Lake Hydrodynamics Laboratory

# "VLIV HYDRAULIKY VODY NAD SEDIMENTEM NA TRANSPORT LÁTEK PŘES ROZHRANÍ SEDIMENT-VODA

Borovec Jakub, Bretón Felipe, Jiří Jan

Brno, 23.10.2019

BIOLOGY CENTRE CAS
EUROPEAN UNION
European Structural and Investment Func
Operational Programme Research, Development and Education
MINISTRY OF EDUCATION, YOUTH AND SPORTS

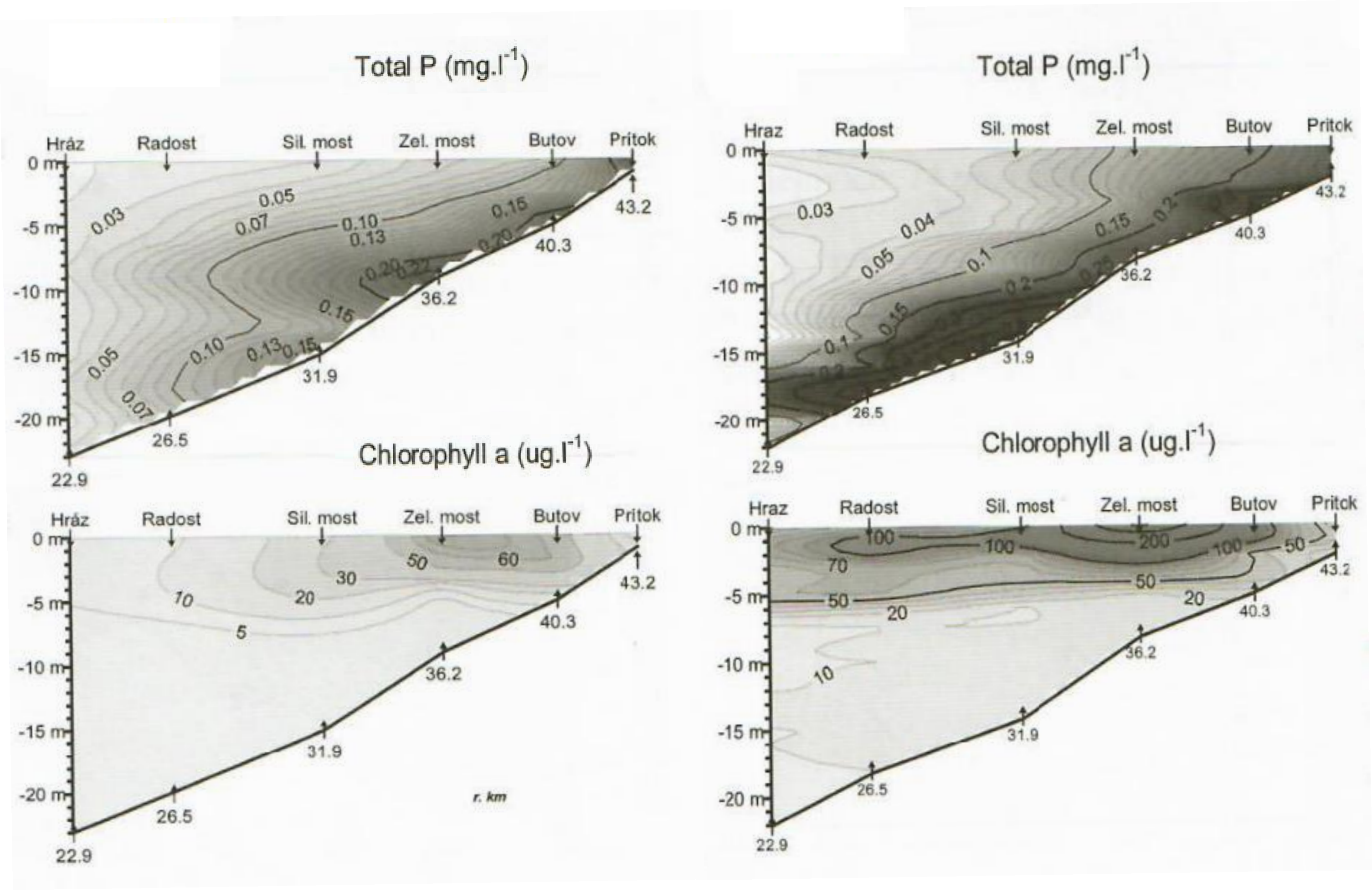
# Motivation: the phosphorus elixir

- Freshwater ecosystems provide <u>ecological services</u> and also social benefits, e.g. as a drinking-water source
- <u>Eutrophication</u> is an undesirable scenario as it can result in water quality depletion or massive fish death (Merel et al., 2013)
- Phosphorus is usually the <u>limiting macronutrient</u> for primary production (Schindler et al., 2016)

The Orlík Reservoir with substantial accumulation of cyanobacterial bloom.
(Photo by Petr Znachor)

