D544

MODELING EFFECTS OF PHYSICAL AND CHEMICAL HETEROGENEITY OF ALLUVIAL SEDIMENTS ON HYPORHEIC EXCHANGE

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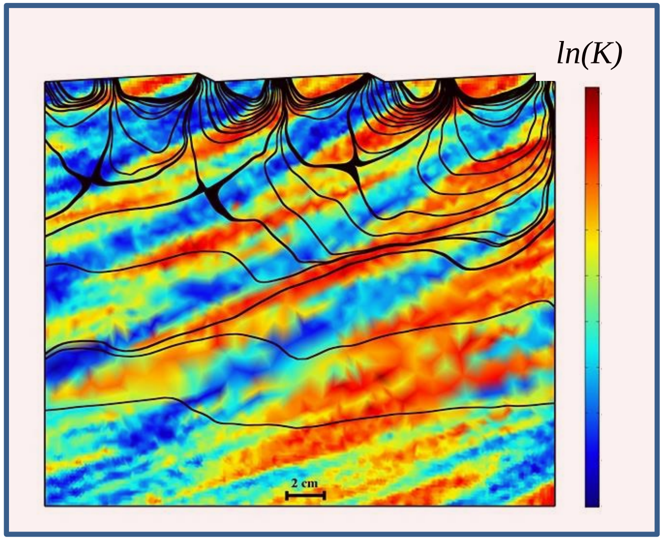
HS10.7 Groundwater - Surface Water Interactions: Physical, Biogeochemical and Ecological processes
Tuesday 05 May 2020

Motivations and aims

- **SEDIMENT HETEROGENEITY** is known to **influence hyporheic exchange**, but it is **relatively understudied** because it is difficult to generalize its structure.

- **Heterogeneity** includes:
  1. **PHYSICAL HETEROGENEITY**: variations in **hydraulic conductivity** due to coarser/finer sediment fractions;
  2. **CHEMICAL HETEROGENEITY**: variations in sediment composition, and specially **organic carbon content** in finer fractions (silt, clay).



BOTH ASPECTS ARE RELEVANT!

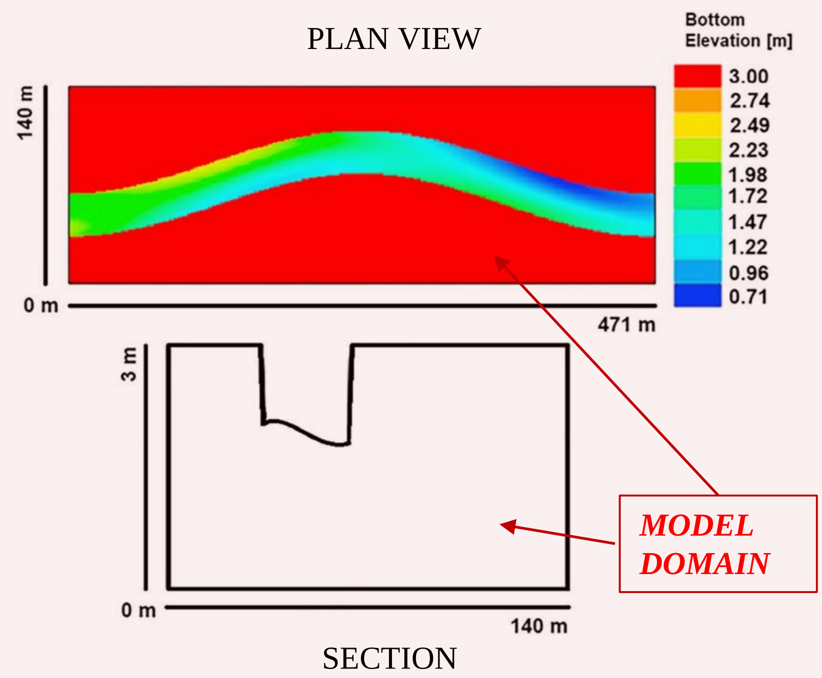
[Figure modified from: Bardini, L., Boano, F., Cardenas, M. B., Sawyer, A. H., Revelli, R., and Ridolfi, L. (2013), Small-scale permeability heterogeneity has negligible effects on nutrient cycling in streambeds, Geophys. Res. Lett., 40, 1118– 1122, doi:10.1002/grl.50224.]

