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L Gond, E Mignot, J Le Coz, L Kateb. Mixing in rivers under complex conditions. Journée du GIS HED2 (Groupement d'Intérêt Scientifique "Hydraulique pour l'Environnement et le Développement Durable"), Société Hydrotechnique de France (SHF) / GIS-HED, Nov 2019, Marne la vallée, France. cea-02972469

HAL Id: cea-02972469

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Submitted on 20 Oct 2020

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Mixing in rivers under complex conditions

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Mixing in rivers under complex conditions

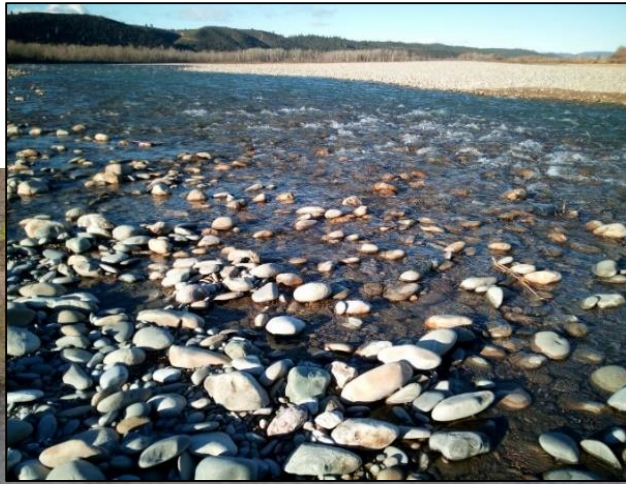
1/ Goal

2/ Theoretical aspects

3/ Field procedure and application



1. Goal



Evaluate the variability of the transverse mixing coefficient in inhomogenous rivers



2. Theoretical aspects

Simulation of a pollutant release in river



Advection-diffusion in turbulent regime

$$\frac{\partial c}{\partial t} + \bar{u}_i \frac{\partial c}{\partial x_i} = D \frac{\partial^2 c}{\partial x_i^2} + \frac{\partial \left(\epsilon_{ti} \frac{\partial c}{\partial x_i} \right)}{\partial x_i}$$

- D = molecular diffusivity
- ϵ_{ti} = turbulent diffusivity
- \bar{u}_i = Time-averaged velocity vector
- c = Concentration
- overbar = time-averaged
- x = space, t = time, $i=1,2,3$

Scalar dispersion in rivers is governed by:

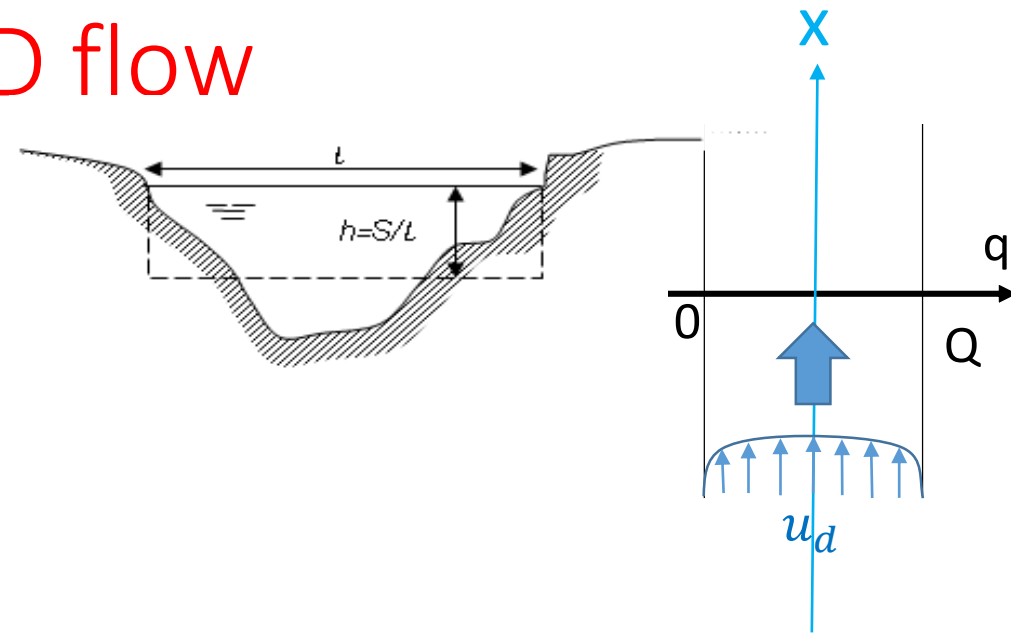
- 1/ molecular diffusion
- 2/ turbulent diffusion
- 3/ advection by secondary currents + recirculation zones



Simplification for a 1D flow

Hypotheses =

- * **Turbulent** regime $\rightarrow D \ll \epsilon_t$
- * **Uniform 1D horizontal** flow \rightarrow depth averaging: $\overline{U_x} = u_d(z)$ and $U_z = U_y = 0$
- * **Vertical mixing** \gg transverse mixing \rightarrow vertical dispersion neglected
- * Considering the **averaged** transverse mixing coefficient E_z



