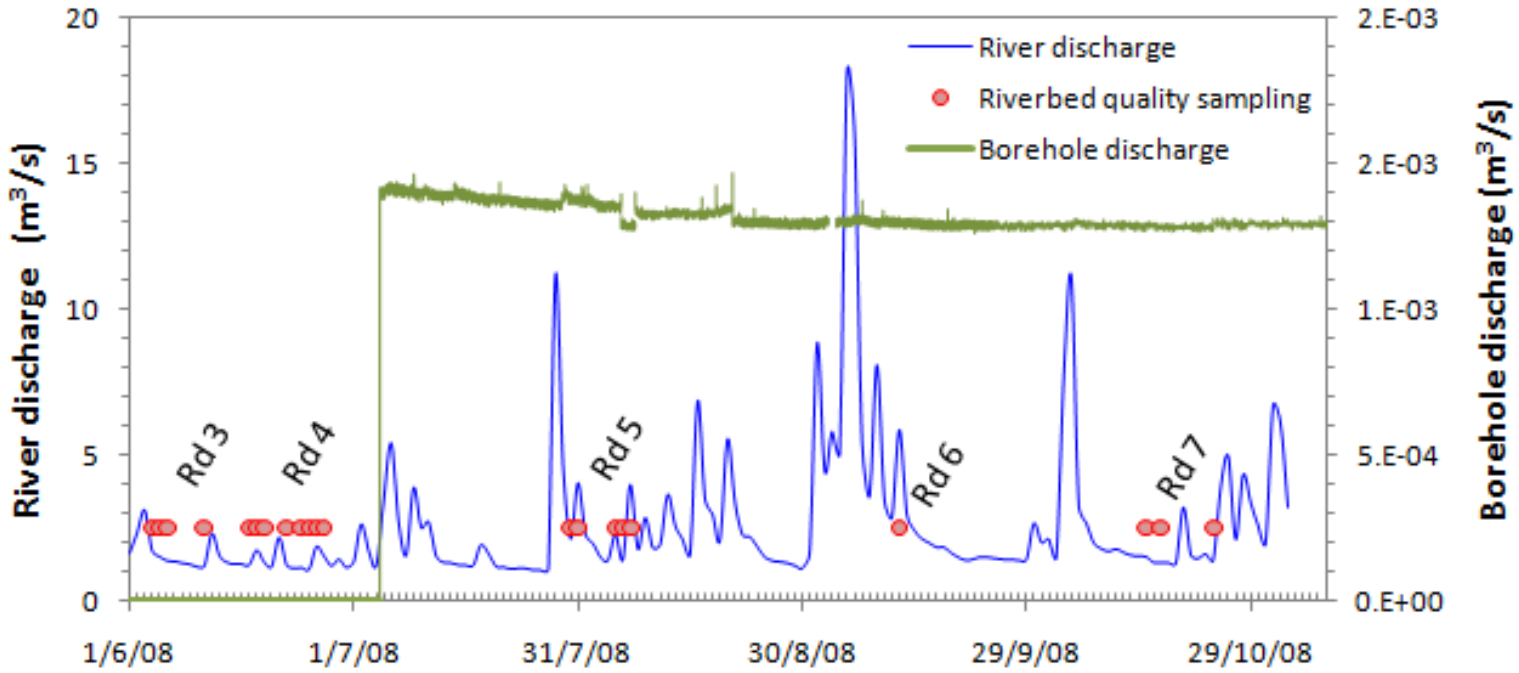
Transects and extraction well





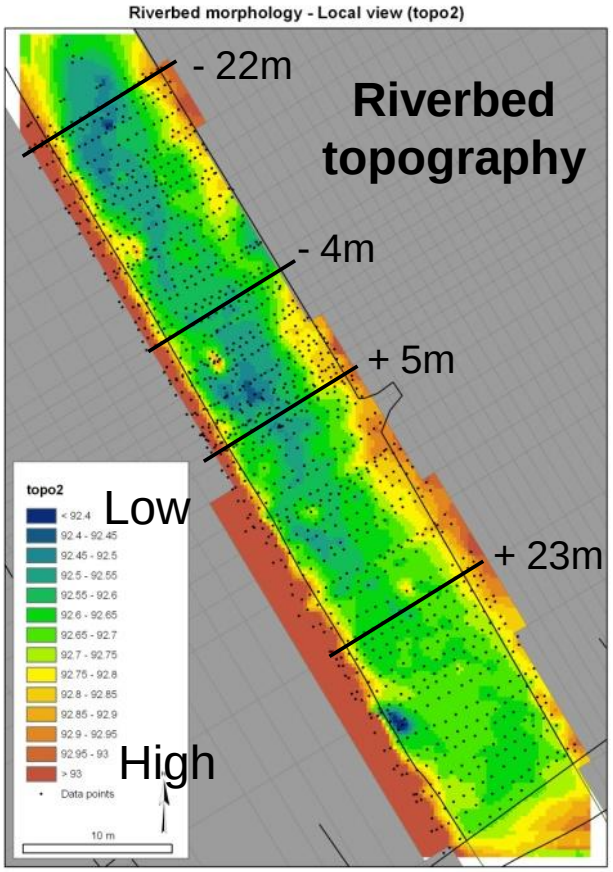
Flows, monitoring rounds

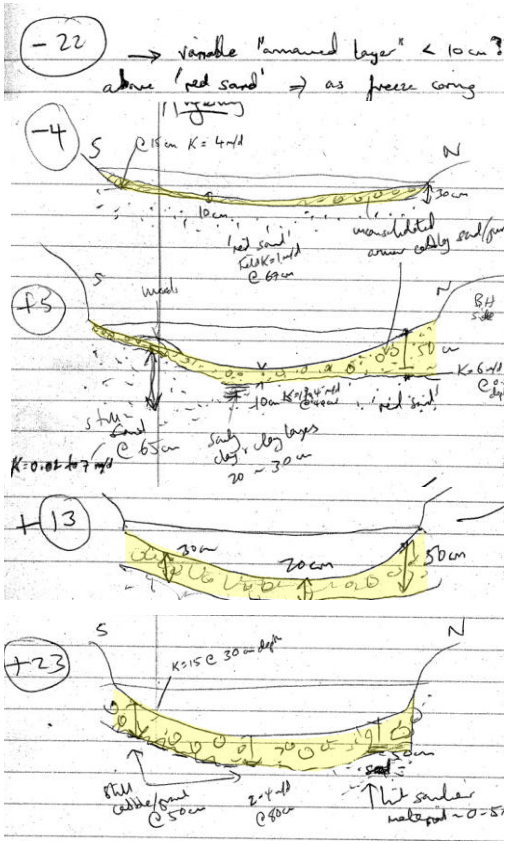
- Urban river flow “natural variability” largely masked influences of the extraction well on HZ flow regime