Methods: mathematical model

We developed a **numerical model** of hyporheic exchange in an **idealized** **<u>meandering river</u>:**

- Simulated with MODFLOW
- 3D, steady state, Darcy flow
- Exchange driven by **meander sinuosity and meander bars** (no ripples/dunes)
- Large scale morphology
  → **long residence times** (months to years)

MODEL GEOMETRY

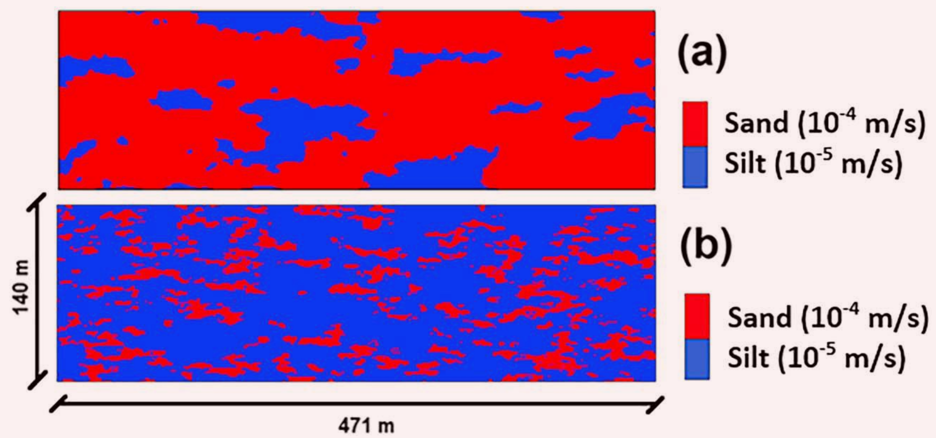


[Figure modified from Pescimoro et al., 2019]

Methods: mathematical model

HYDRAULIC CONDUCTIVITY (K)

- Simulated with TPROGS
- Random mix of
  - a) **sand (high K, no carbon)** units
  - b) **silt (low K, high carbon)** units
- **Silt/sand ratios: 1:4 to 4:1**, with 30 random realizations for each value

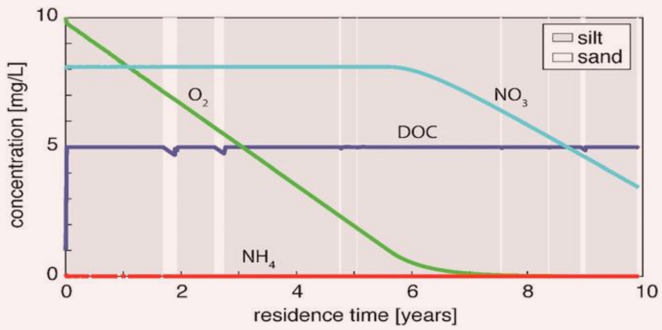


Plan view of two K realizations for silt/sand of 1:4 (a) and 4:1 (b)

[Figures modified from Pescimoro et al., 2019]

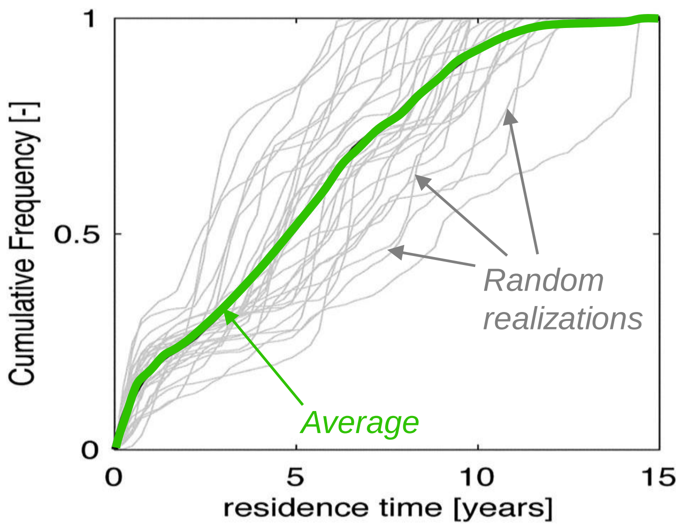
BIOGEOCHEMICAL MODEL

- Simulated with MATLAB
- Solutes: DOC, O_2, NO_3^-, NH_4^+
- Reactions:
  - a) **<u>DOC release</u> (only from silt)**
  - b) **Aerobic respiration**
  - c) **Denitrification and nitrification**