# Motivation: lentic but shallow waters

- Example




**Total phosphorus distribution in Hracholusky Reservoir**

(Source: Duras, 2006)

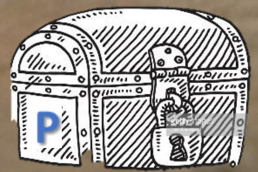
# Lit. Review: biogeochemical recipes


**Sink effect:**

1. Presence of reactive Al, Ca, Fe minerals
2. OM content & sedimentation rates
3. Close-to-neutral pH
4. Sorption (chelation) by OM during resuspension events
5. Biological uptake in the water column and sediments

**Uncertain effect…**

- **Other types of anaerobic respiration (NO3-, SO42+ , Mn4+ , etc.)**
- **Solubility products**
- **Bio-convection (Sommer et al, 2017)**

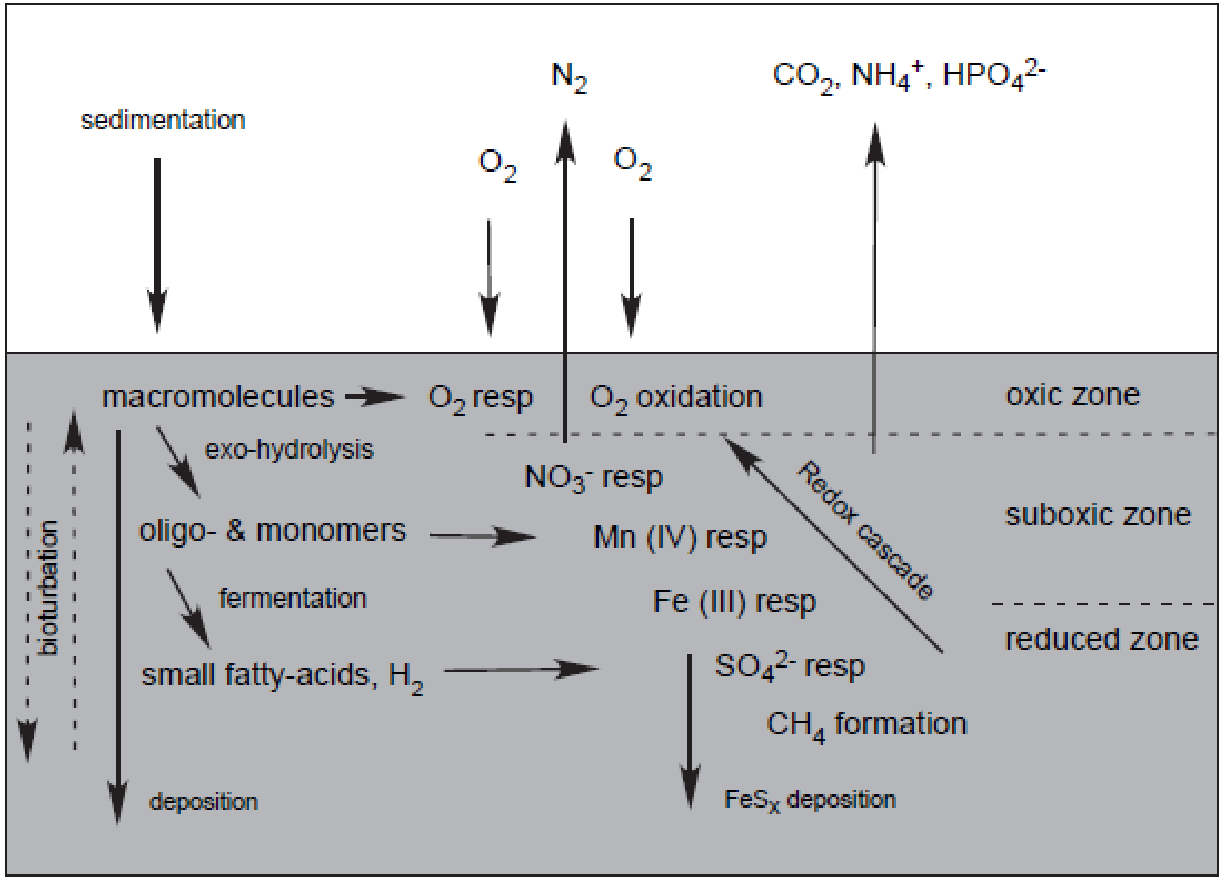



**Source effect:**

1. **Iron-based OM respiration**
2. **Temperature**
3. **Basic conditions (high pH)**
4. **Desorption during resuspension events**
5. **Acidic conditions (low pH)**
6. **Bioturbation**
7. **Gas ebullition**
8. **Hydrolytic enzymes**

