Vertical variation of turbulence driven hyporheic exchange coefficients

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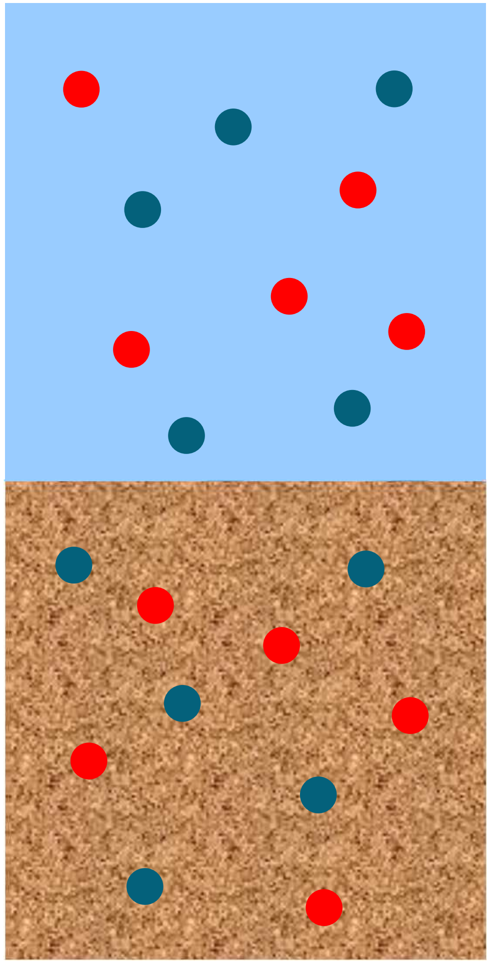
Hyporheic Exchange

- Transfer of fluid between bed and overlying flow
- Important in predicting fate of pollutants
- Tracer experiments used to mimic and understand pollutant movement

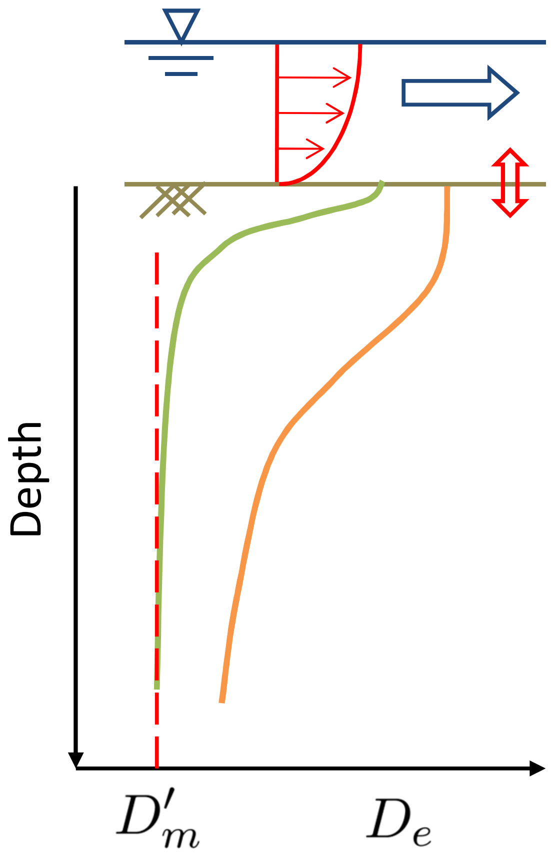


Previous studies

- Studied in the field or the laboratory
- Most laboratory studies conducted on re-circulating flumes
- Long setup time ~ days, long run time ~ hours
- Limits the range of conditions tested

Dutton, R. J. (2004), Modelling Transient Storage Processes, PhD thesis, University of Sheffield, UK.