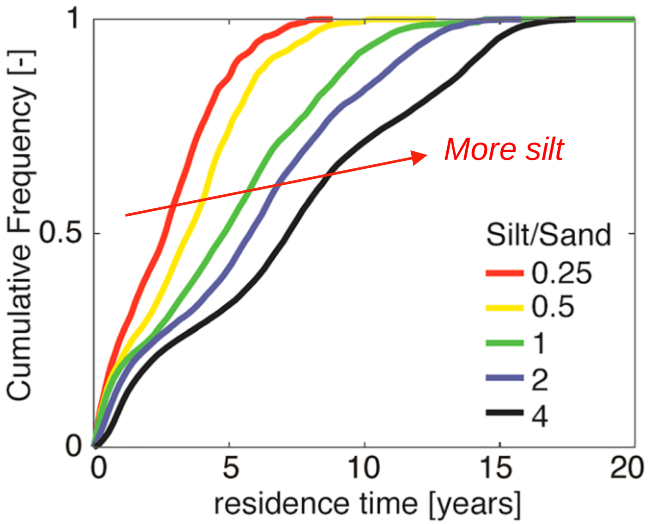


Example of concentration dynamics along a flowpath (silt/sand=1:1)

Results: Residence times



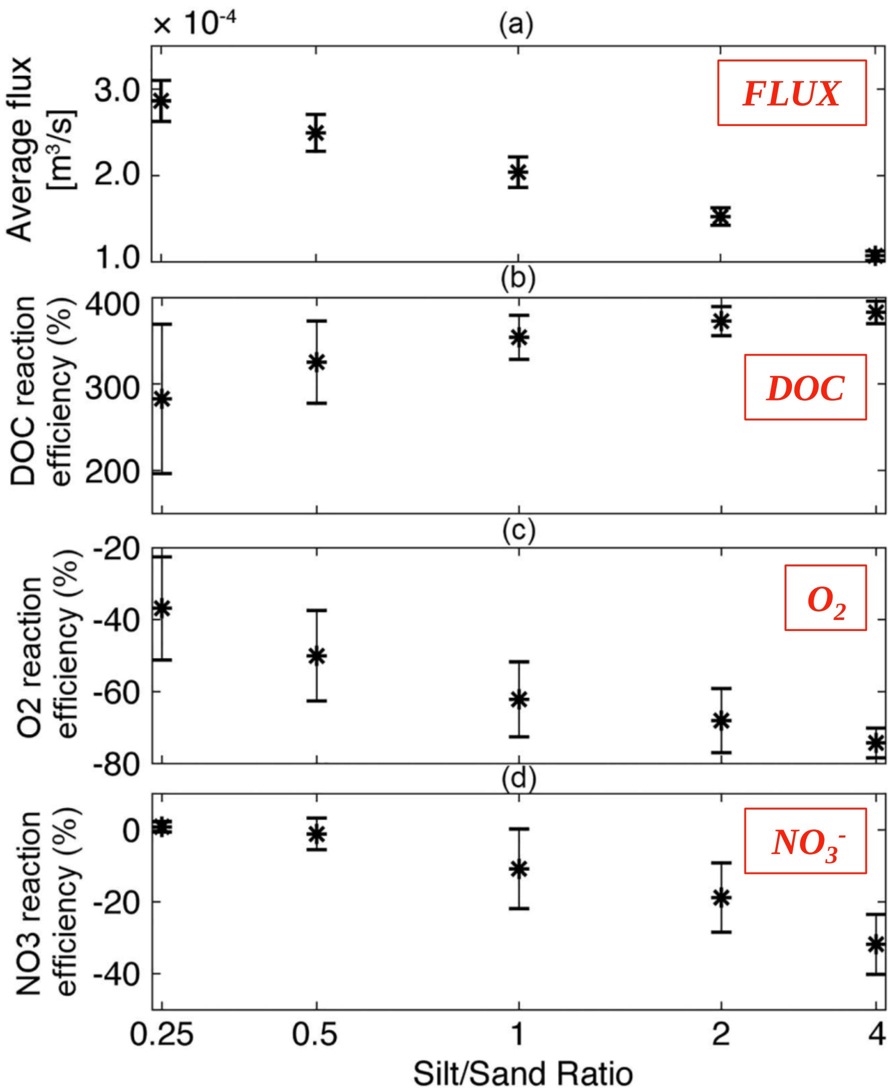
- Large scale morphology implies very **long residence times** (months to years)
- For a given silt/sand ratio, **residence times differ considerably** due to random arrangement of sand and silt units



- On average: higher residence time when silt/sand ratio increases (as expected)

[Figures modified from Pescimoro et al., 2019]