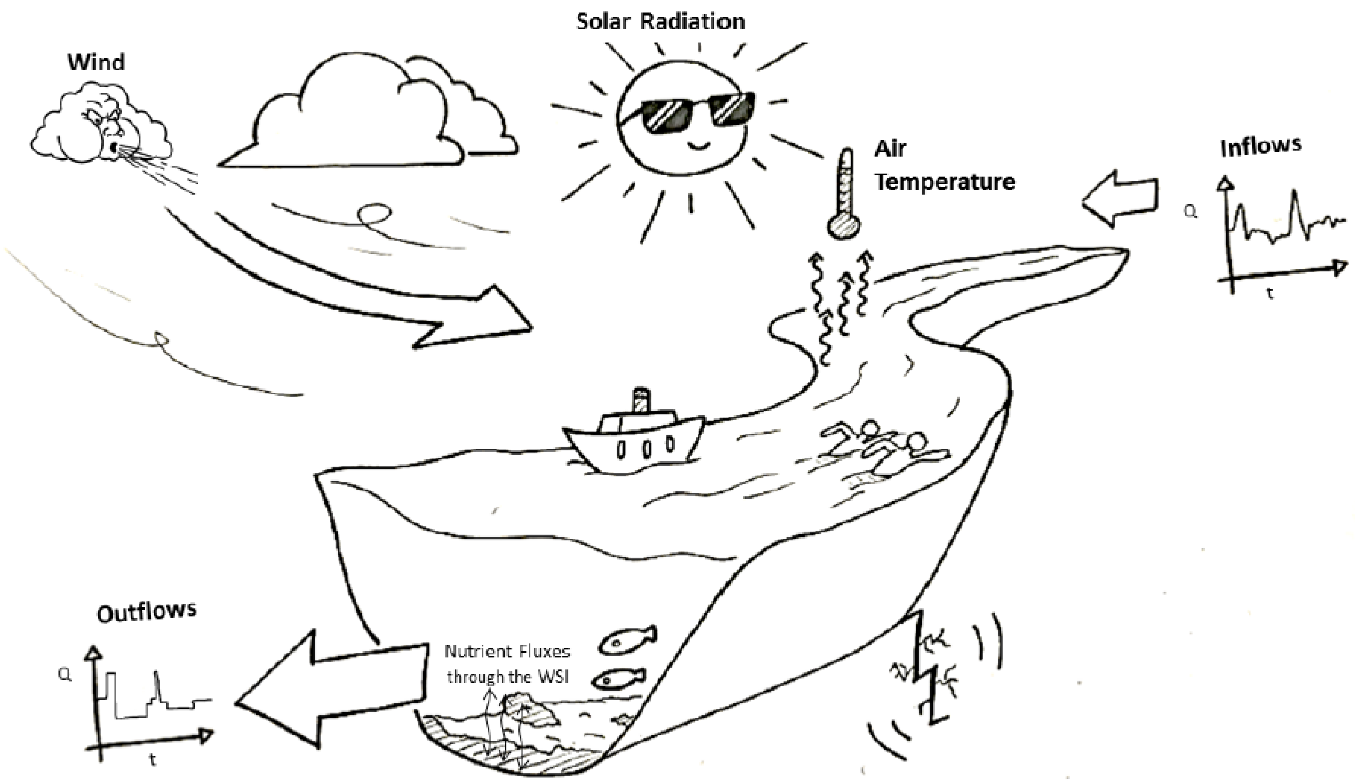
# Lit. Review: diagenetic processes

- Sediment diagenesis is a complex process
- The availability of alternative electron acceptors structures biological communities organizing them in sediment layers
- Hydrodynamics may control this availability




Glud (2008)