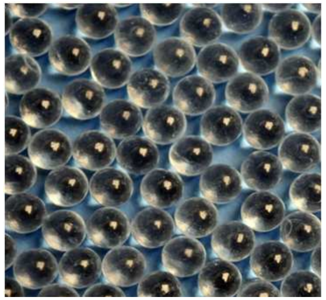
Vertical variation



Molecular Diffusion

Low permeability, low turbulence

High permeability, high turbulence

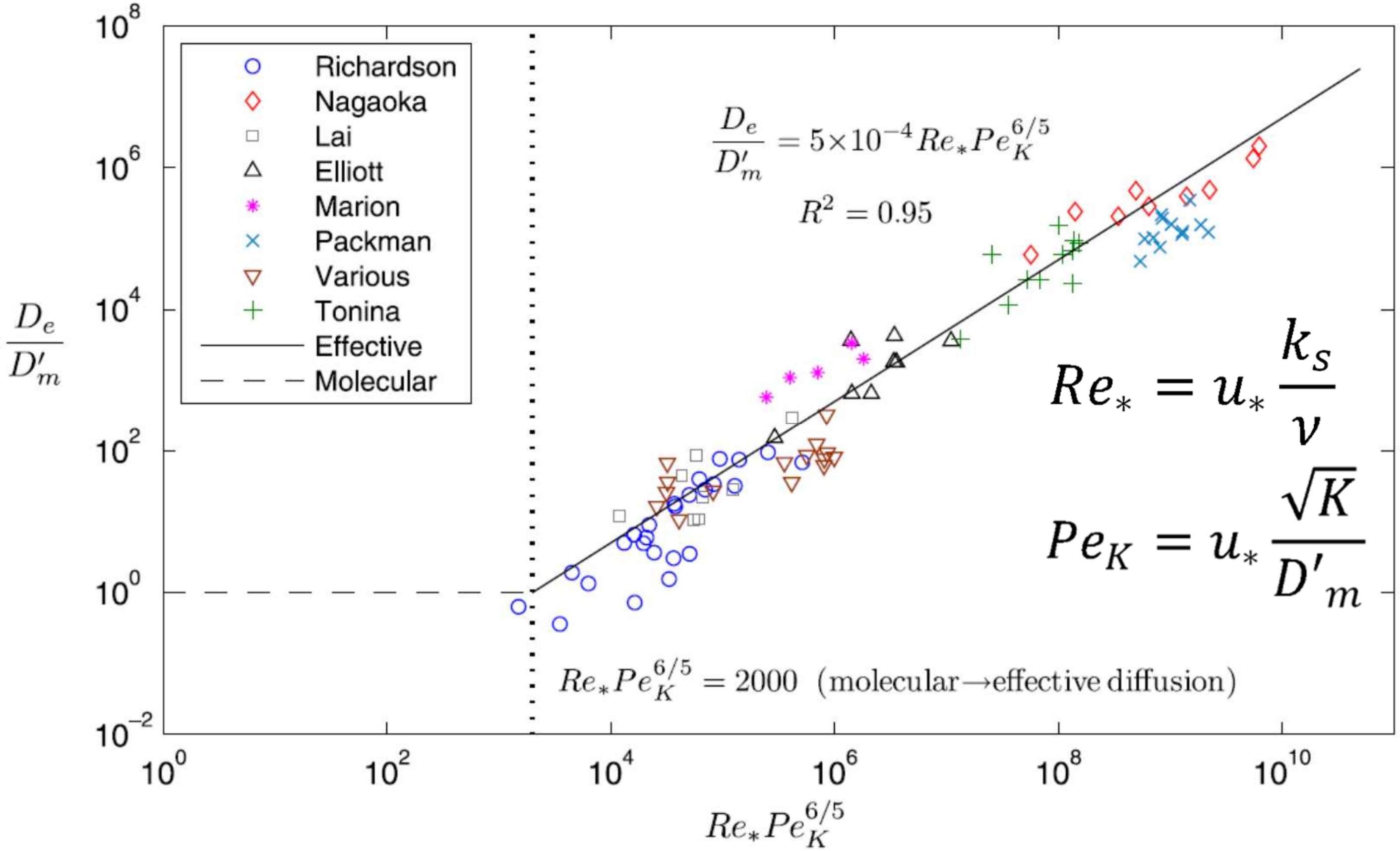


The EROSIMESS-System

- An in-situ erosion-meter IWW, RWTH, Aachen.
- Designed to determine critical shear stress
- Modified to study effects of sediment re-suspension on dissolved oxygen content
- Extended for hyporheic exchange studies

Theory

- O'Connor and Harvey (2008), Scaling hyporheic exchange and its influence on biogeochemical reactions in aquatic ecosystems



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O'Connor, B. L., & Harvey, J. W. (2008), Scaling hyporheic exchange and its influence on biogeochemical reactions in aquatic ecosystems, Water Resources Res., Vol. 44, W12423, doi:10.1029/2008WR007160, Figure 3, p 10.

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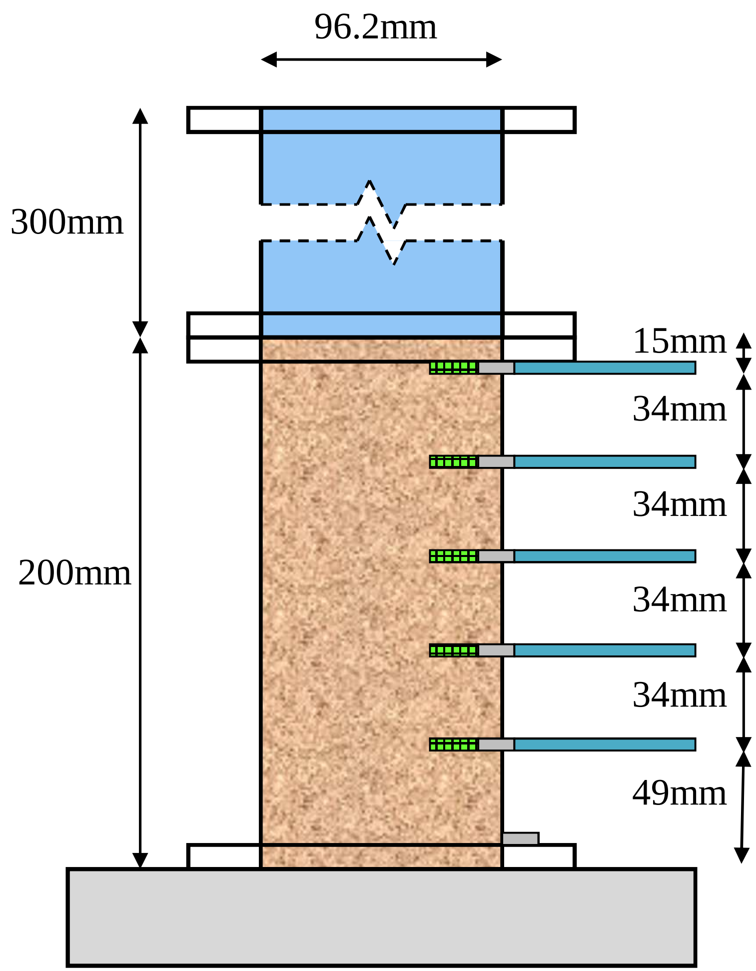
Laboratory experiments