Streamtube model equation

$$\frac{1}{u_d} \frac{\partial c_d}{\partial t} + \frac{\partial c_d}{\partial x} = \frac{\partial}{\partial q} (\epsilon_z u_d h^2 \frac{\partial c_d}{\partial q})$$

Constant coefficient equation

$$\frac{1}{u_d} \frac{\partial c_d}{\partial t} + \frac{\partial c_d}{\partial x} \approx E_z \psi U H^2 \frac{\partial^2 \bar{c}_d}{\partial q^2}$$

Yotsukura & Cobb (1972)

- $\rightarrow u_d$ = local streamwise velocity – h = local depth
- $\rightarrow c_d$ = depth average concentration
- $\rightarrow z$ = transverse position
- $\rightarrow \epsilon_z$ = transverse mixing coefficient

$$q = \int_0^z u_d(\delta) h(\delta) d\delta = \text{cumulative discharge}$$

- $\rightarrow E_z$ = averaged transverse mixing coefficient

$$\psi U H^2 = \frac{1}{Q} \int_0^Q u_d(q) h(q)^2 dq$$

Instantaneous injection at $q=q_0$

Time-dependent equation : $c_d(x, q, t = 0) = c_d(x, q, t = +\infty) = 0$

$$\int dt \left(\frac{1}{u_d} \frac{\partial c_d}{\partial t} + \frac{\partial c_d}{\partial x} \right) \approx E_z \psi U H^2 \frac{\partial^2 \bar{c}_d}{\partial q^2}$$

$$\frac{\partial \theta}{\partial x} = E_z \psi U H^2 \frac{\partial^2 \theta}{\partial q^2}$$

Local dosage : θ

$$\theta(x, q) = \int_0^\infty C(x, q, t) dt$$

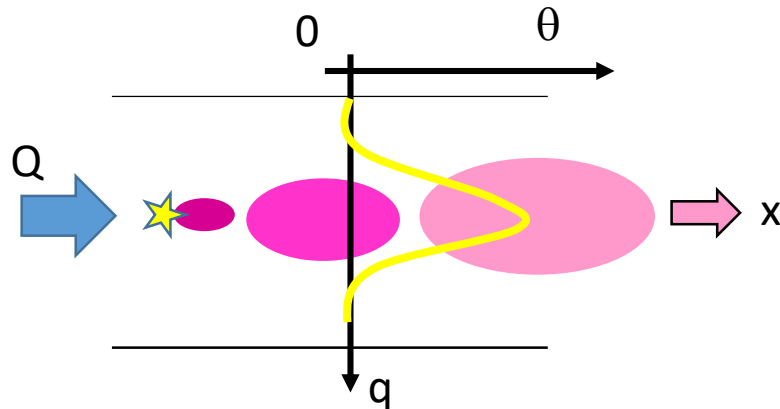
General solution :

$$\theta_u(x, q) = \frac{M}{\sqrt{4\pi E_z \psi U H^2 x}} \exp\left[-\frac{q^2}{4 E_z \psi U H^2 x}\right]$$

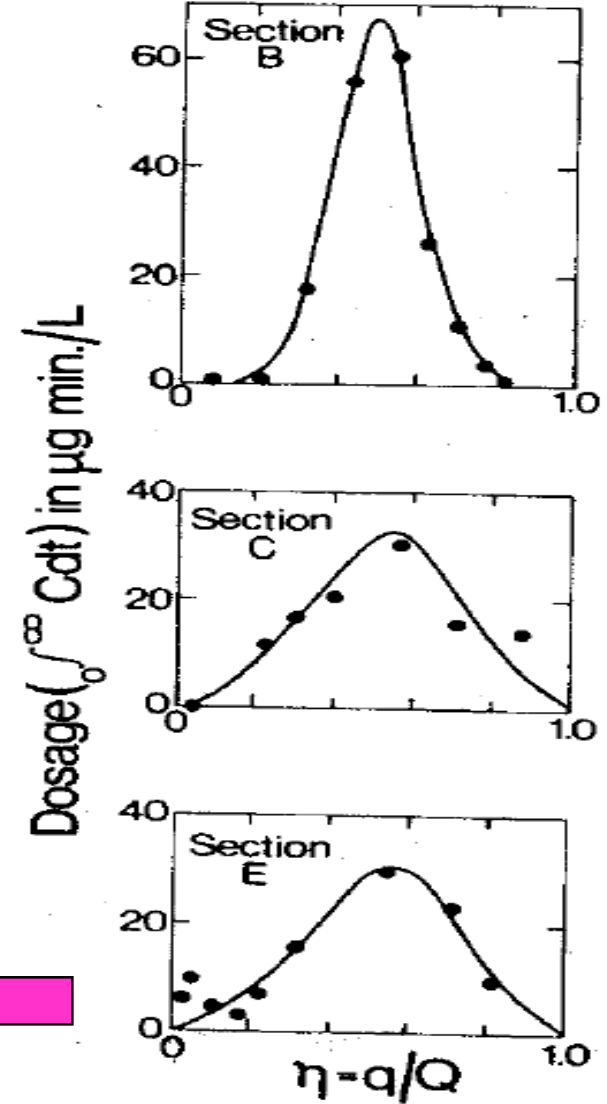
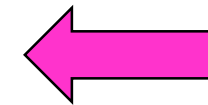
Solution with mirror :

$$\theta(x, y) = \theta_u(x, q + q_0) + \theta_u(x, q - q_0) + \sum_{n=1}^N \theta_u(x, 2nQ \pm q \pm q_0) + \theta_u(x, 2nQ \pm q \pm q_0)$$