# Lit. Review: hydrodynamic recipes



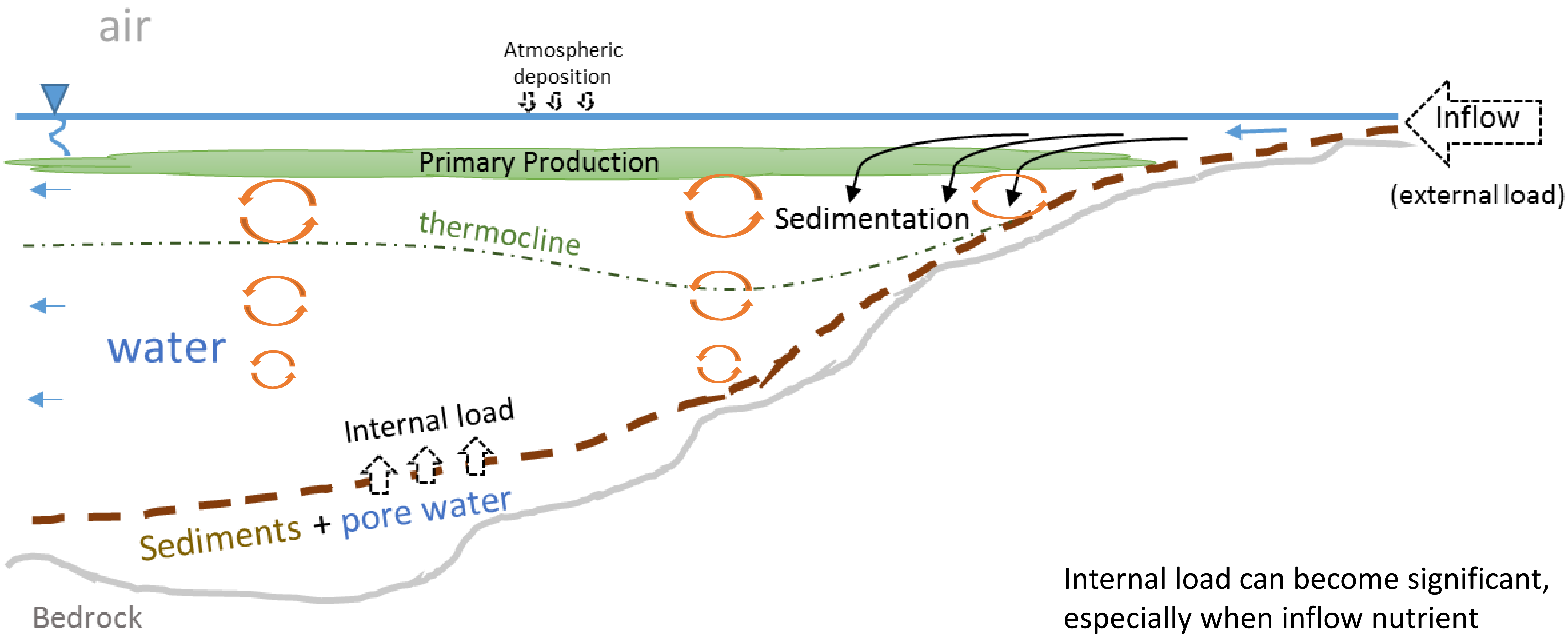

How can we forecast BBL behaviour? It depends on driving forces. Some promote stratification while others mixing.

Wind is relevant for shallow waters:

- resuspension
- stratification disruption

Inflow even when small can impact the BBL environment.

# Motivation: the phosphorus elixir

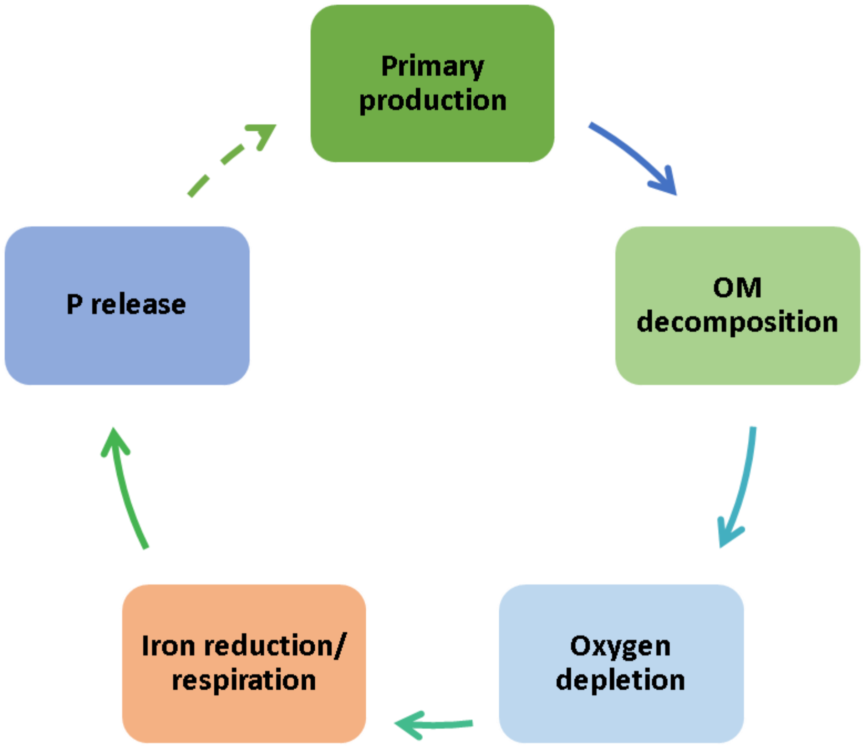



Reservoir inlet schematic (longitudinal profile)

Internal load can become significant, especially when inflow nutrient concentrations are controlled (Søndergaard et al., 2003)

# Key questions: velocity? turbulence? sediment size?

- How relevant are mean velocities (BBL) on predicting nutrient fluxes across the SWI?
- How does the sediment grain-size – distribution affect it?
- What is the role of turbulence in the BBL?
- Can we relate it to any specific hydrodynamic parameter, e.g. Bed Shear Stress?