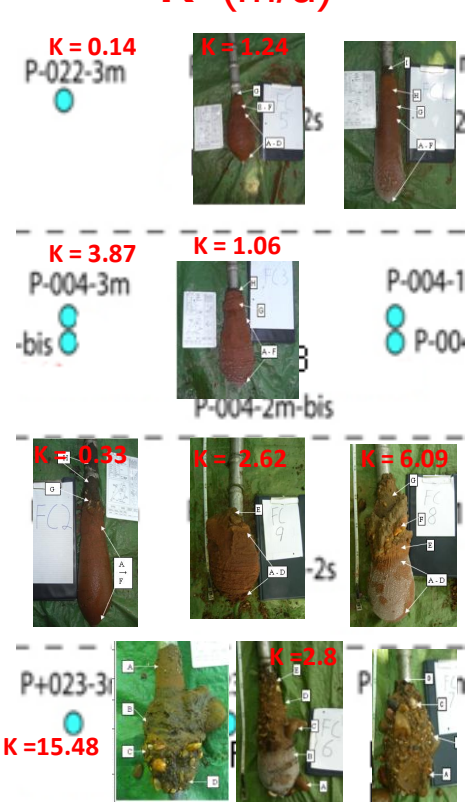


Characterisation

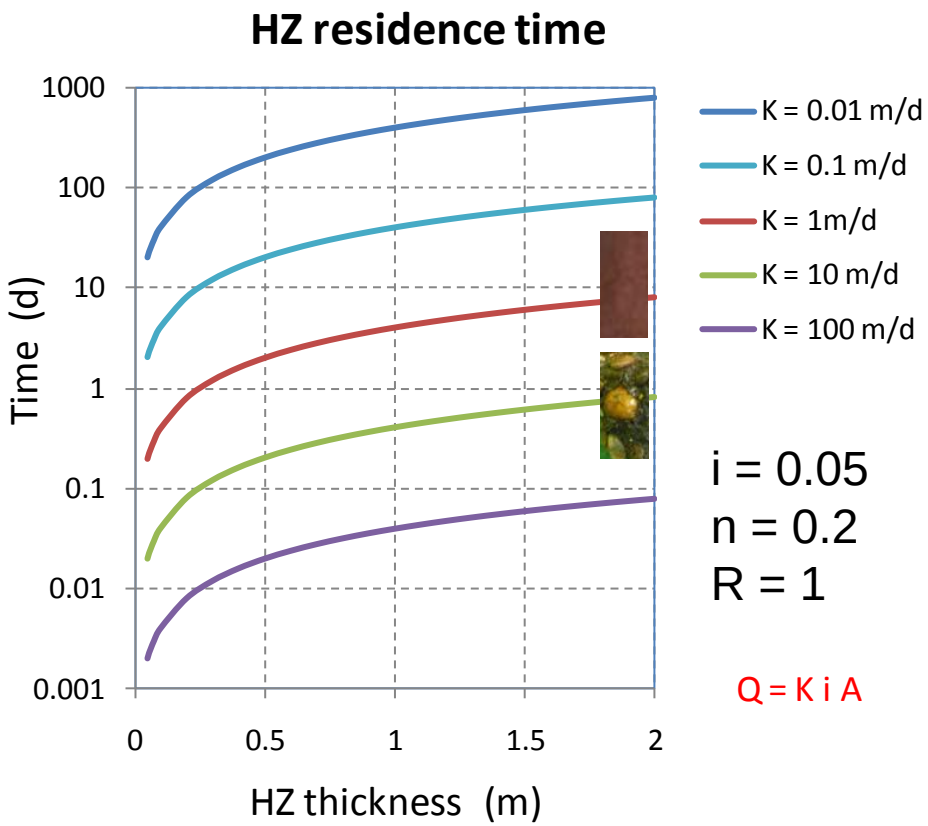
- Topography
- Geology
- Permeability, flow







HZ residence time for attenuation



i = 0.05
n = 0.2
R = 1

Q = K i A

SWITCH HZ site

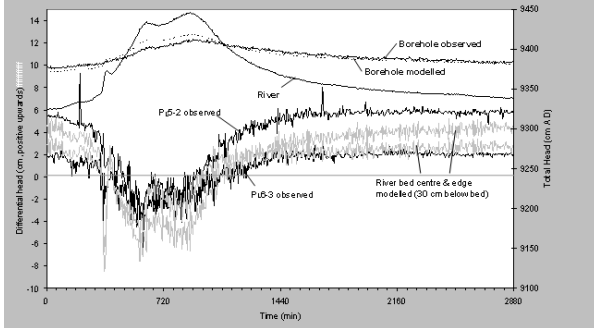
- **Hydraulic conductivity (*K*)** slug tests
  - Range: 0.14 – 15.5 m/d (n = 9)
    - Arithmetic mean 3.73 m/d
    - geometric mean 1.76 m/d
    - median 2.62 m/d

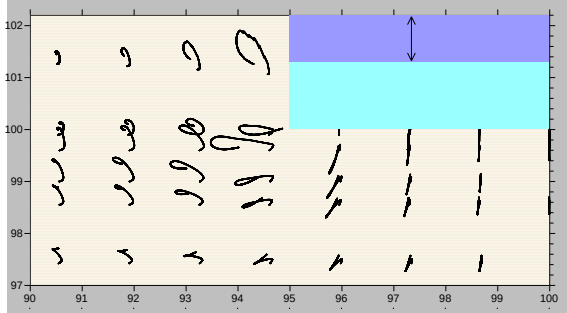
City reach study

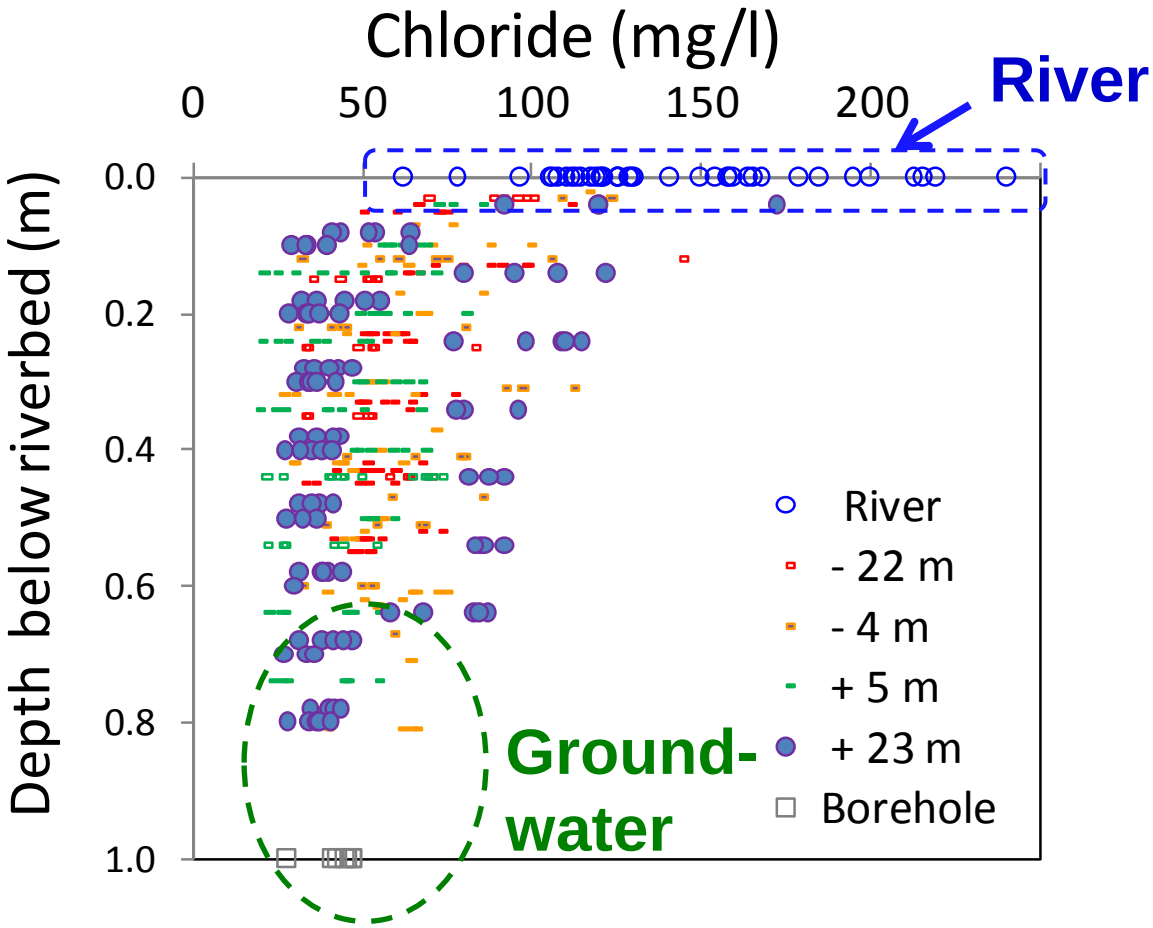
- **Hydraulic conductivity (*K*)** slug tests
  - Range: 0.08 – 23 m/d (n = 44)
    - Arithmetic mean 3.13 m/d
    - geometric mean 1.26 m/d
    - median 1.34 m/d
- **Hydraulic gradients (*i*)** across riverbed
  - Range: -0.03 to 0.28
    - + is baseflow discharge to river
  - Mean: 0.056 $\pm$ 0.06

Surface-water entry to the riverbed

- Chloride provides a good tracer of the interaction
- Flow observations
- Modelling