(Seo & al. (2016))



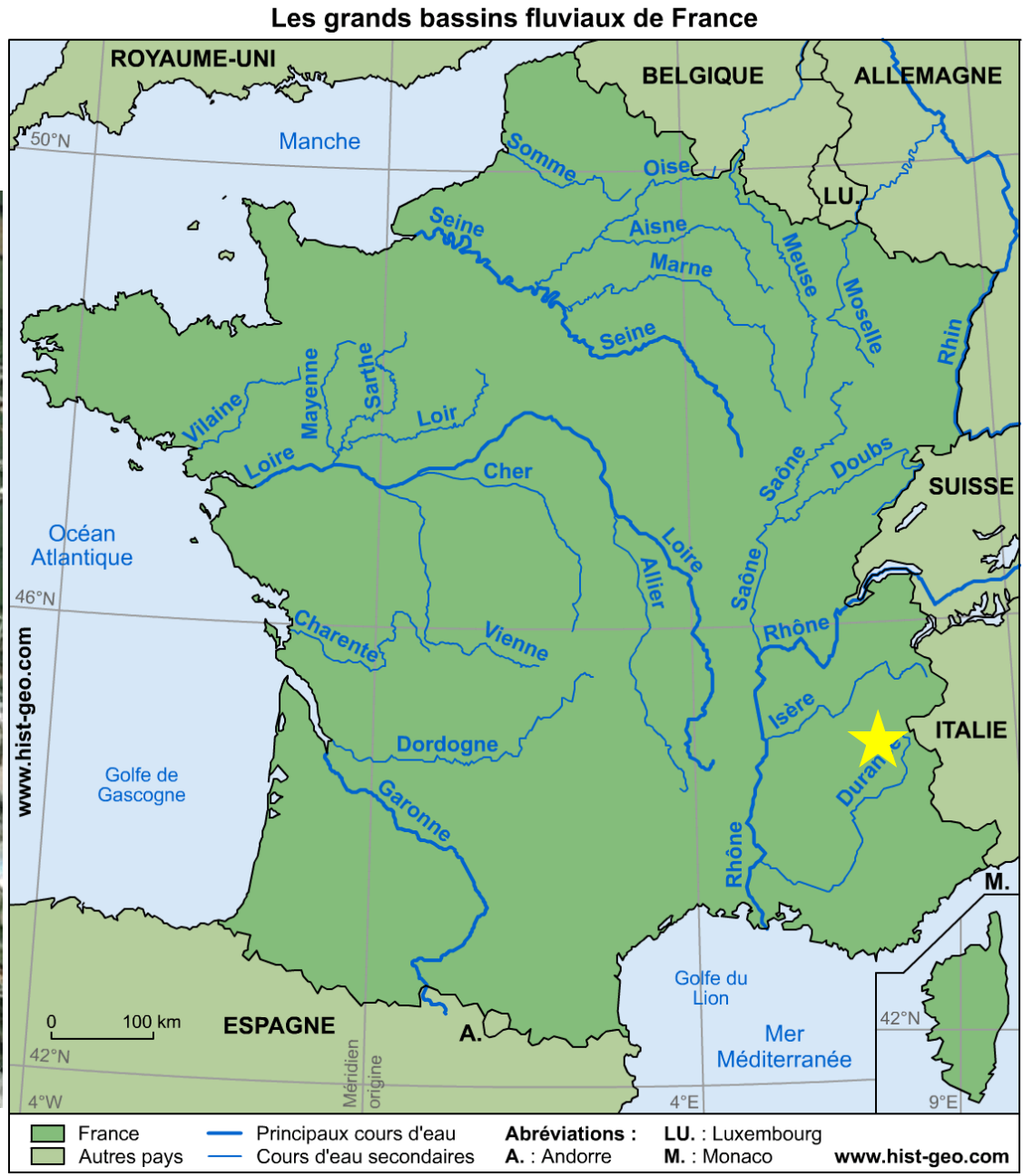
$E_z = \text{best fit}$



(Beltaos, 1980)

3.1 Field procedure : Application to the Drac River

Drac River, France



Step 1 : Determine segments to study

Segments studied must :

- Have an easy access
- Have a homogenous geometry (roughness, width, depth, slope)
- Be long enough (too short -> no mixing measurable)
- Not too far from injection (-> complete mixing)



Step 2 : Calibrate probes

Fluorescence probes :