"When turbulence is of importance, phosphate might escape co-precipitation with iron(hydro)oxides" (Smolders et al., 2001)

# Lit. Review: diffusion of substances in water

- From Fick's law:

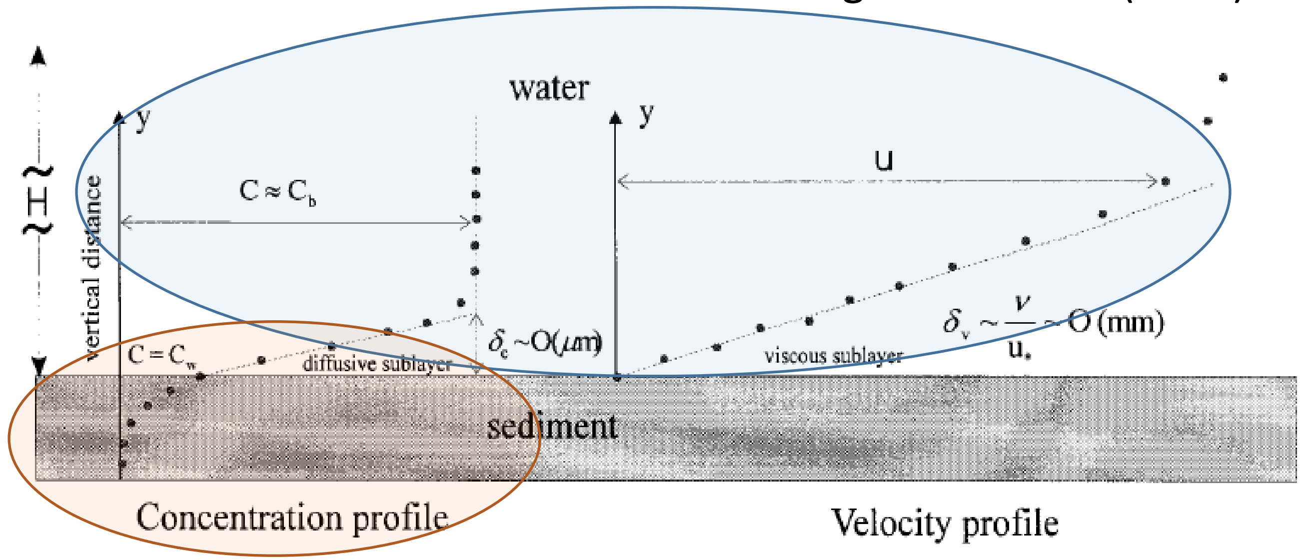
Solute flux

Vertical concentration gradient

$$J = -D\frac{\partial C}{\partial z}$$

diffusivity

Steinberger & Hondzo (1999)



# Lit. Review: mass transfer coefficient or exchange velocity

$$J = -D\frac{\partial C}{\partial z}$$

$$J = -\boldsymbol{K} * \Delta C$$

- A bulk parameter is used instead
- It combines the effect of both molecular diffusivity and diffusive boundary layer
- Transport might be controlled by the sediment-side or the water-side, or both:

$$\frac{1}{K} = \frac{1}{K_s} + \frac{1}{K_w}$$

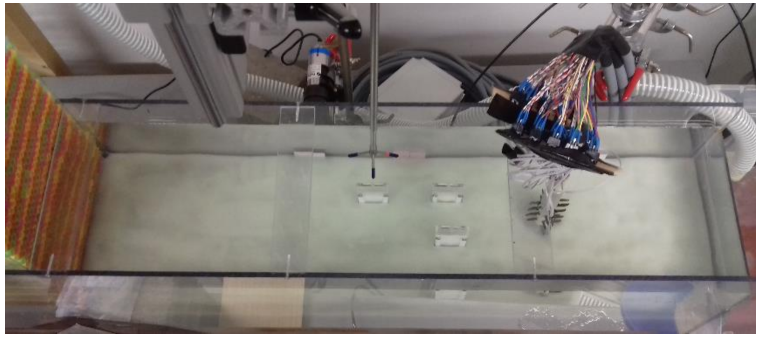
- Sediment-side fluxes estimations must consider production and consumption within the sediment
- In the water-side it is usually neglected

For simplicity:
Mass-Transfer Coefficient (MTC) is adopted! (Thibodeaux, 2011)

# Garage Experiment: playing with artificial sediment

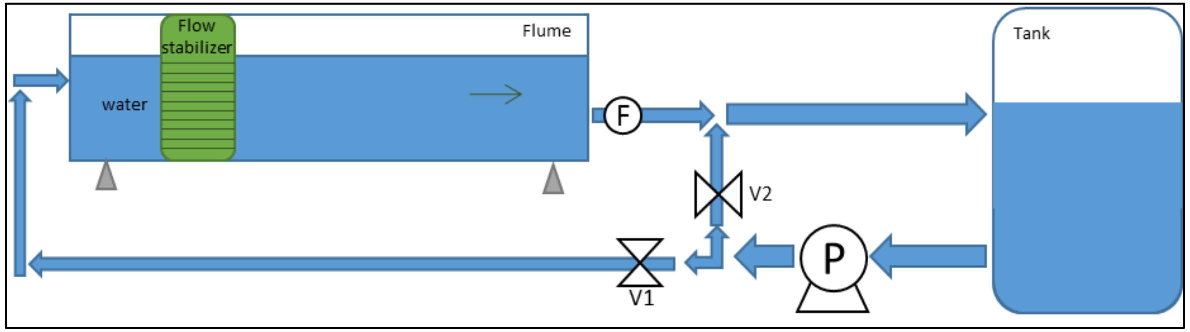
- Goal: to evaluate the effect of both sediment-size-distribution and flow velocities on SWI fluxes.
- Artificial sediment was saturated with a chemical cocktail
- Tap water (100 l) was recirculated at various flow rates
- Solute release was tracked in time