Results: Exchange flux & Reaction efficiencies



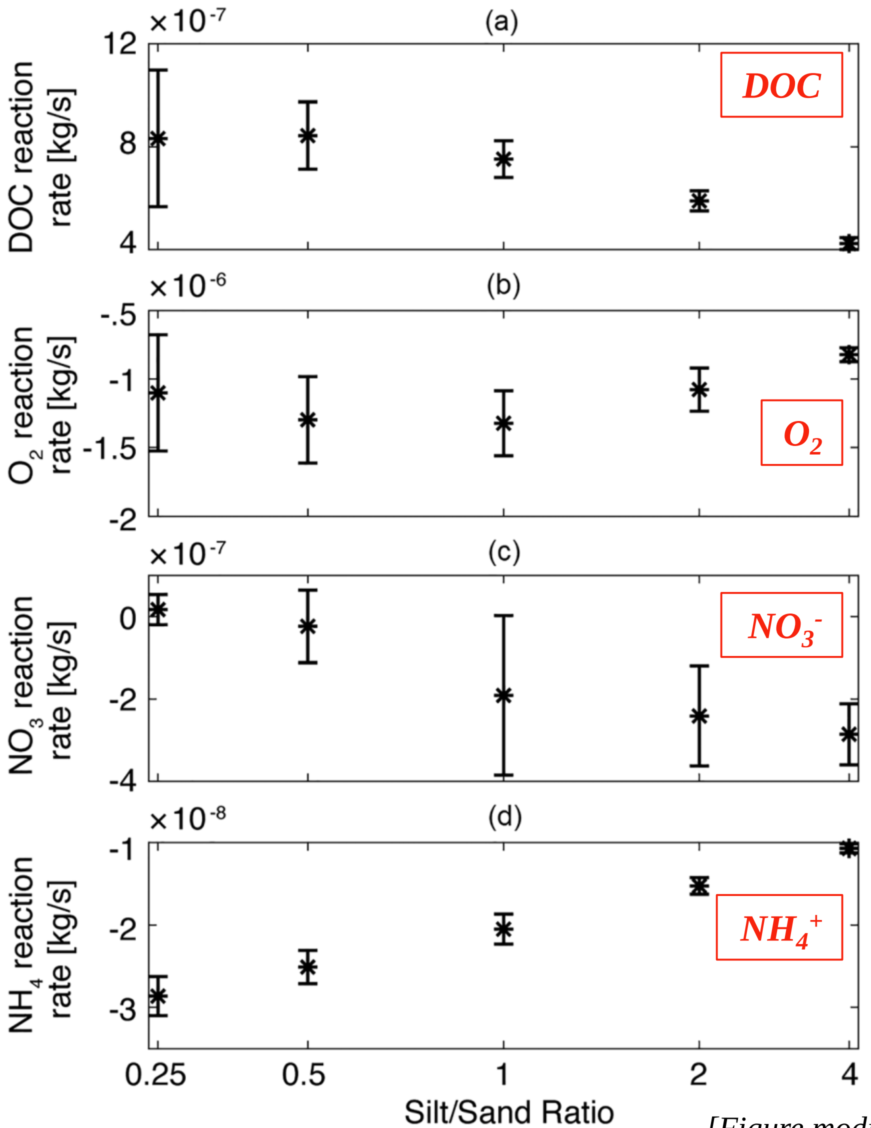
Higher silt/sand ratios result in**:**

1. **Lower hyporheic <u>exchange flux</u>** (due to lower K)
2. **Increase in <u>DOC concentration</u>** (due to more release from silt)
3. **Decrease in <u>O_2 and N concentration</u>** (due to longer contact times)

Less nutrient supply to streambed (1)
BUT
more efficient reactions (2,3)

[Figure modified from Pescimoro et al., 2019]

Results: Reaction rates



[Figure modified from Pescimoro et al., 2019]

What is the NET EFFECT on REACTION RATES?

Higher silt/sand ratios result in**:**

- **Lower** **<u>DOC production</u> rates** → flux limited (on average)
- **Lower** **<u>NH_4^+ and O_2 consumption</u> rates** → flux limited (on average)
- **Higher** **<u>NO_3^- consumption</u> rates** → reaction limited (on average)

Also notice the **considerable variability** (error bars) for each silt/sand ratio!

Conclusions

For large-scale exchange driven by meandering morphology:

1. [ON AVERAGE] The hyporheic zone **generally** behaves as a net **DOC source** (released from silt fraction) and as **NO_3^- sink** (due to denitrifaction);
2. [ON AVERAGE] Higher **silt content generally increases denitrification rates** (reaction limited) while reducing other reaction rates (flux limited);
3. [FOR SPECIFIC CASES] Random variations due to the specific spatial arrangement of silt/sand units may result in different behaviors. **This should be kept in mind when drawing lessons from specific field cases**.

FOR MORE DETAILS:

Pescimoro, E., Boano, F., Sawyer, A. H.,& Soltanian, M. R. (2019). Modeling influence of sediment heterogeneity on nutrient cycling in streambeds. *Water Resources Research*, 55. https://doi.org/10.1029/2018WR024221.