- probes = Albillia GNU-FL30 series 500 & 900 *6
- probes = TQ-tracer *2

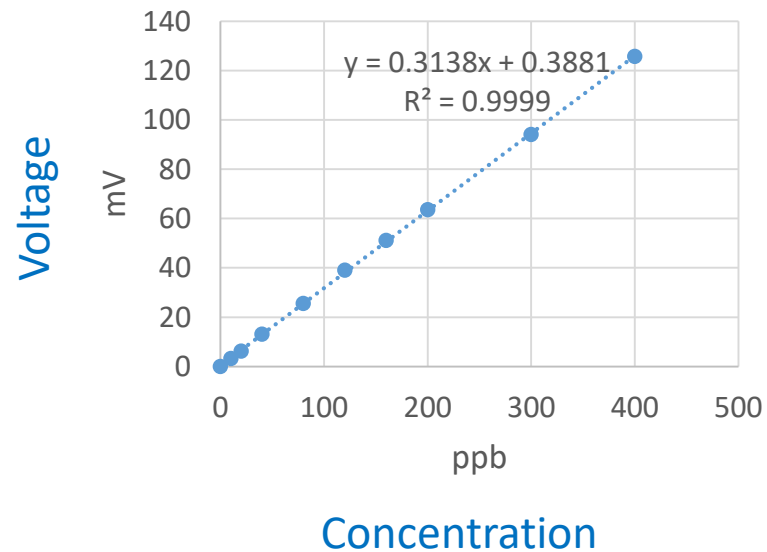


Calibration with several controled Rhodamine concentration

+ Temperature corrections

(EDF)

Calibration Albillia probe



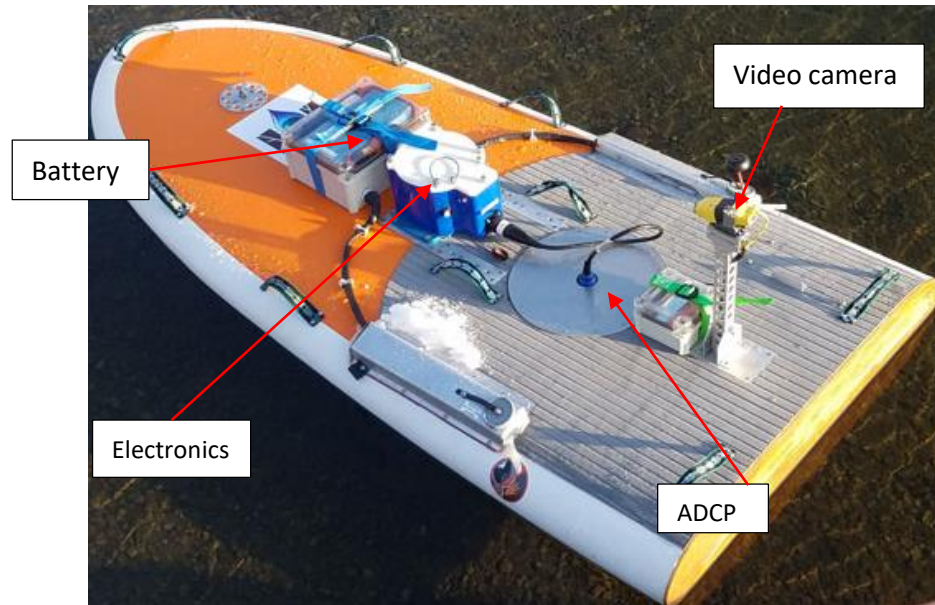
Albillia



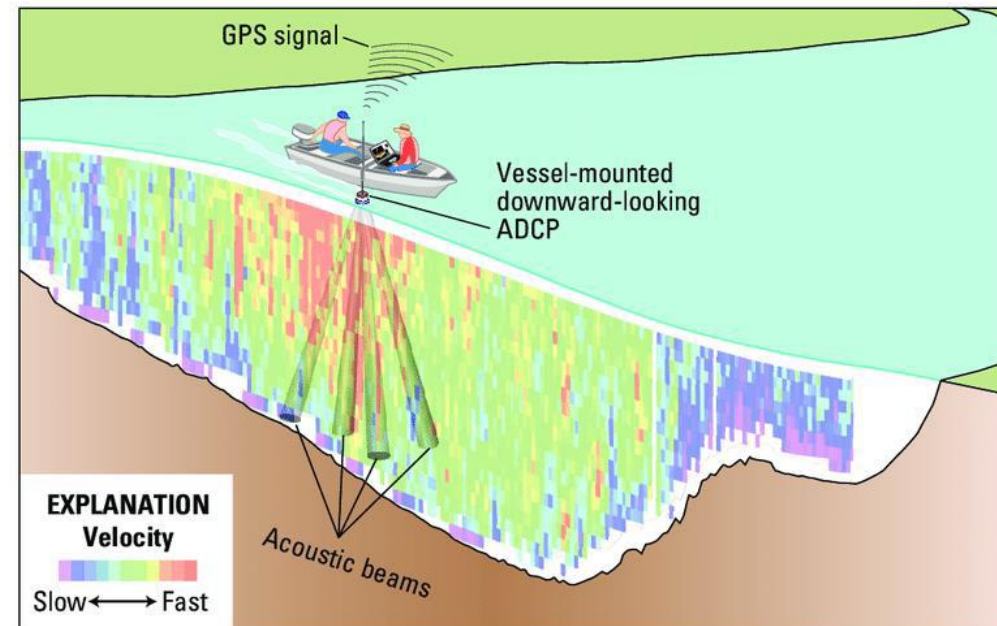
TQ-tracer

Step 3 : Measure bathymetry + velocity field at each survey cross sections

ADCP (Acoustic Doppler Current Profiler)