Flume top view

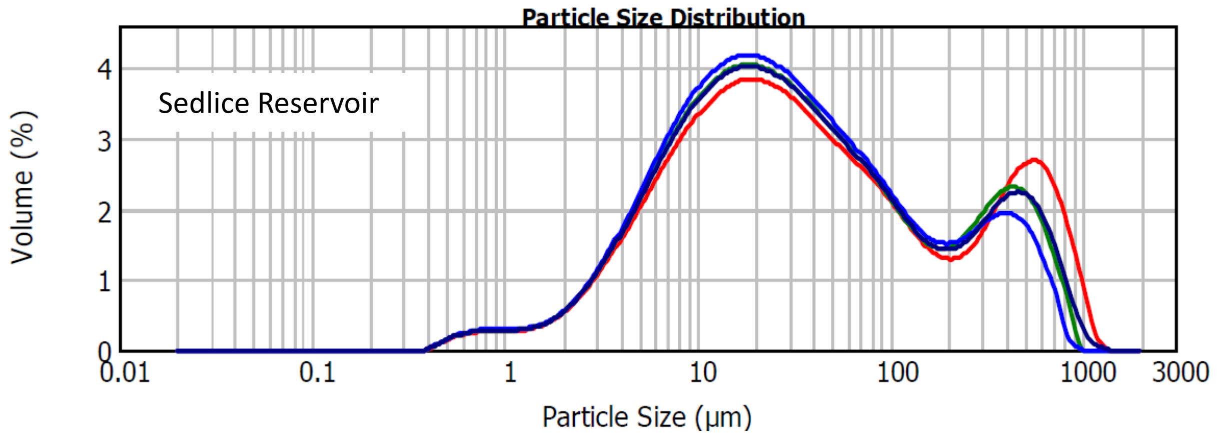


Flume lateral view

Schematic of water recirculation system



# Garage Experiment: playing with artificial sediment




Artificial sediment

| Symbol | Classification | Size range (µm) |
|---|---|---|
| S1 | medium sand | 300-400 |
| S2 | fine sand | 150-250 |
| S3 | silt & clay | < 45 |

Pore water solution

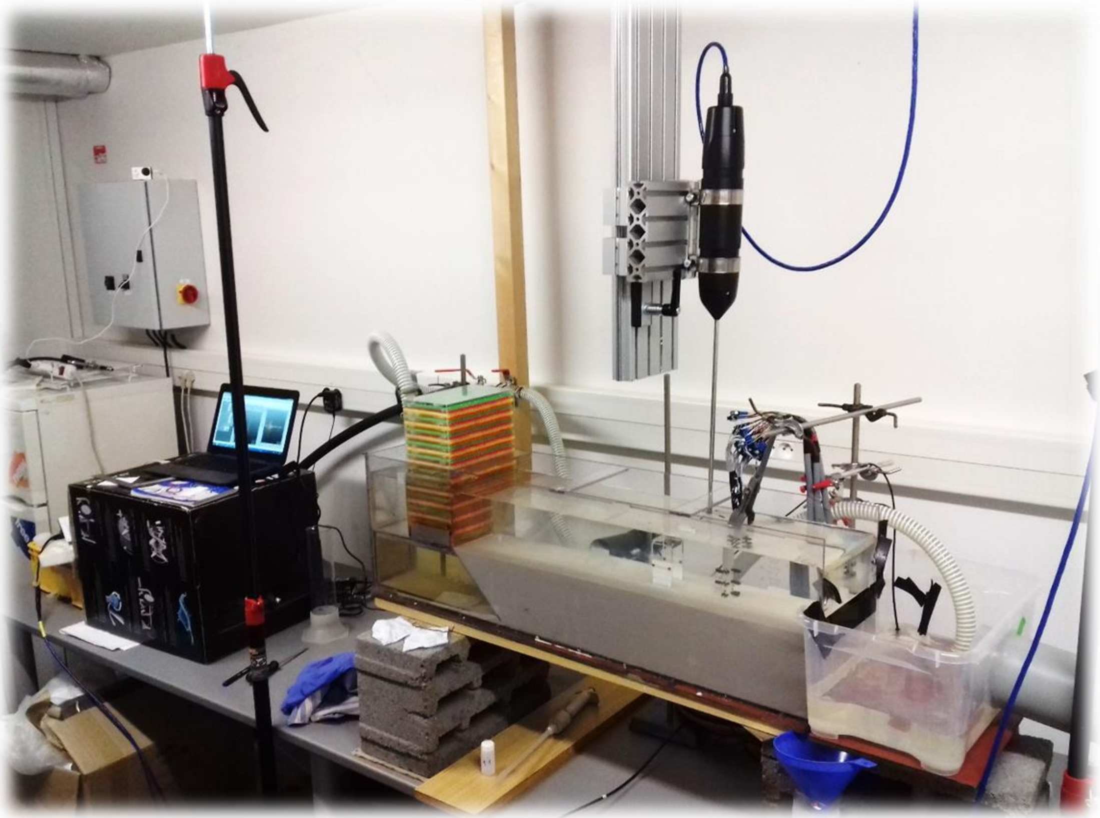
| Compound | Name | C (g/l) | Role |
|---|---|---|---|
| $Na_2S_2O_4$ | Sodium dithionite | 0.87 | Oxygen consumer |
| $NaHCO_3$ | Sodium bicarbonate | 0.42 | pH buffer |
| KCl | Potassium chloride | 3.16 | Tracer |
| $Na_2HPO_4.12H_2O$ | Sodium hydrogen phosphate | 1.85 | P source |