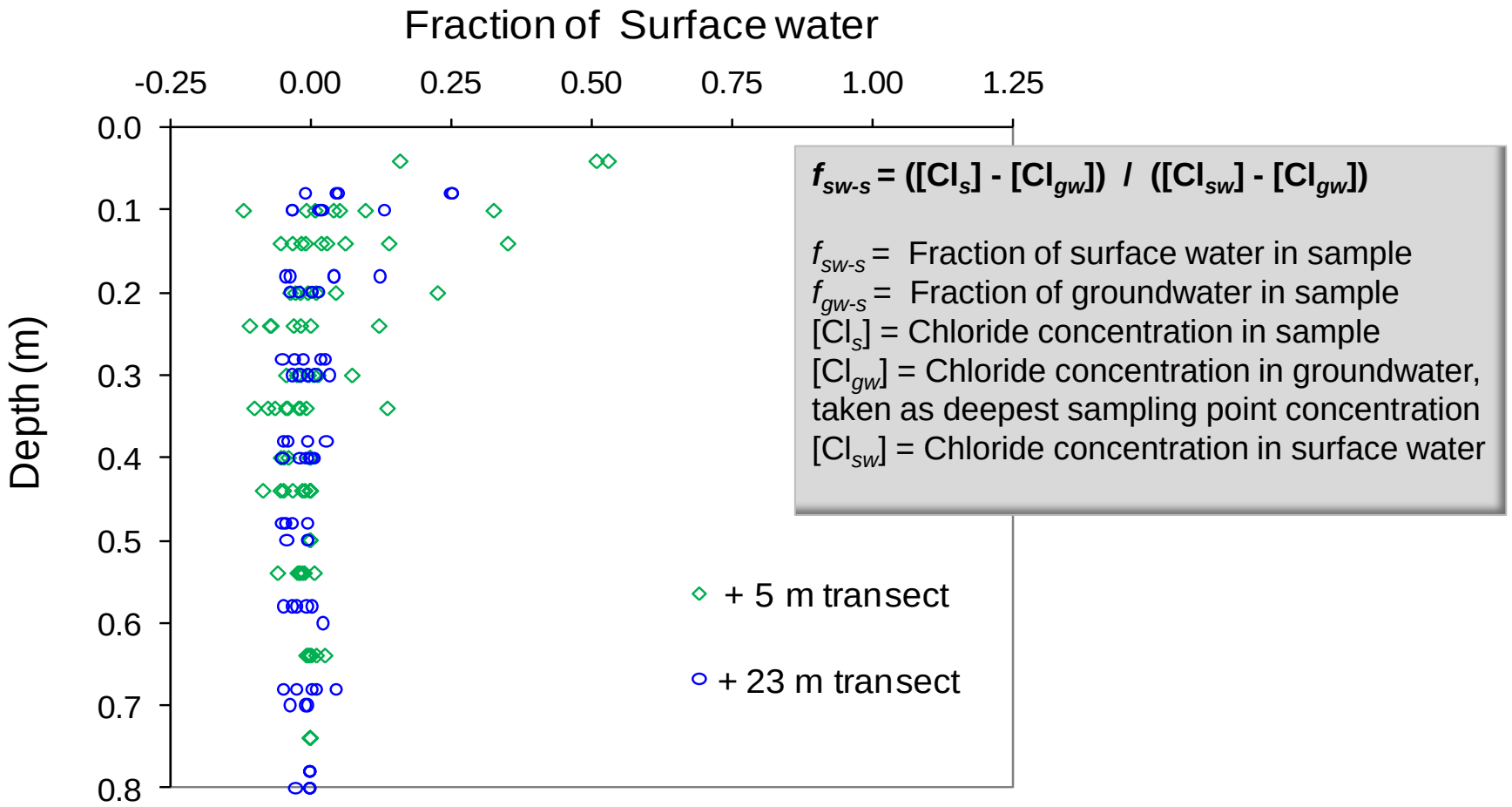






Surface water mixing into riverbed

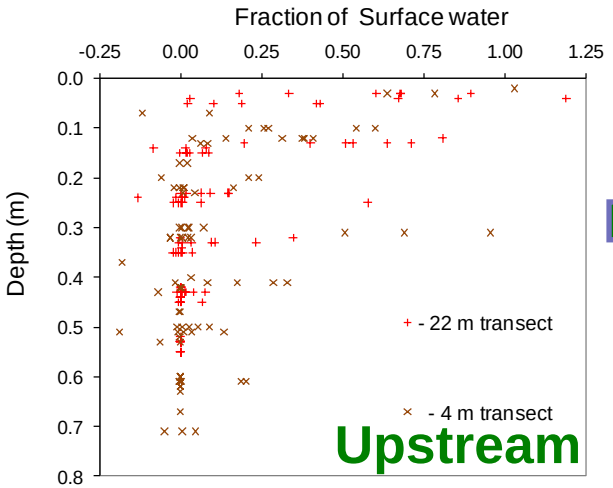
- **Surface-water fraction** estimated from groundwater - surface-water end member chloride concentrations

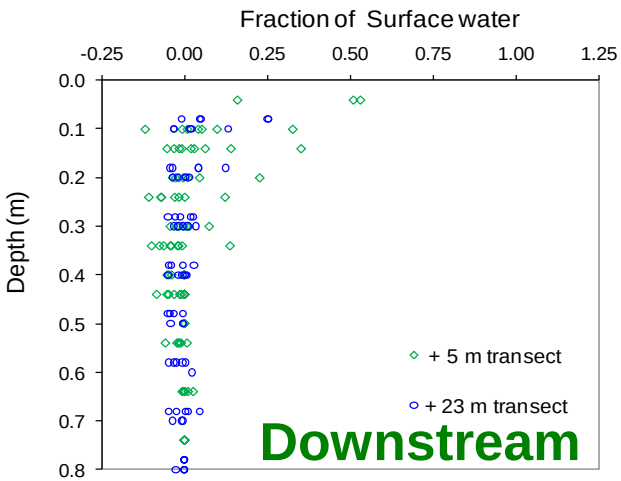


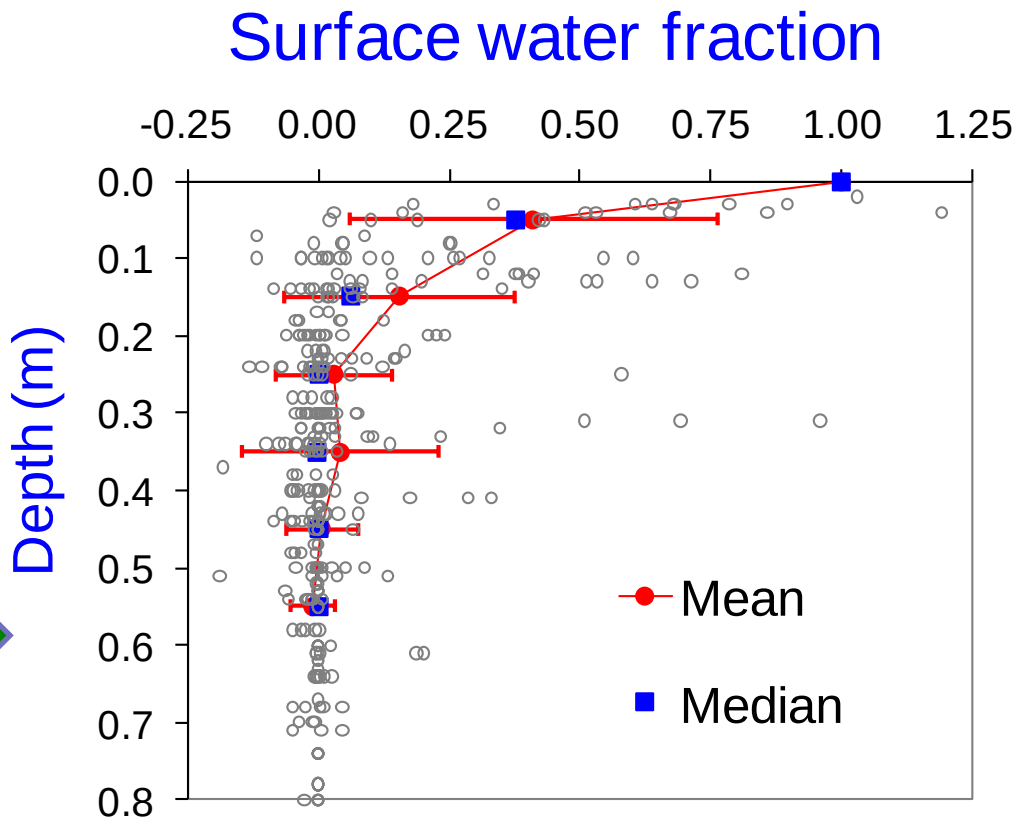
$f_{sw\text{-}s} = ([Cl_s] - [Cl_{gw}]) \;/\; ([Cl_{sw}] - [Cl_{gw}])$

$f_{sw\text{-}s}$ = Fraction of surface water in sample
$f_{gw\text{-}s}$ = Fraction of groundwater in sample
$[Cl_s]$ = Chloride concentration in sample
$[Cl_{gw}]$ = Chloride concentration in groundwater, taken as deepest sampling point concentration
$[Cl_{sw}]$ = Chloride concentration in surface water