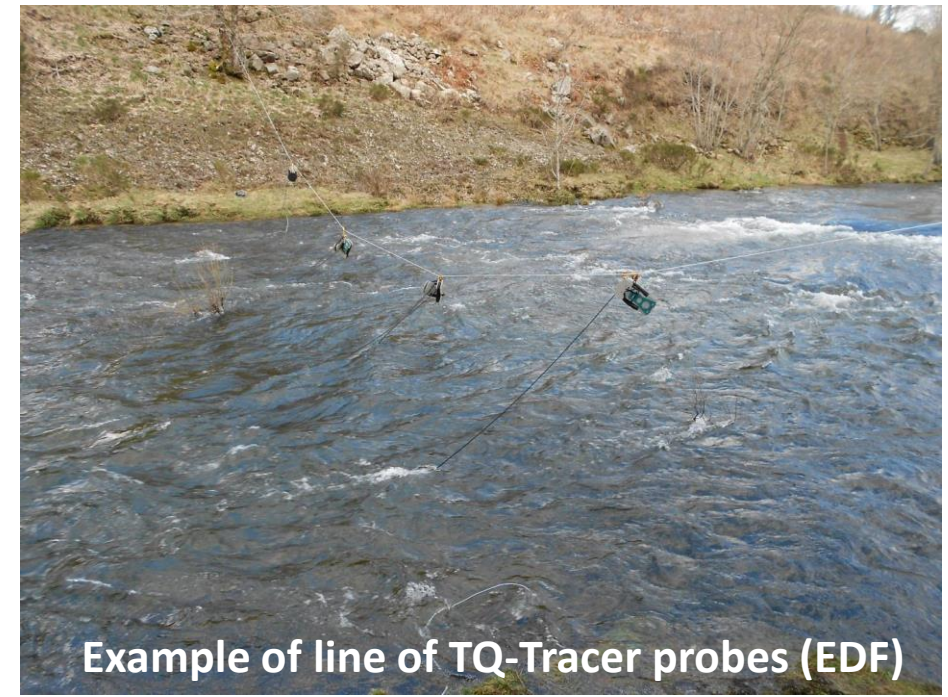


ADCP installed on a River-Drone

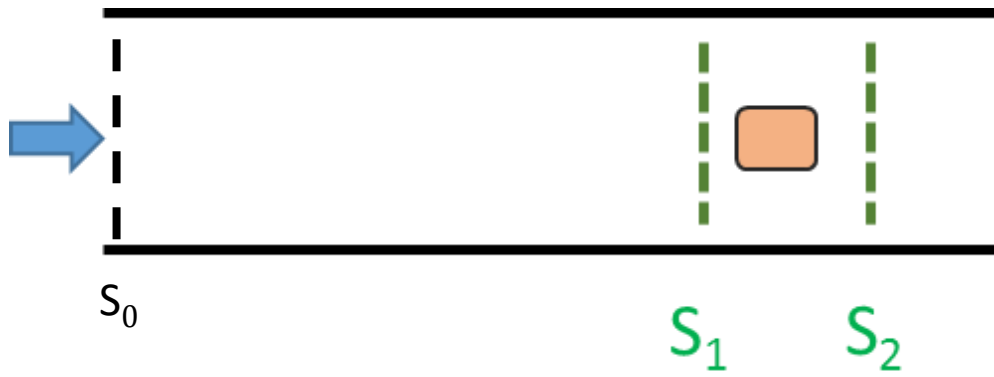


ADCP system (from Muller & Wagner, 2013)

Step 4 : Install sensors along 2 cross sections (near-bed)



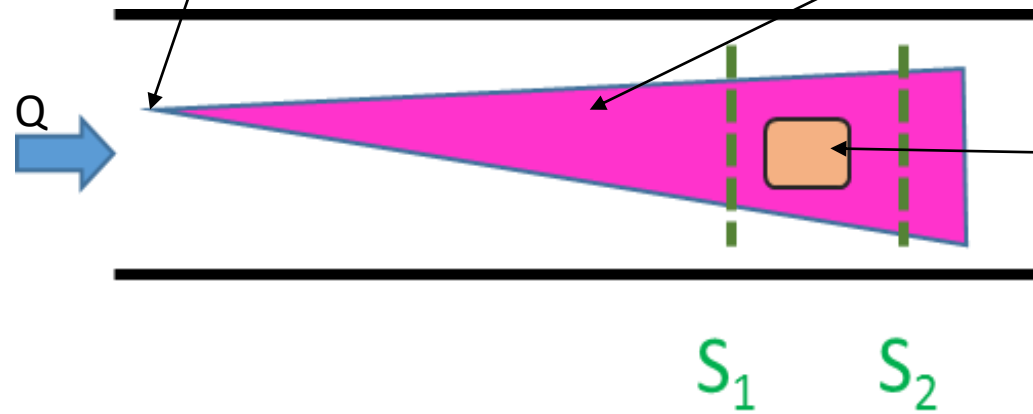
Example of line of TQ-Tracer probes (EDF)