# Garage Experiment: playing with artificial sediment

- Four flow conditions were tested progressively (12 hours each):

Tested conditions

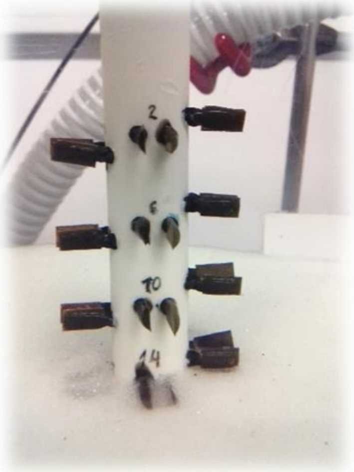
| Flow condition | Symbol | Q (l/min) | V (cm/s) | WRT (h) |
|---|---|---|---|---|
| Close to stagnant | Q0 | 0.4 | 0.03 | 4.2 |
| Minimum | Q1 | 1.2 | 0.08 | 1.6 |
| Medium | Q2 | 6 | 0.43 | 0.3 |
| Maximum | Q3 | 19 | 1.30 | 0.1 |



# Garage Experiment: playing with artificial sediment

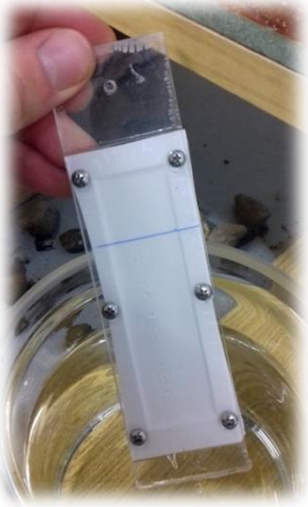
| Data collection | Location, frequency |
| --- | --- |
| Water samples | at one point, conveniently distributed in time (x16). |
| Oxygen sensor | at fixed position, every 15 minutes |
| Gel mini-peepers | one per flow condition, removed after 12 hours |
| Conductivity profiler | at 20 points, every 5 mm (vertical range of 10 cm) |
| ADV profiler | (1 mm cell x22 at 100 Hz) |
| | close to other measuring points (4), bottom measurement for 5 min |
| | five random points, vertical profile made of 3 points for 1 min |