Surface water fraction in riverbed

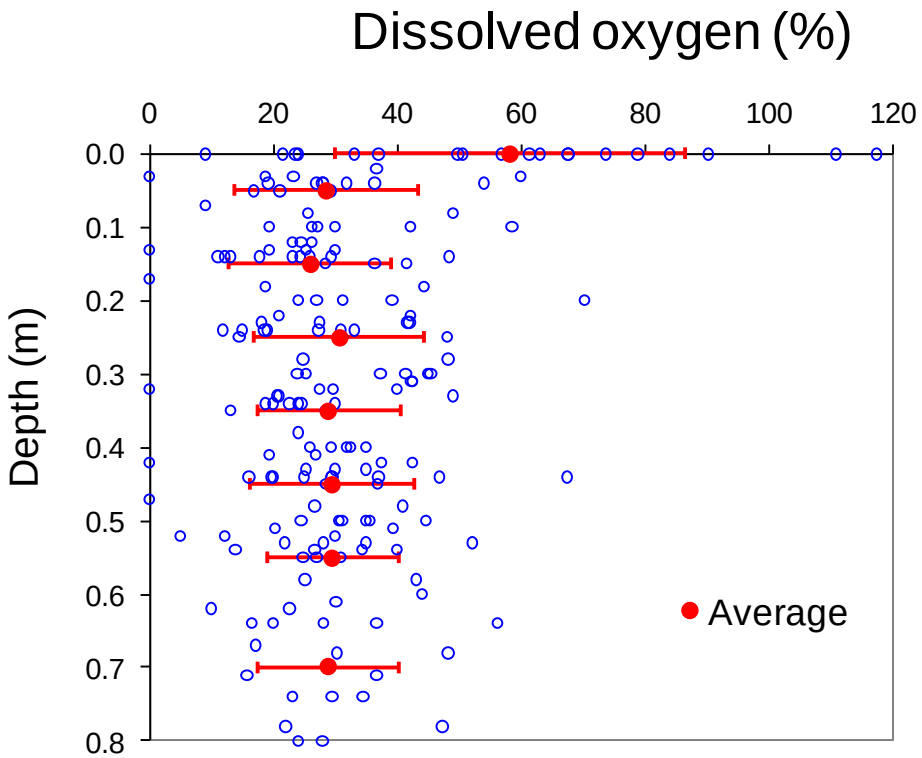


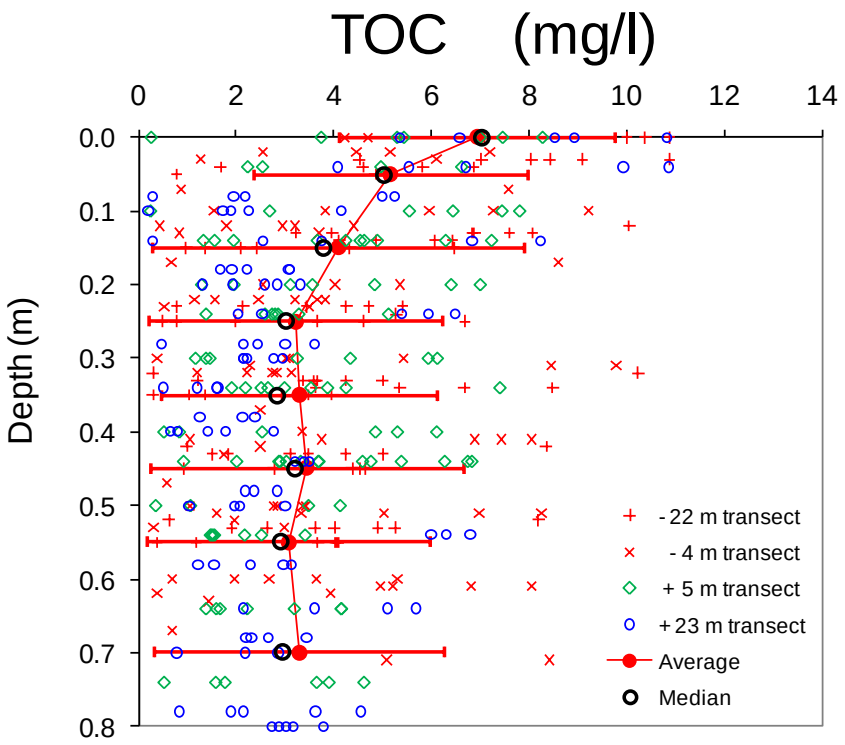




Reactive attenuation in the HZ

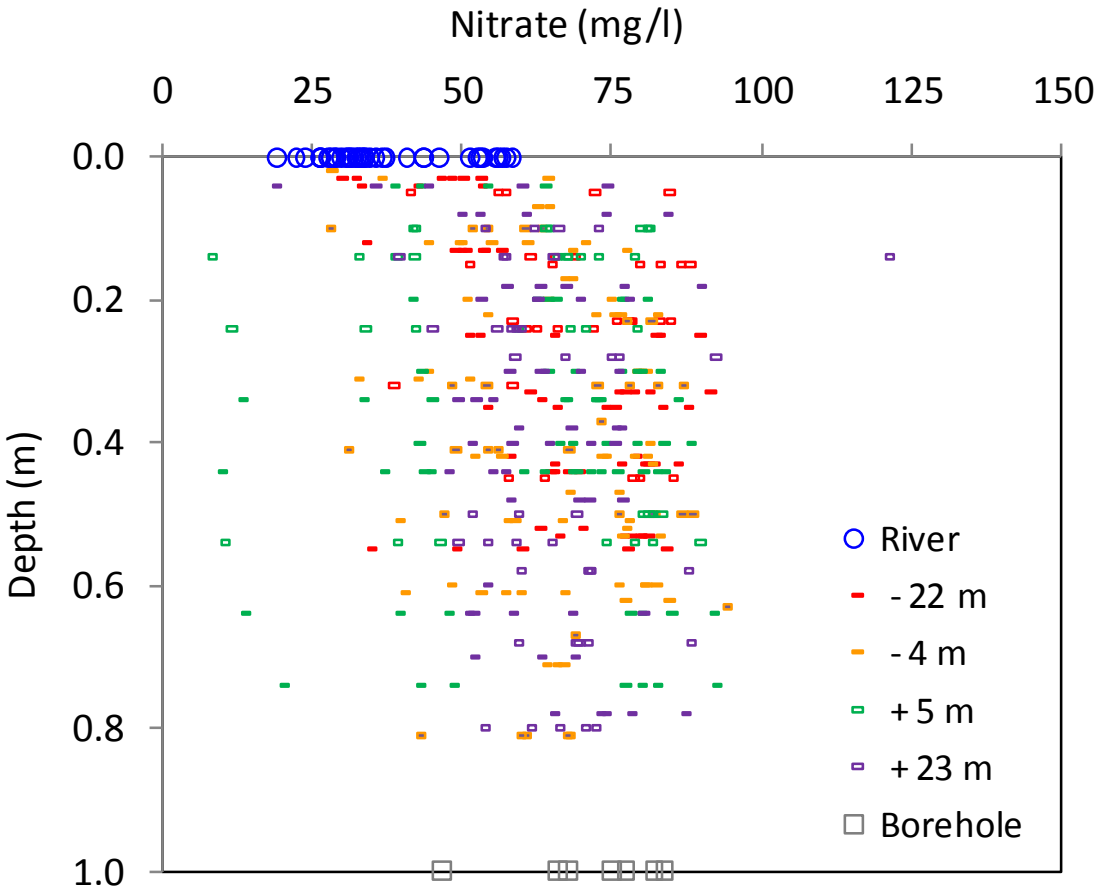
- Low oxic conditions except near to riverbed surface
- Organic carbon elevated and variable





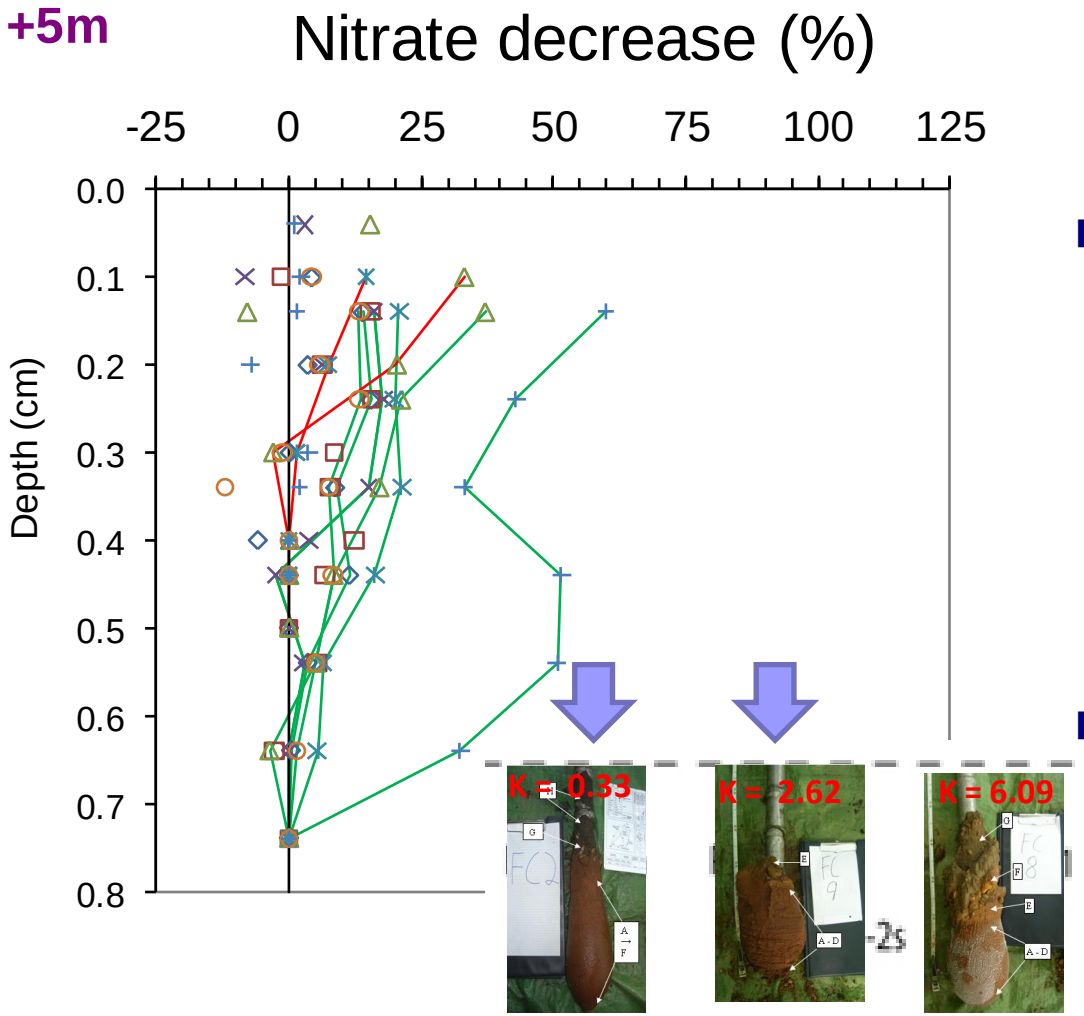
Nitrate

- Dilution by surface-water mixing, or attenuation due to denitrification ?