- Laboratory testing completed
- 26 tests conducted

Bed shear velocity (m/s)	Mean Sediment Diameter (mm)				
	5.000	1.850	0.625	0.350	0.150
0.040	III	X	X	X	X
0.030	II	II	X	X	X
0.020	II	II	X	X	X
0.015	II	II	II	I	X
0.010	II	II	II	I	I



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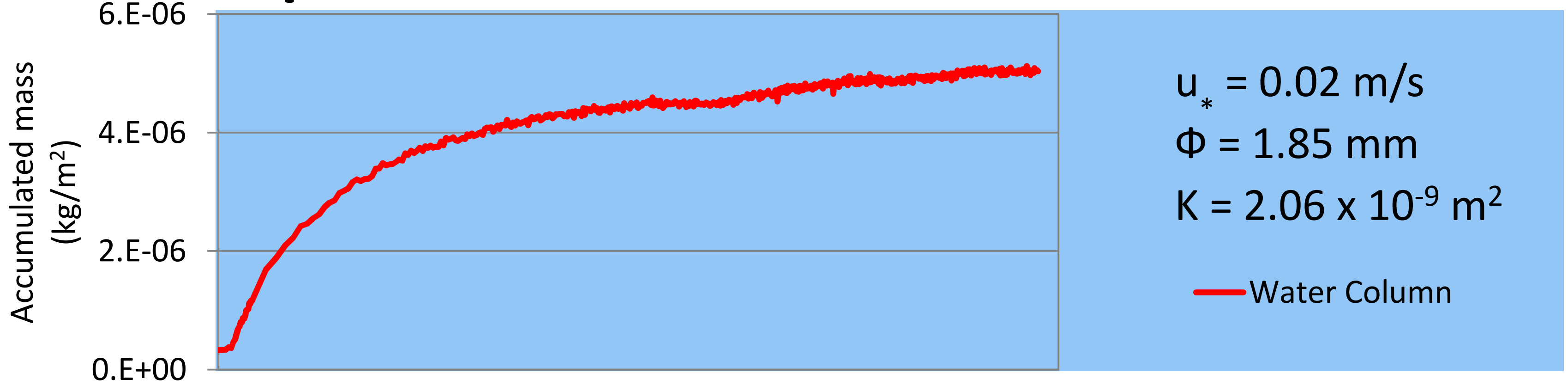
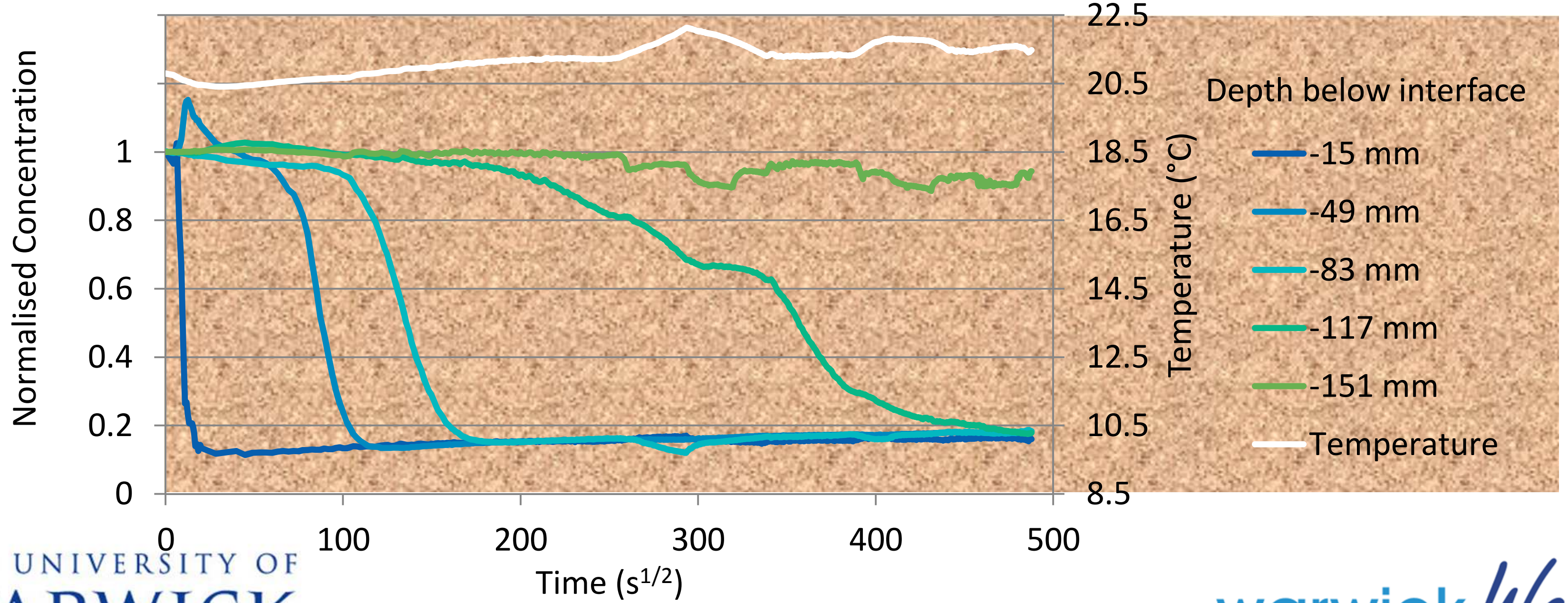
Example Raw Data





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O’Connor & Harvey (2008) Analysis