ADV profiler

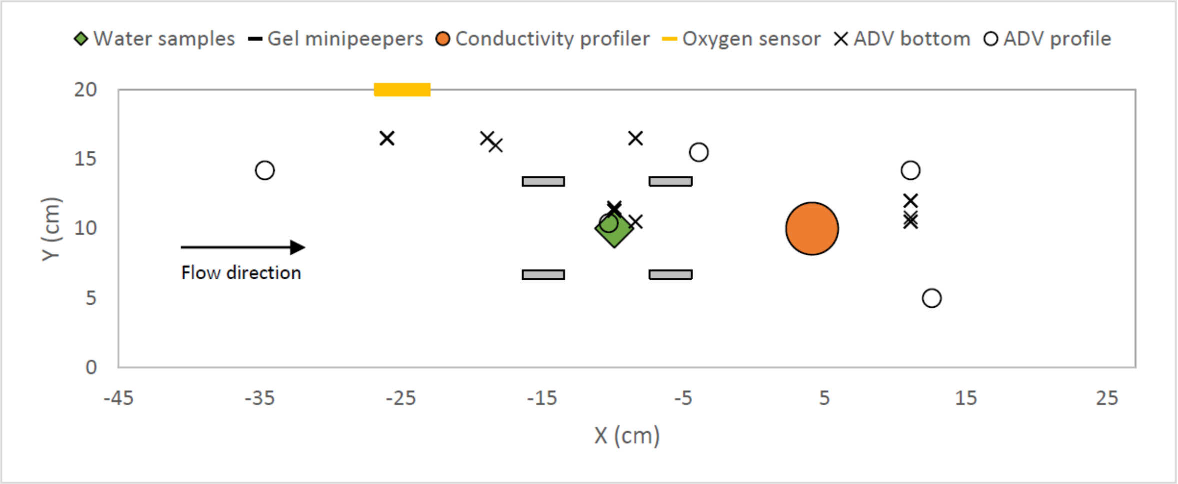


Conductivity profiler

Gel minipeeper



Oxygen sensor and camera



# Garage Experiment: playing with artificial sediment

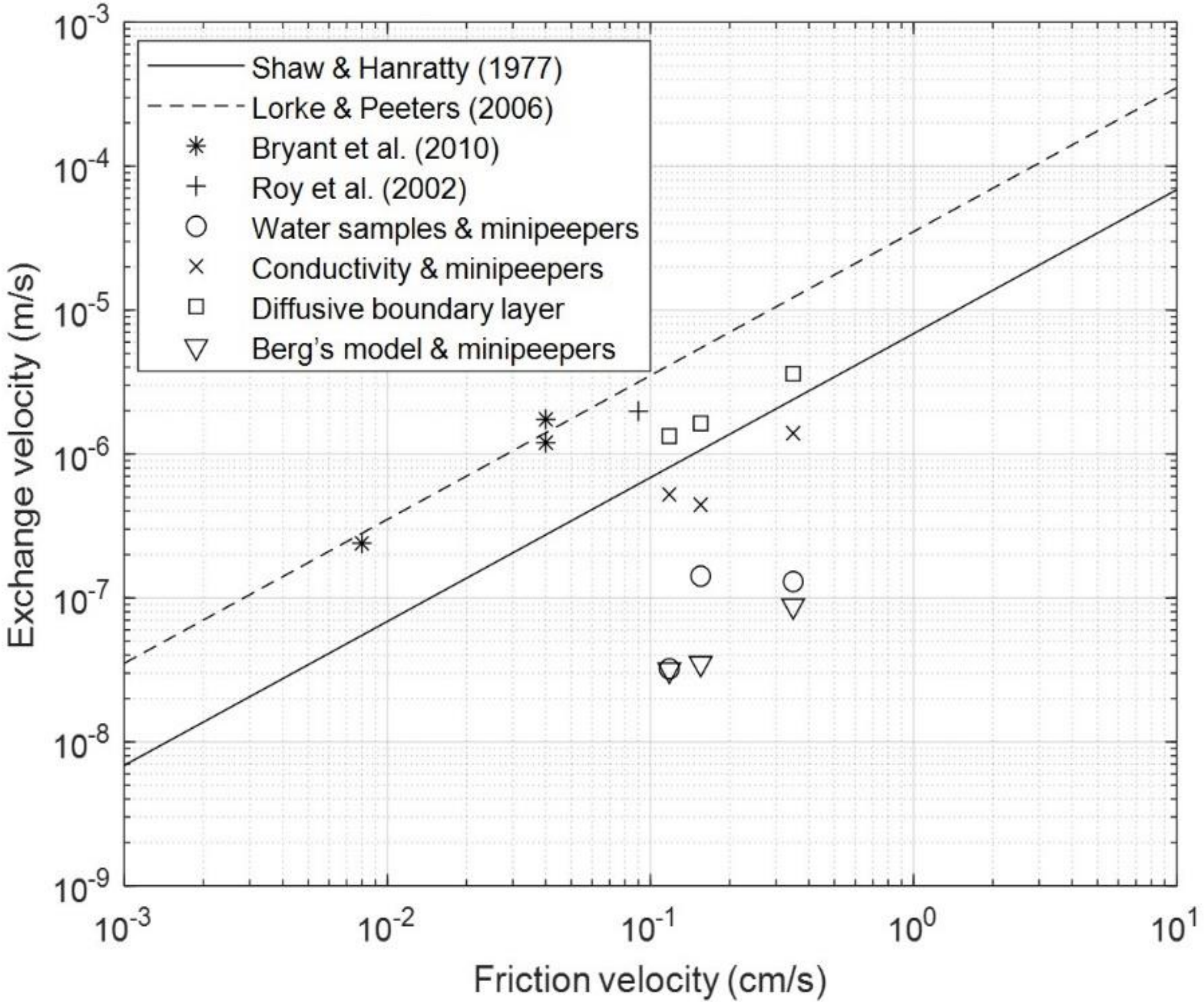
***Exchange velocity estimations***

- **Four methods were used (not described here):**
    1. **Water samples & minipeepers**
    2. **Conductivity & minipeepers**
    3. **Diffusive boundary layer (DBL)**
    4. **Berg's model & minipeepers**

Methods 1–3: Water-side methods

Method 4: Sediment-side method

# Garage Experiment: playing with artificial sediment



# Conclusions:

- Existing scaling relations overestimate exchange velocities for the flows studied here (Re = 10 - 700)
- Exchange velocities significantly change depending on the applied method
- We will invest next efforts in evaluating a wider range of friction velocities, as well as in decreasing methodological uncertainties of the selected approach
- The goal is the development of a practical methodology for evaluating internal loading linked to hydrodynamics

SOWA Research Infrastructure
Lake Hydrodynamics Laboratory

Thanks for listening ;)

BIOLOGY CENTRE CAS
EUROPEAN UNION
European Structural and Investment Func
Operational Programme Research, Development and Education
MINISTRY OF EDUCATION, YOUTH AND SPORTS