Attenuation in the HZ

- Denitrification



- % concentration decrease plots are corrected for surface water dilution (use the chloride data)
- Decrease indicates chemical removal due to reaction

Surface water mixing (Cl)

Nitrate attenuation

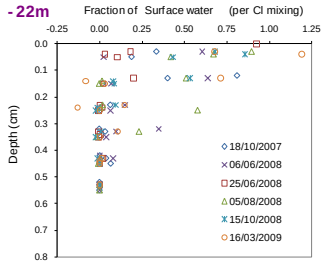
Sulphate attenuation

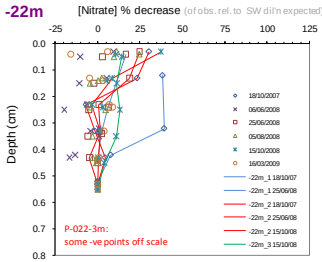
- 22 m

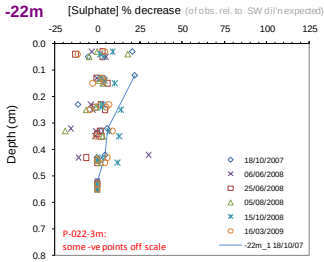
- 4 m

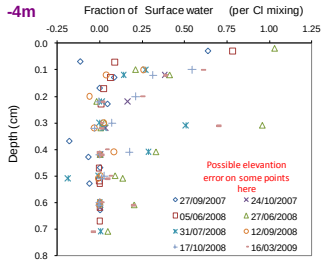
+ 5 m

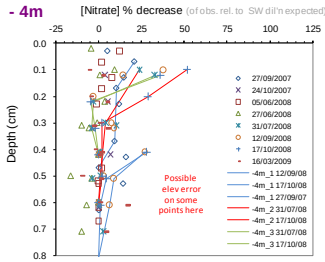
+ 23 m

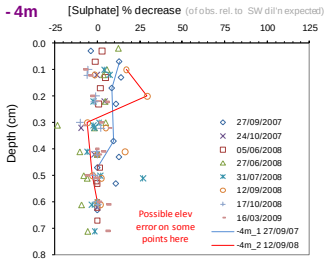


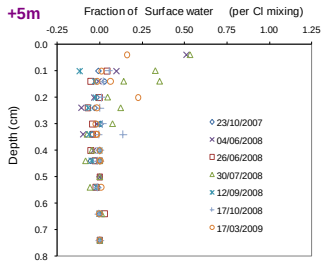


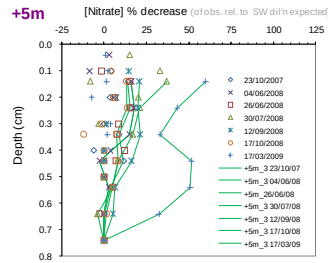


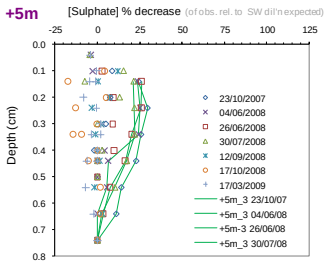