- Water Column D_e

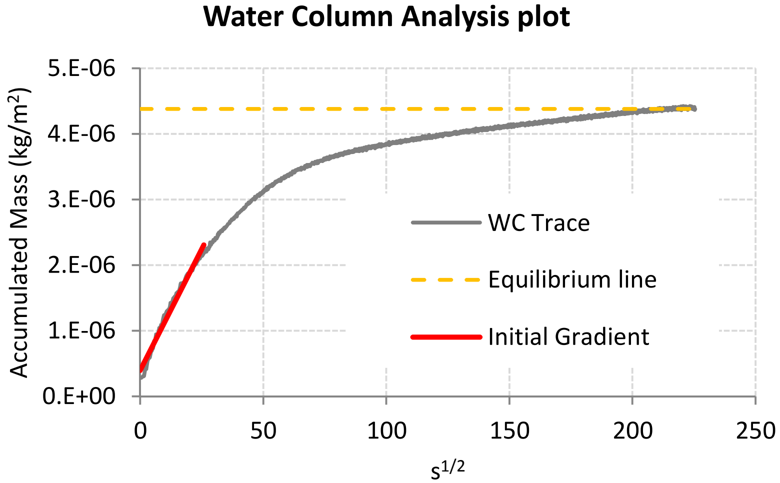
$$D_e = \left(\frac{\sqrt{\pi}}{2C_{0,s}} \frac{\mathrm{d}M_w}{\mathrm{d}(t^{1/2})} \right)^2$$

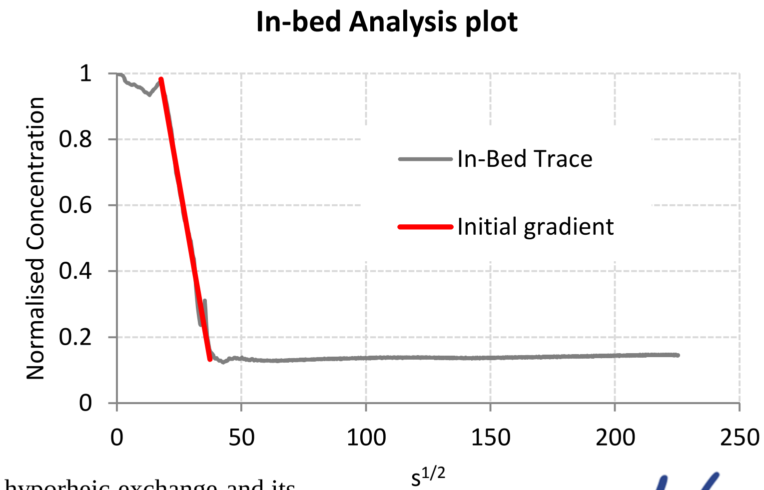
•M_w = accumulated mass of solute tracer in the overlying fluid (kg/m^2)

•C = solute concentration (kg/m^3)

•$C_{0,s}$ = initial solute concentration within the sediment pore water (kg/m^3)

•t = time (s)





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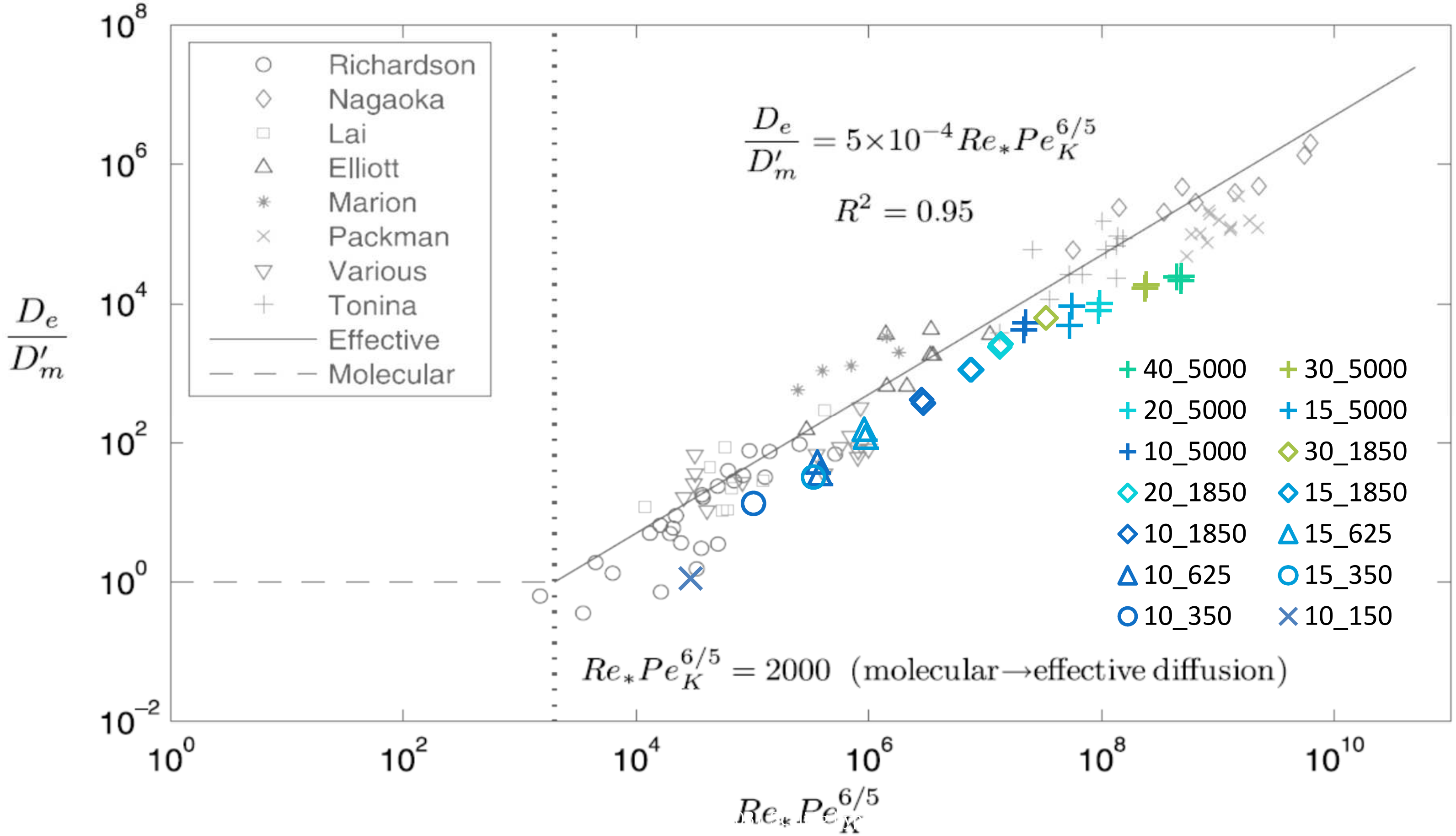
Water Column Data