Survey cross-sections



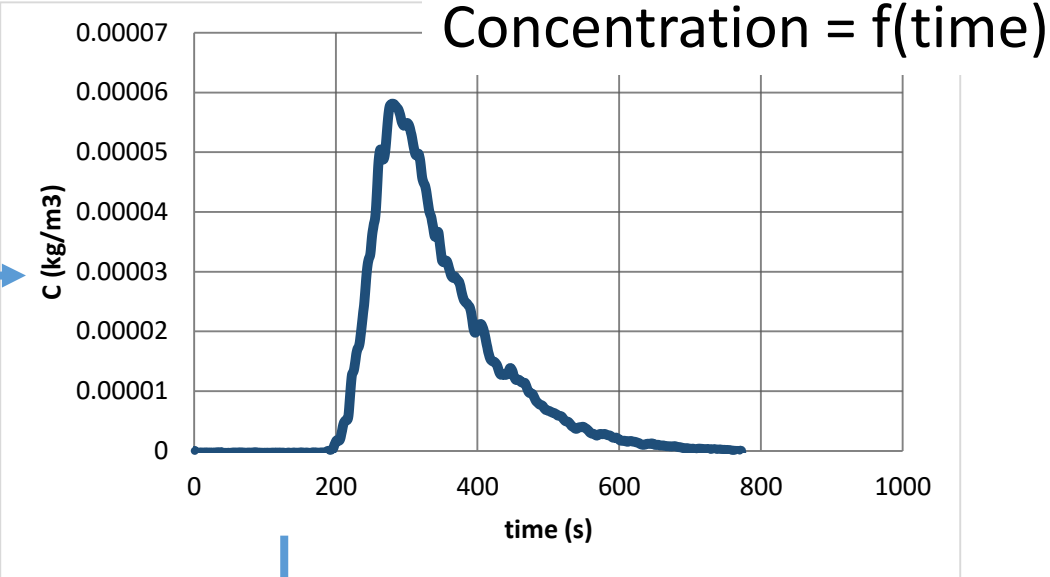
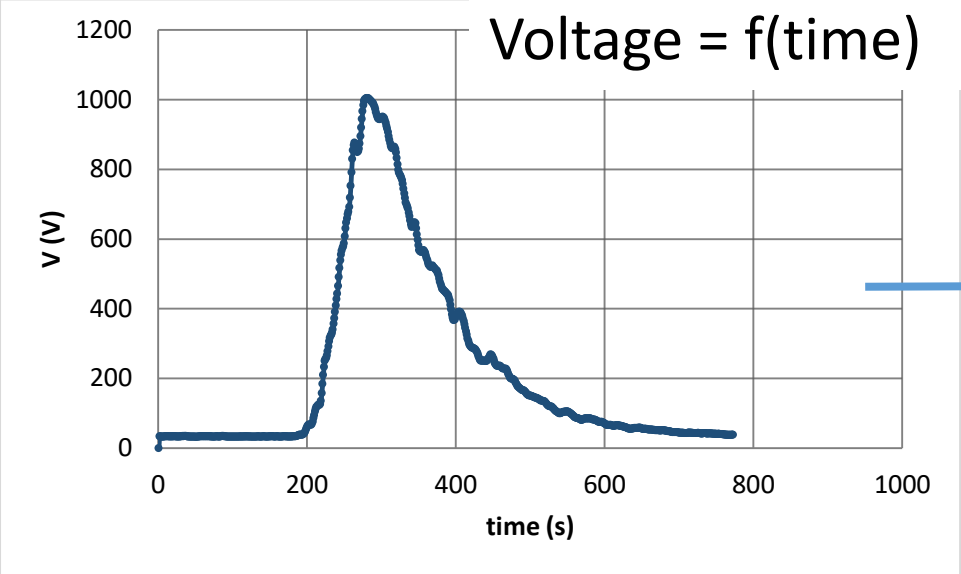
Step 5 : Sudden Rhodamine injection upstream