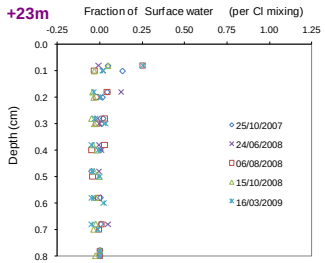


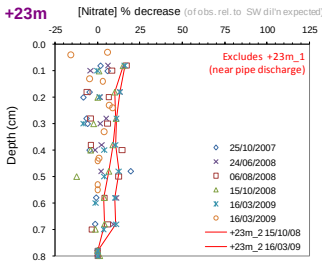


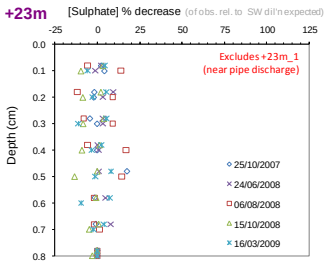






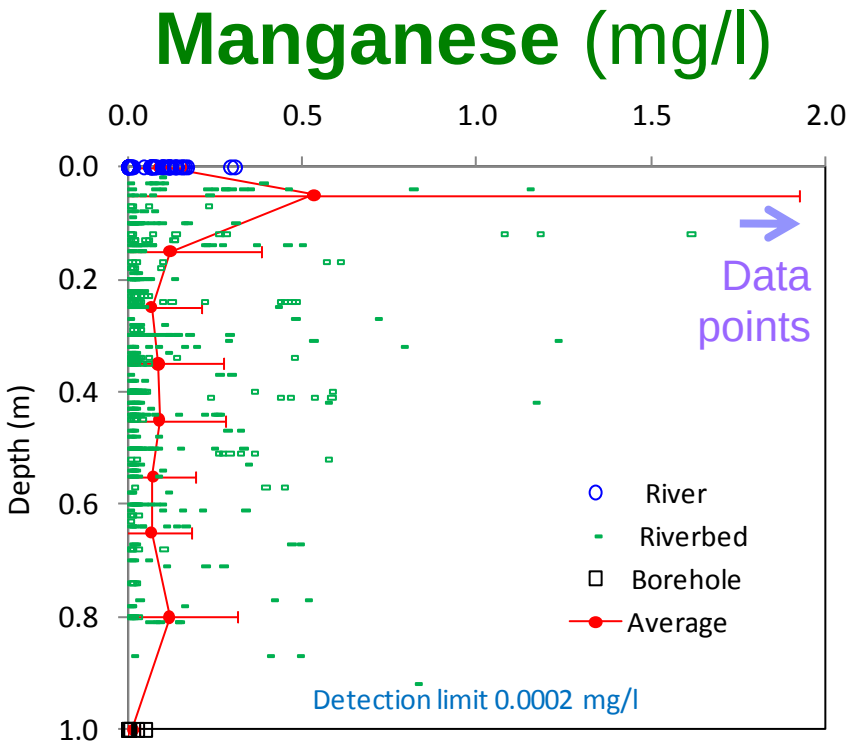


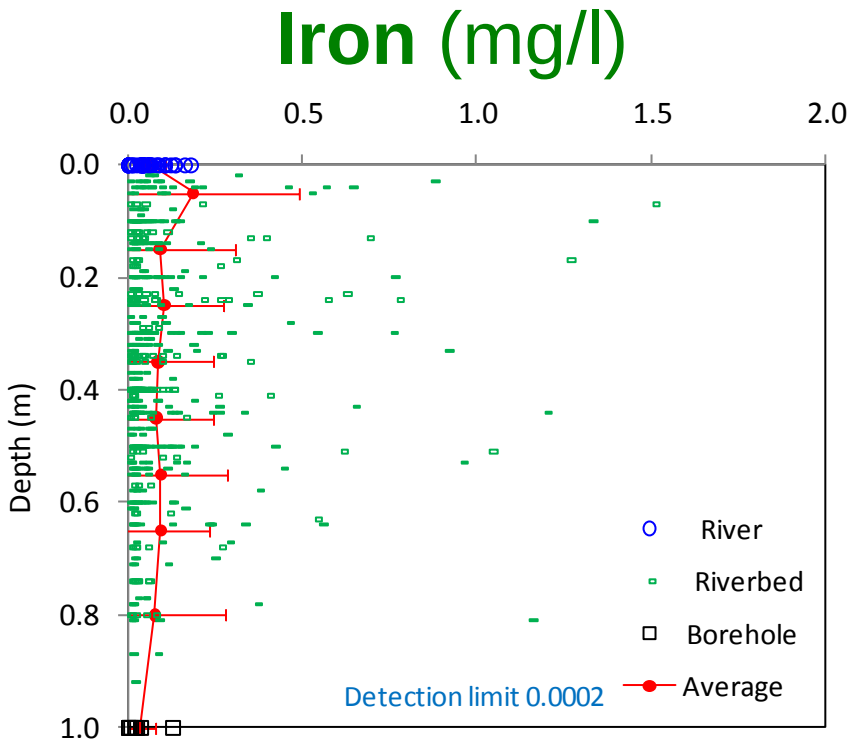




Manganese or iron reduction

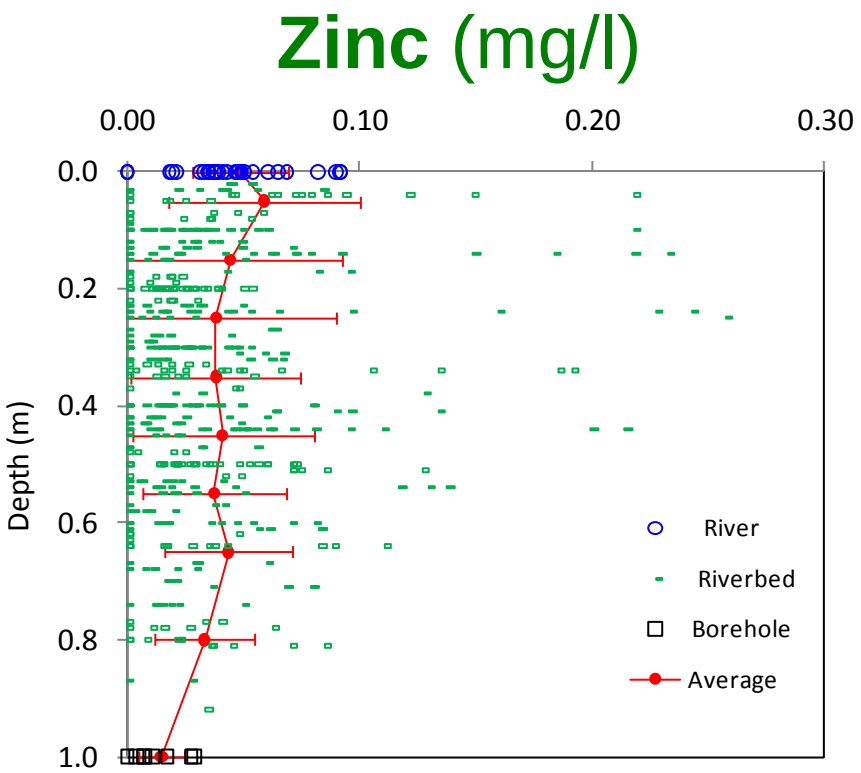
- Localised occurrence may drive oxidation of contaminant / chemical / TOC

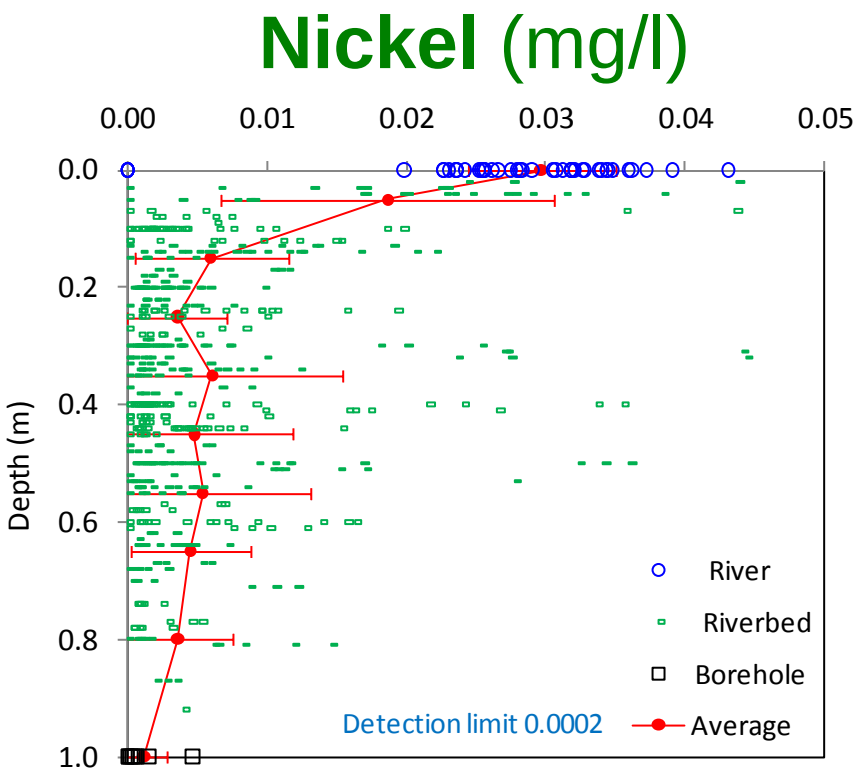




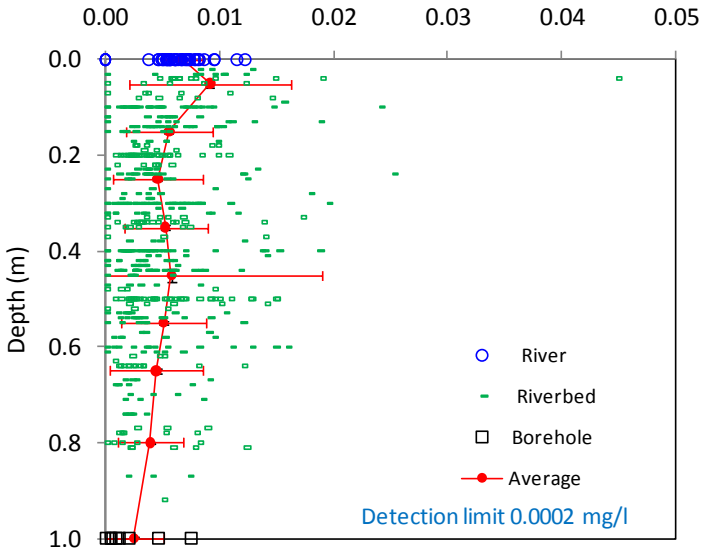
Toxic metals

- Groundwater discharge through the urban HZ
  - **For better, or for worse?**

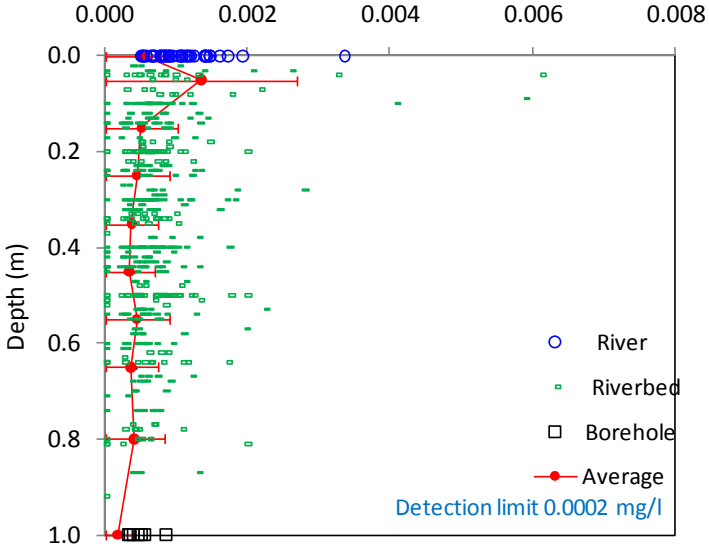




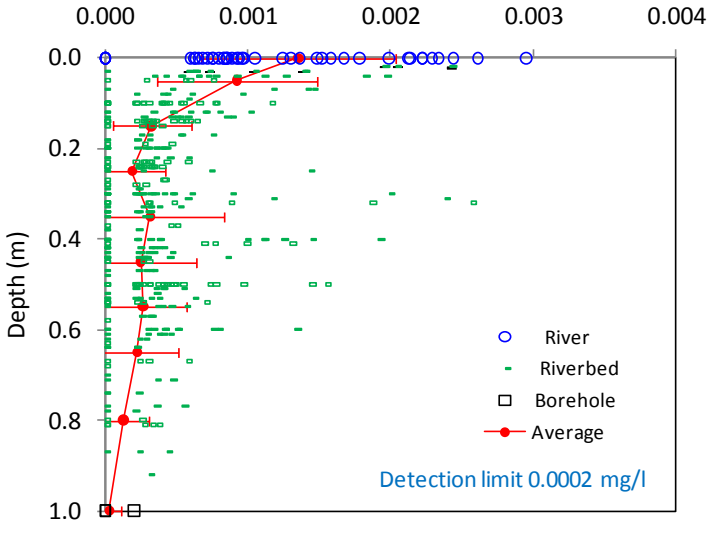
Copper (mg/l)



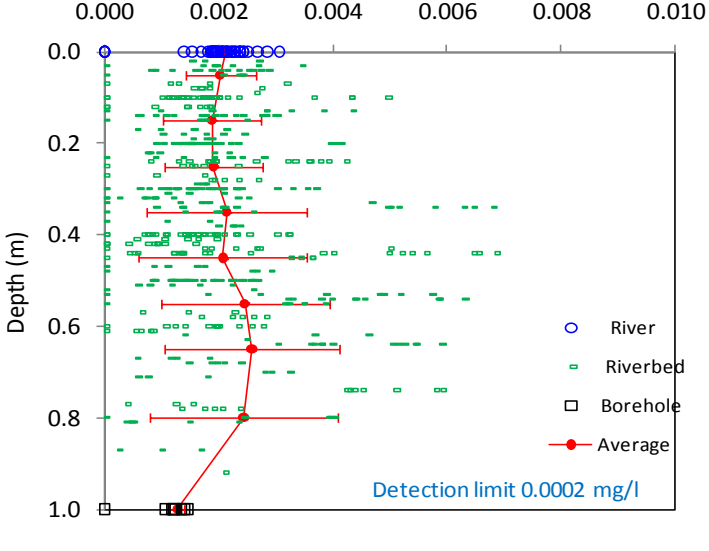
Chromium (mg/l)