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Nagaoka & Ohgaki (1990) Analysis

- In-bed analysis
- Fit predicted temporal profile from upper profile to lower profile

$$C_A[f(t), D_1, D_2] = \frac{L}{(a+1)\sqrt{\pi D_1}} \times$$
$$\int_0^t \frac{f(\tau)}{(t-\tau)^{3/2}} \sum_{n=0}^{x} b^n (2n+1) \exp\left(-\frac{(2n+1)^2 L^2}{4D_1(t-\tau)}\right) d\tau$$

- Where: $a = \sqrt{\frac{D_2}{D_1}}$, $b = \frac{a-1}{a+1}$
- D_1 = Diffusion coefficient between the two profiles (unknown)
- D_2 = Diffusion coefficient below the lower profile (known)

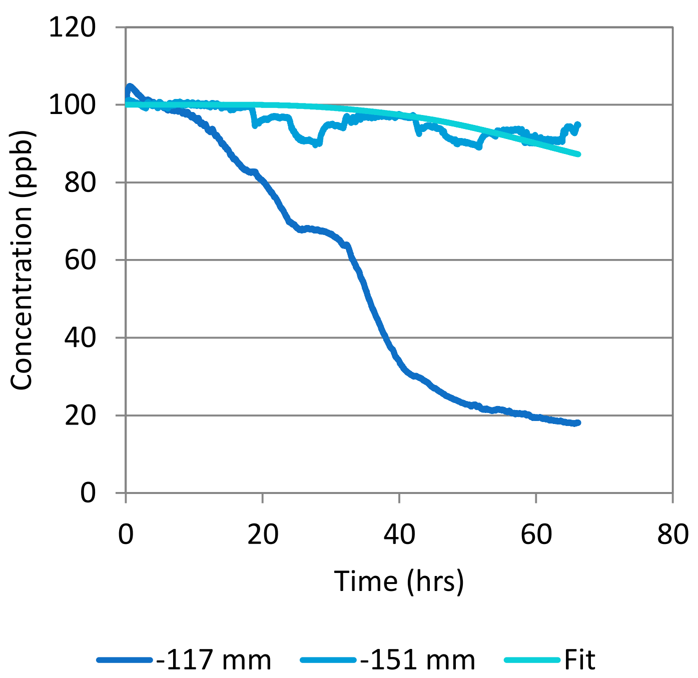
u_* = 0.02 m/s

Φ = 1.85 mm

K = 2.06 x 10^{-9} m^2

D_1 = 2.3 x 10^{-9} m^2/s

R_t^2 = 0.9988



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Nagaoka, H., and Ohgaki, S. (1990), Mass transfer mechanism in a porous riverbed, Water Research, 24, 417-425.