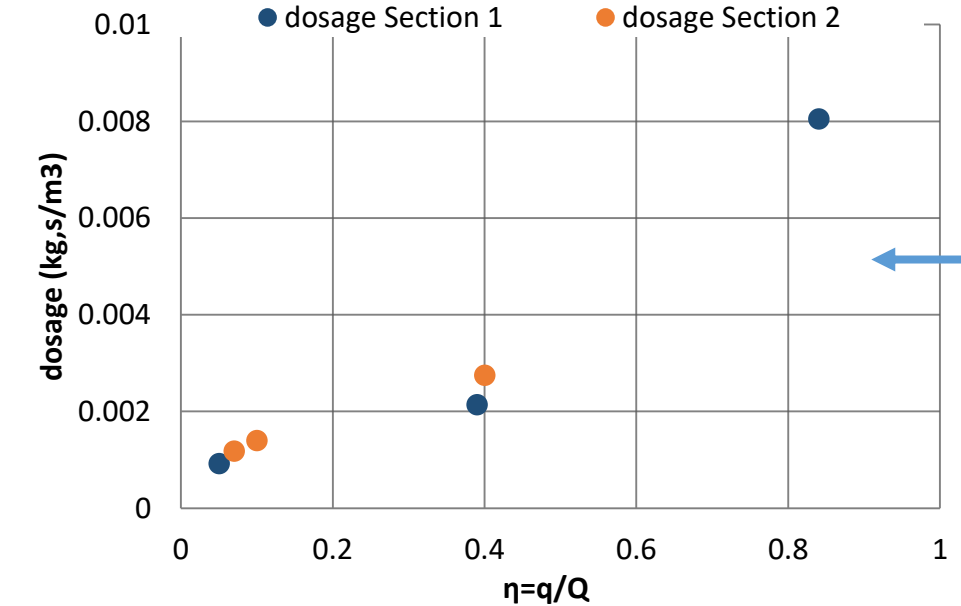
Survey cross sections



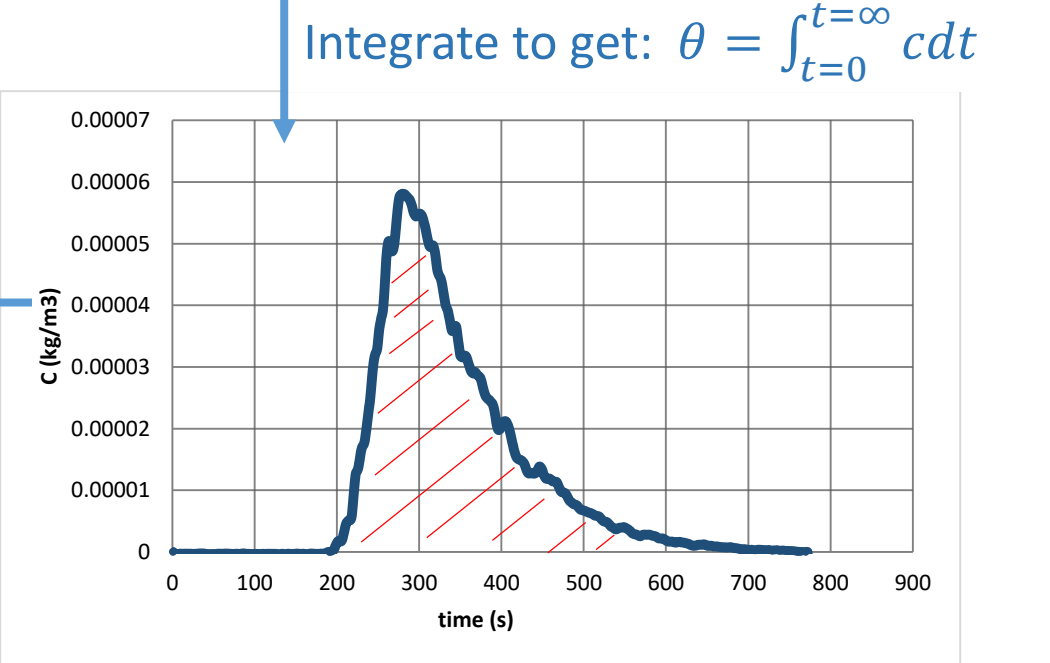
Step 6 : Measure $C(t)$ on each probe, evaluate θ , $\theta=f(q)$