Antimony (mg/l)



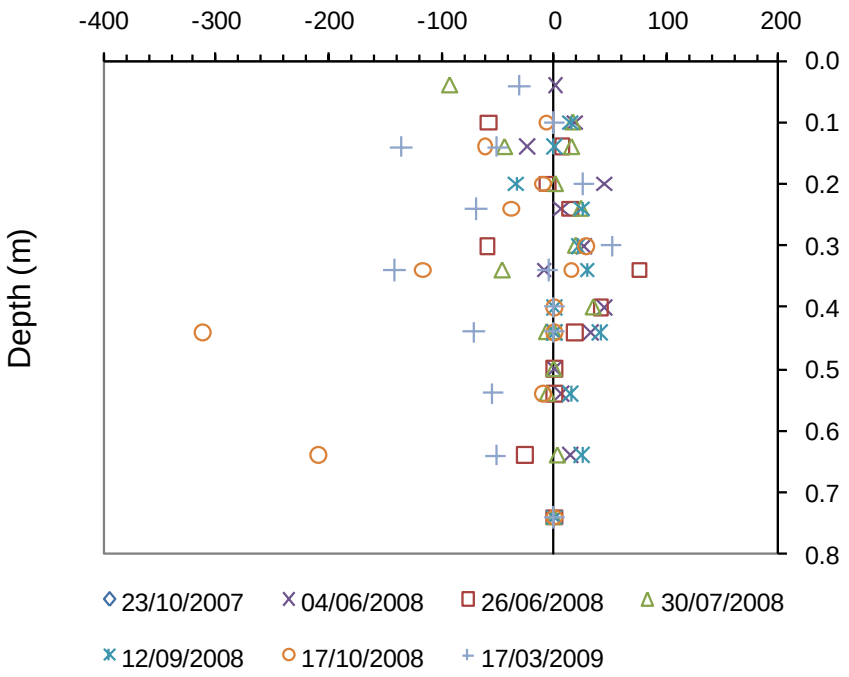
Arsenic (mg/l)



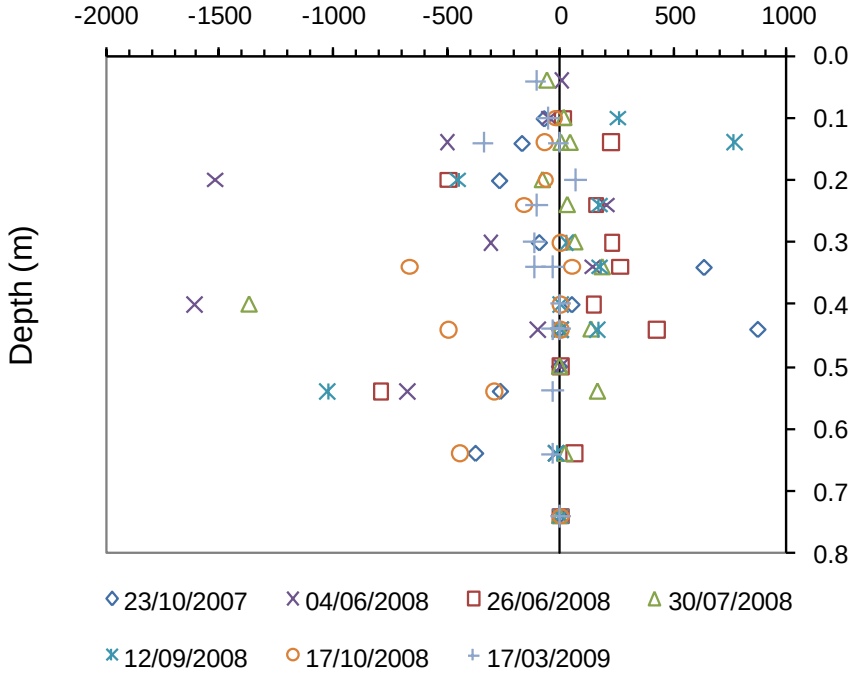
Hyporheic zone “treatment”
- For better, or for worse?

- % Decrease plots (allowing for surface water mixing)

Zinc % decrease

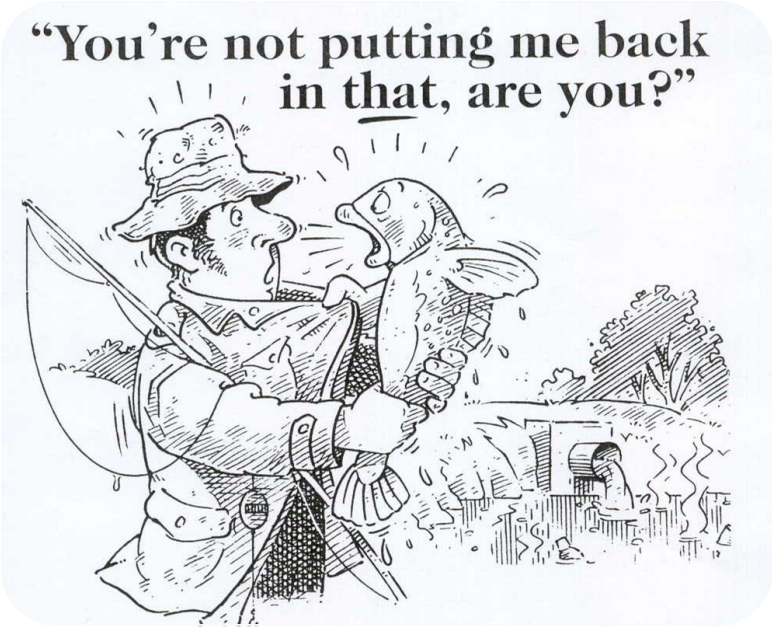


Nickel % decrease



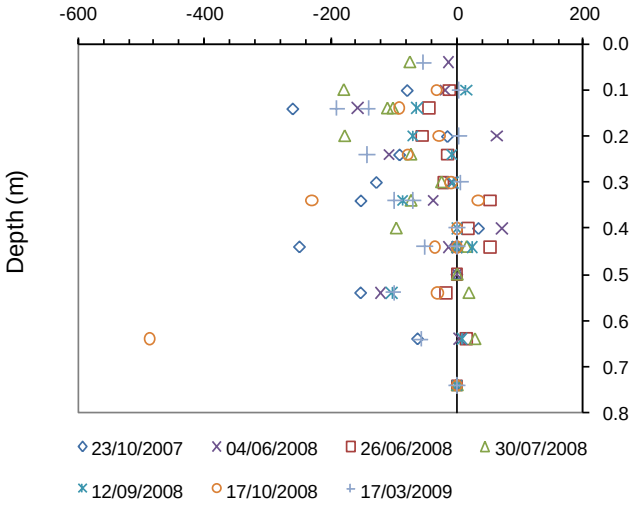
For worse...

- 200 + years of industrial effluent discharge to river
- Historic urban-contaminated sediment influences