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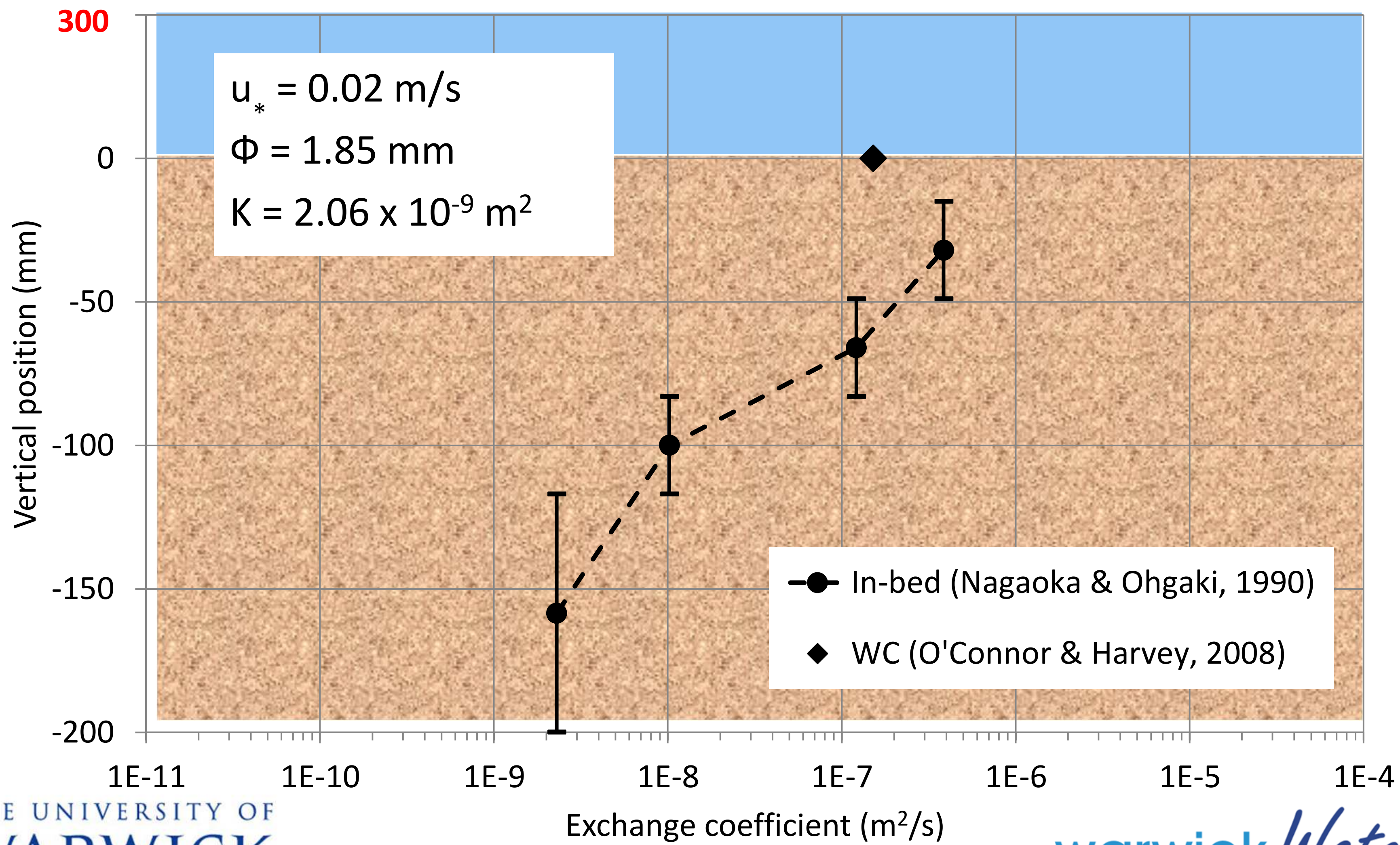
In-Bed Analysis



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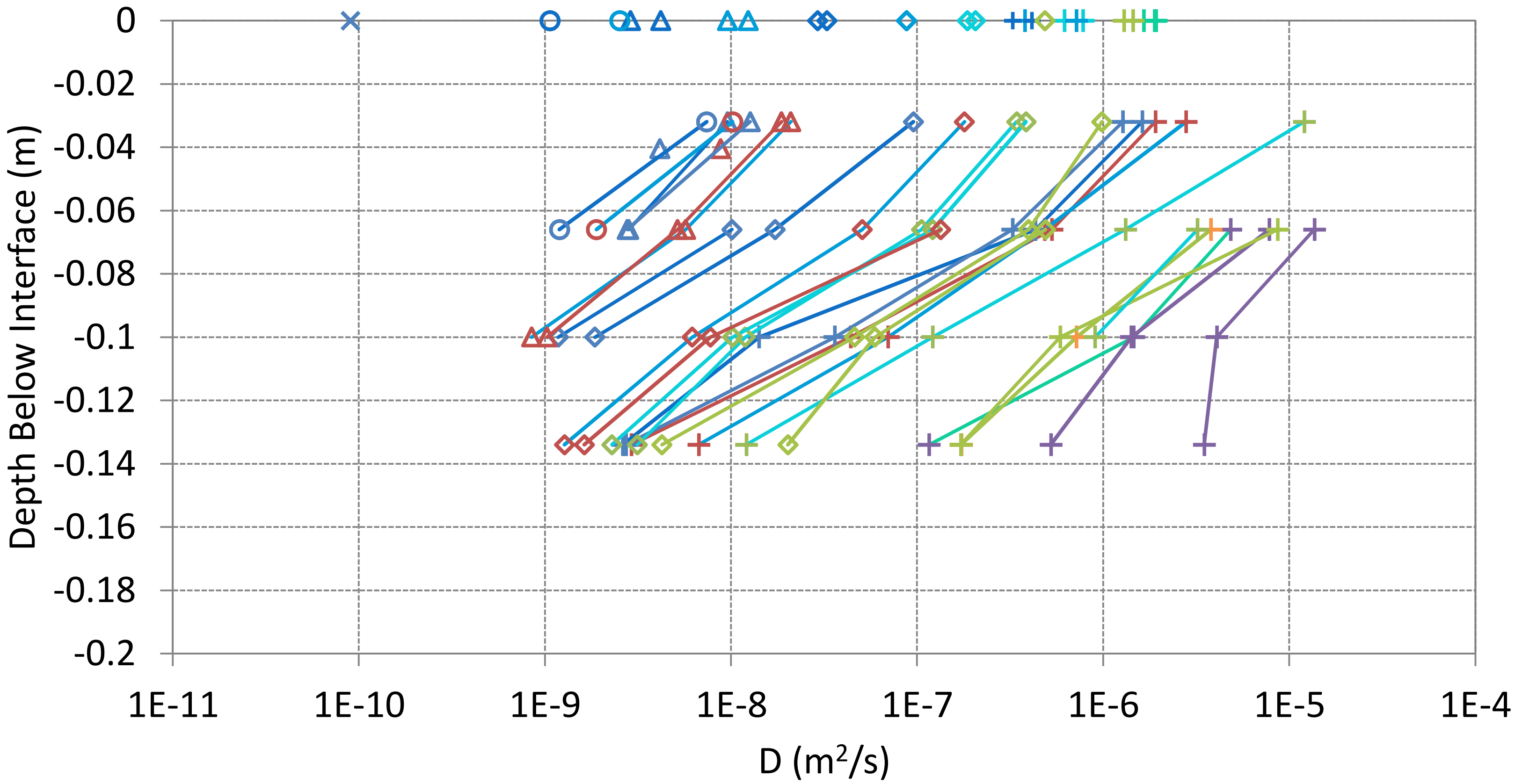
Full Results - In-bed Analysis



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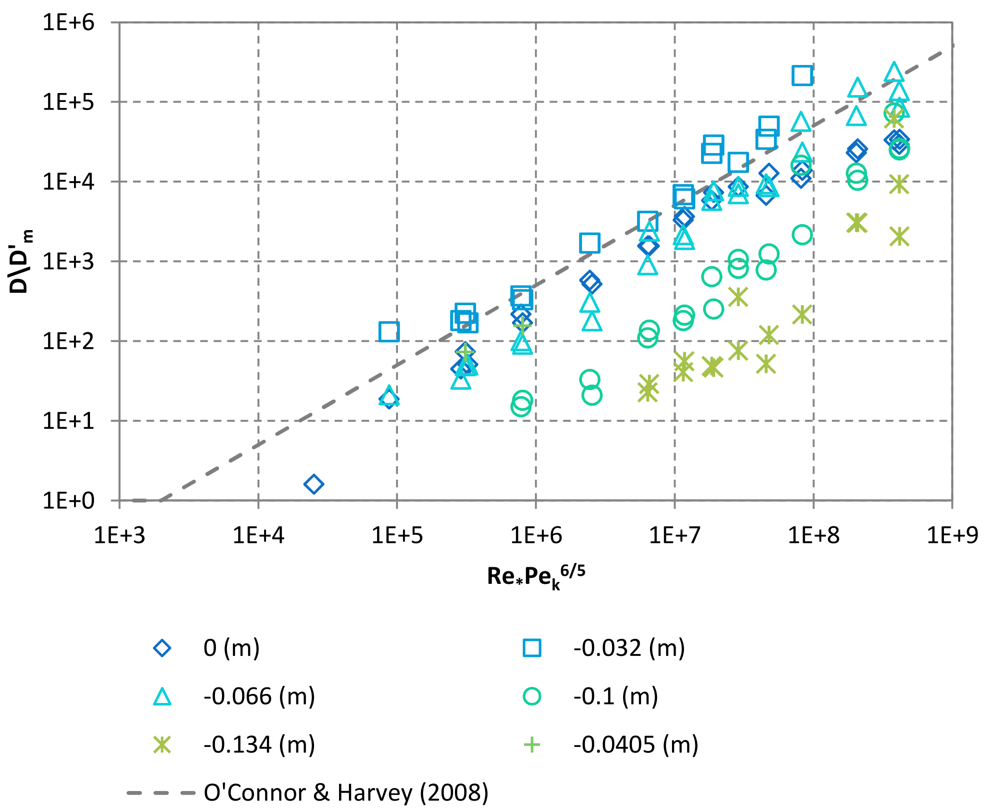
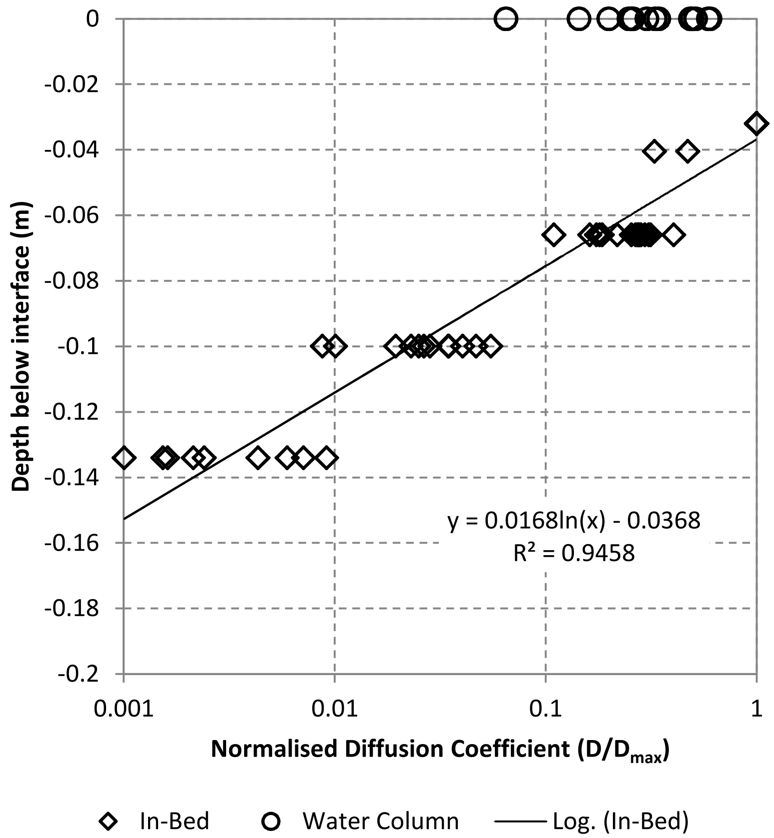
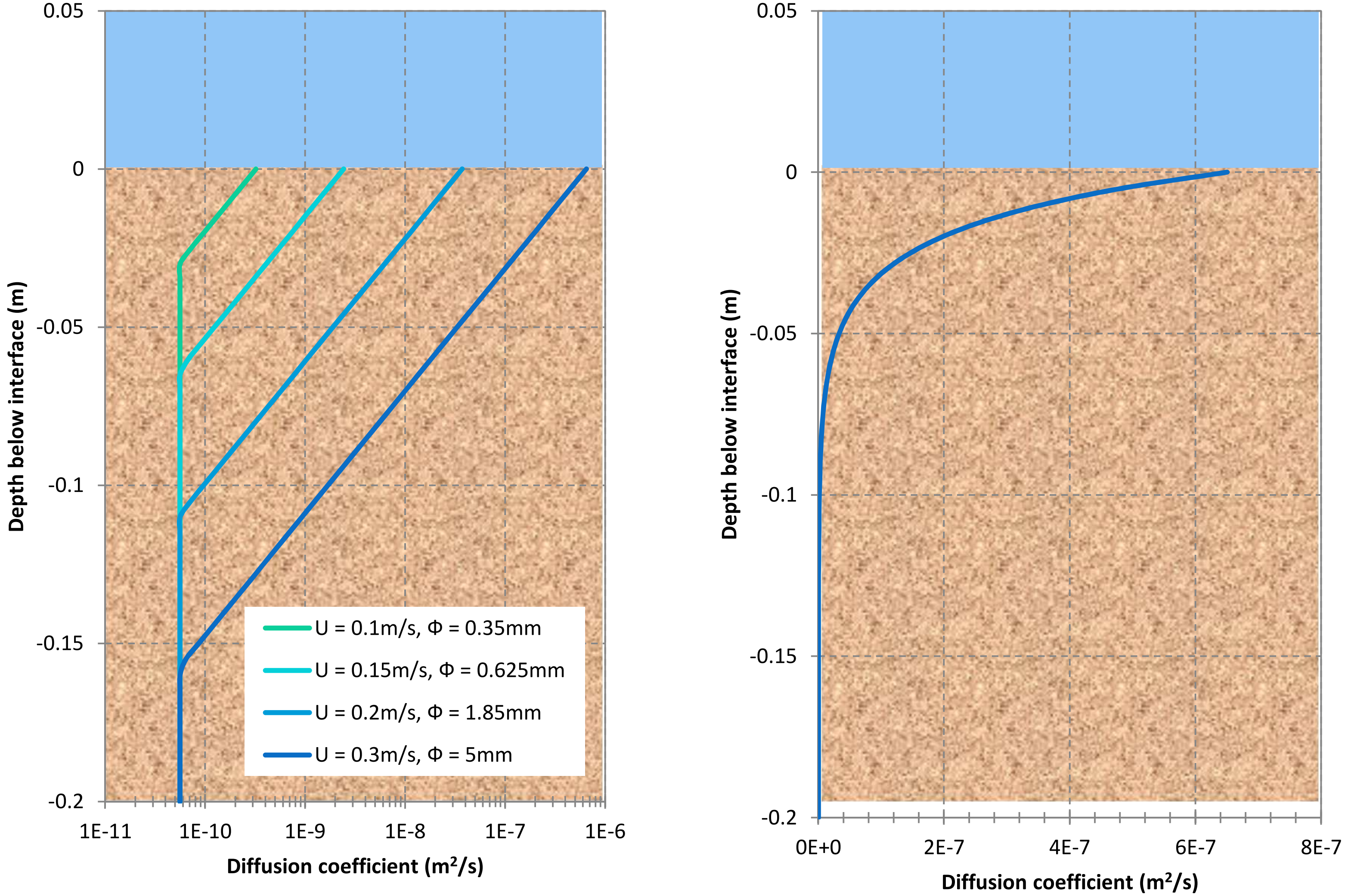
In-Bed Results