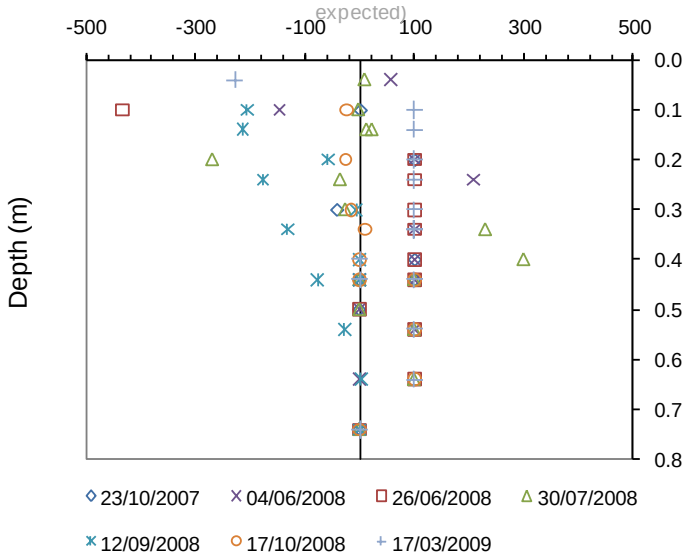


From: Anglers Cooperative Association

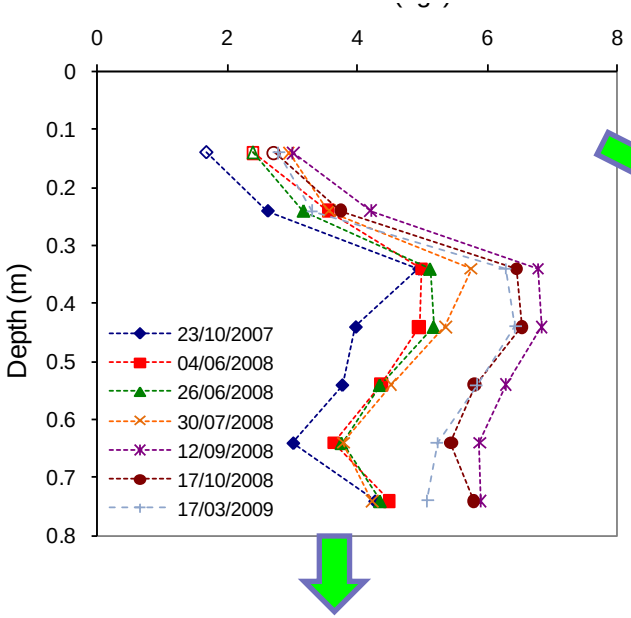
Copper % decrease



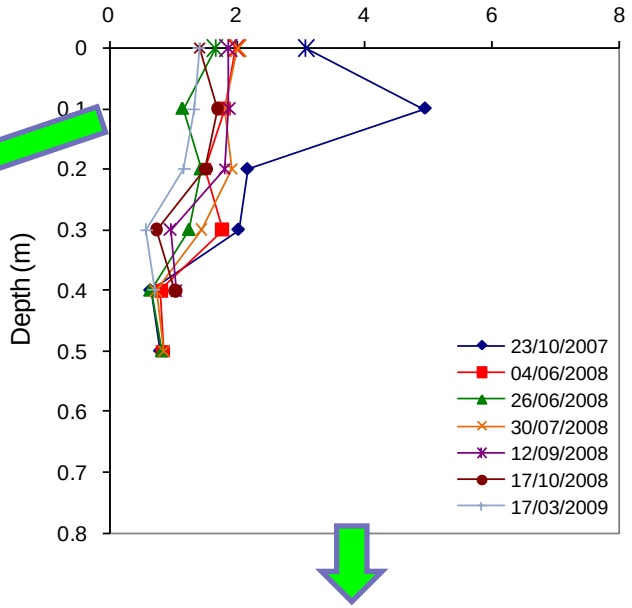
Antimony % decrease



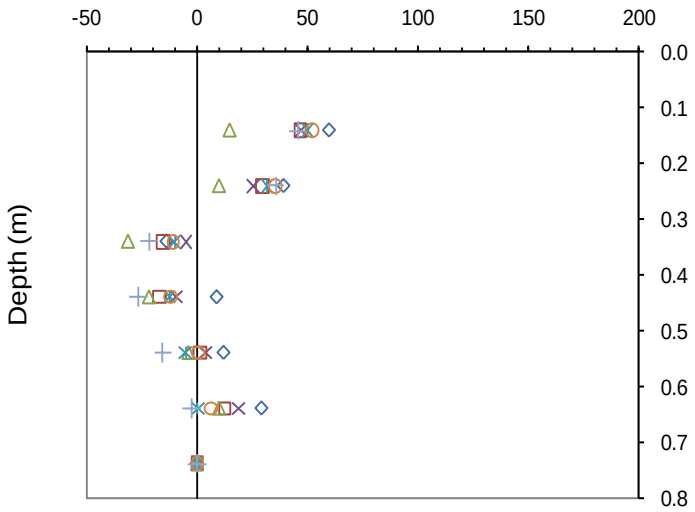
Arsenic (ug/l)

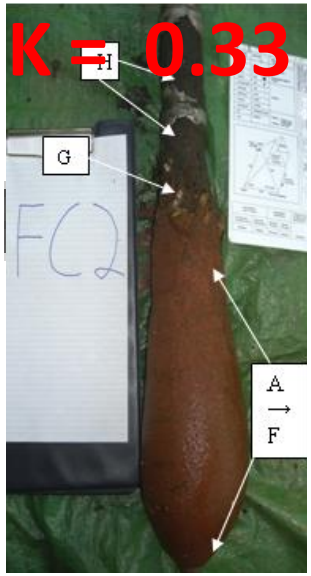


Arsenic ug/l

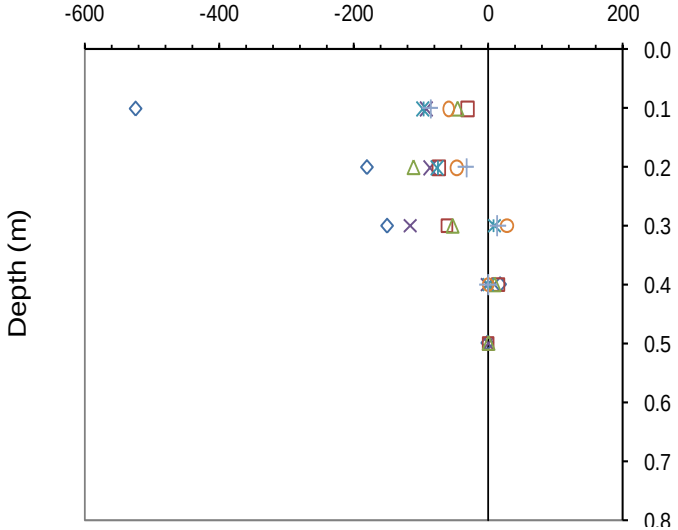


Arsenic % Decrease



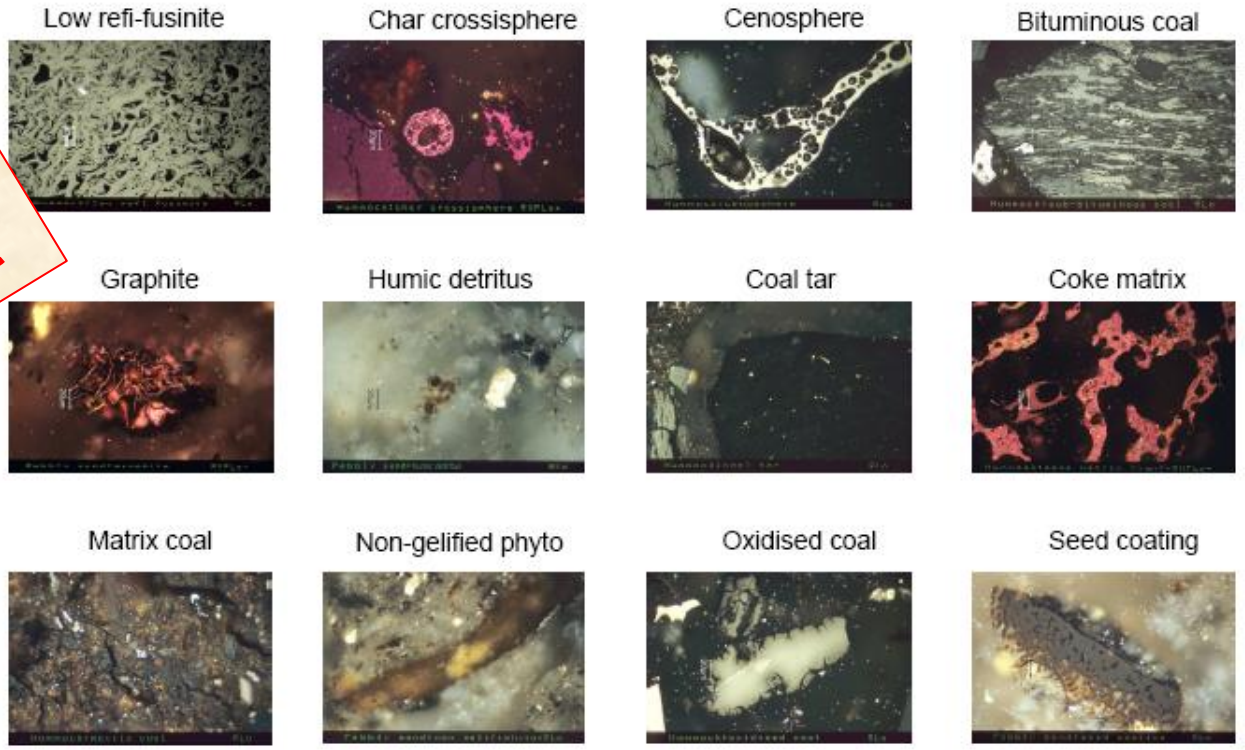


Arsenic % Decrease



Petrographic analysis of organic matter in bed sediments

Urban fingerprint



- Samples contained nearly all types of anthropogenic particles (with a high degree of contamination, **up to 94% of anthropogenic contamination.**
- The principal sources of the particles found are the coal mining and the coal industry (cokes; residues and solids produced during coal hydrogenation processes).

So ?

Natural attenuation potential of the urban hyporheic zone

- Natural attenuation potential may be significant, but variable
- Within moderate to high baseflows, it is doubtful whether attenuation capacities will be sufficient
- The HZ should be regarded as a buffer zone providing added ‘comfort’ (perhaps) to bankside well compliance
  - a MNA protocol for the HZ is not particularly practicable
- Urban HZ sediments may be historically contaminated by sorbing metals/organics and derogate some baseflows
- River restoration incorporating enhanced natural attenuation in the HZ would require careful engineering, via say:
  - Riverbed amendments
  - Bankside permeable reactive barriers (PRBs)

Thanks

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