- Log variation in diffusion coefficient with depth

Predicted Vertical Variation



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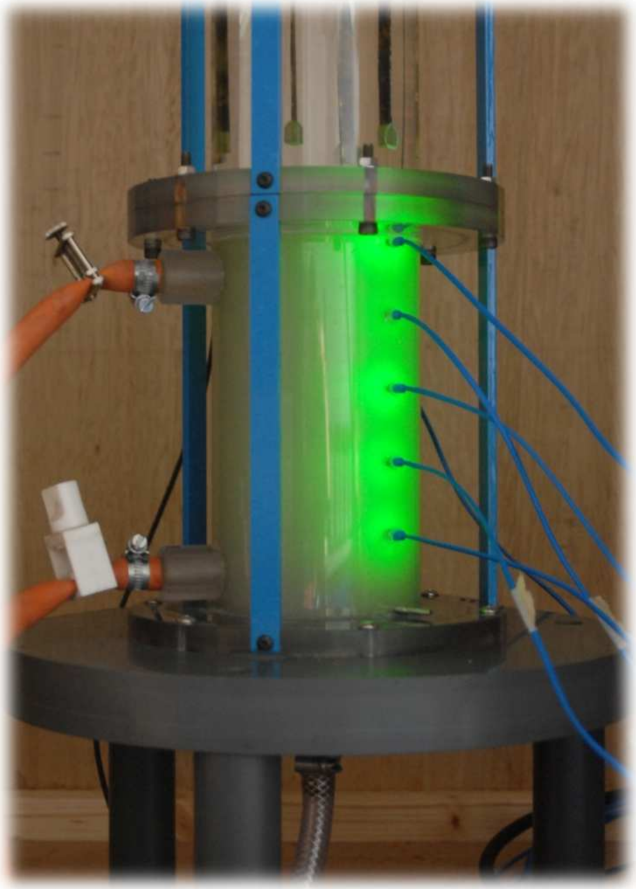
Conclusions

- Prediction of effective exchange coefficient given u_*, K and depth below interface based on laboratory data

- Define an ‘active’ layer affected by a pollutant from water column using simple numerical model



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