Using Calibration + temperature correction



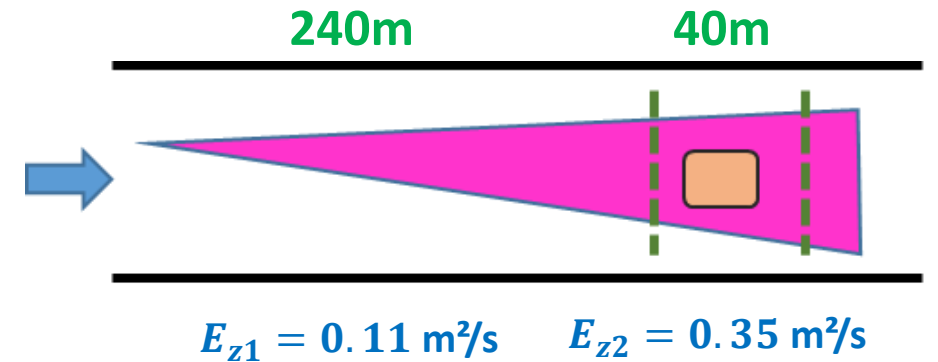
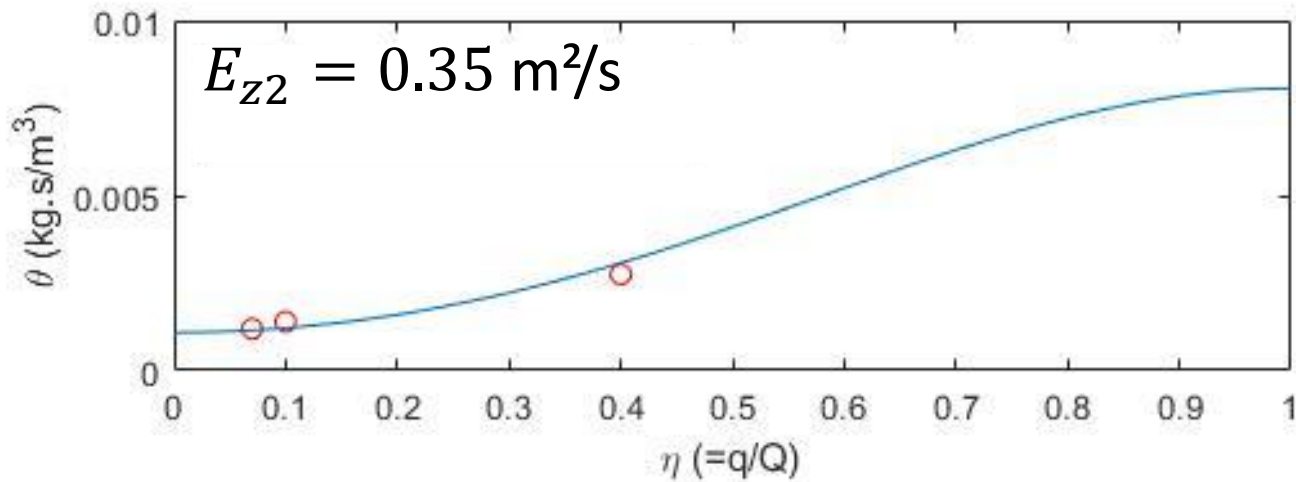
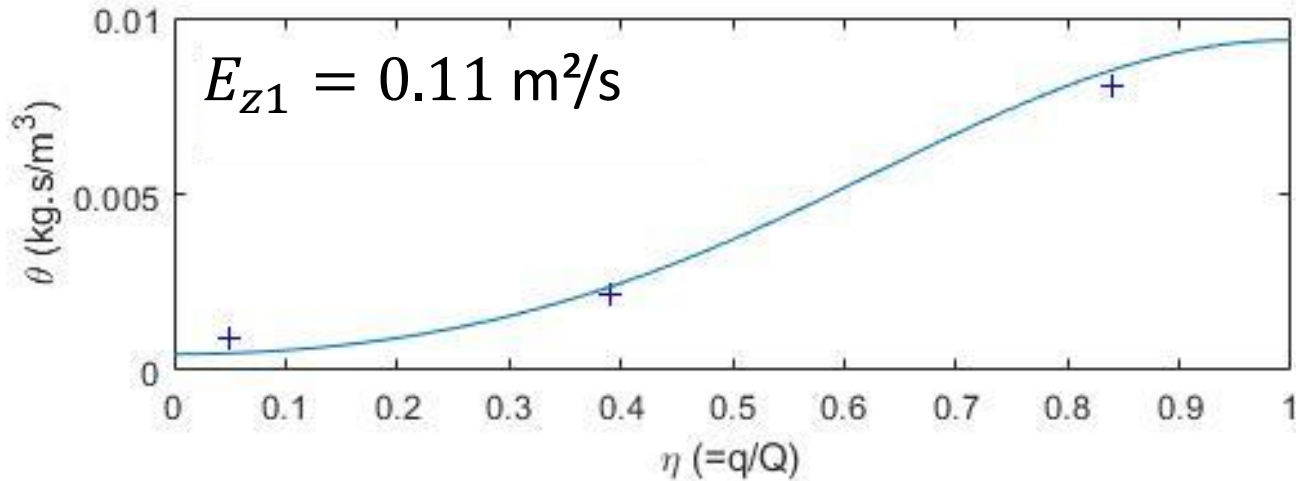
Aggregate all data



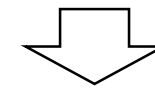
Integrate to get: $\theta = \int_{t=0}^{t=\infty} c dt$

Step 7 : Fit analytical model & estimate E_z

$$\frac{\partial \theta}{\partial x} = E_z \psi U H^2 \frac{\partial^2 \theta}{\partial q^2}$$

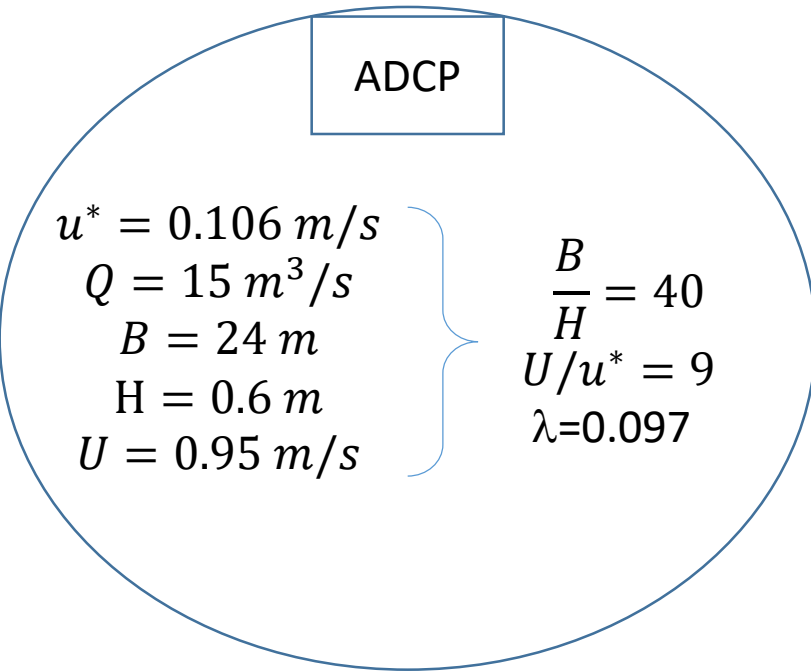


From injection to S1 : $E_{z1} = 0.11 \text{ m}^2/\text{s}$
 From S1 to S2 : $E_{z2} = 0.35 \text{ m}^2/\text{s}$



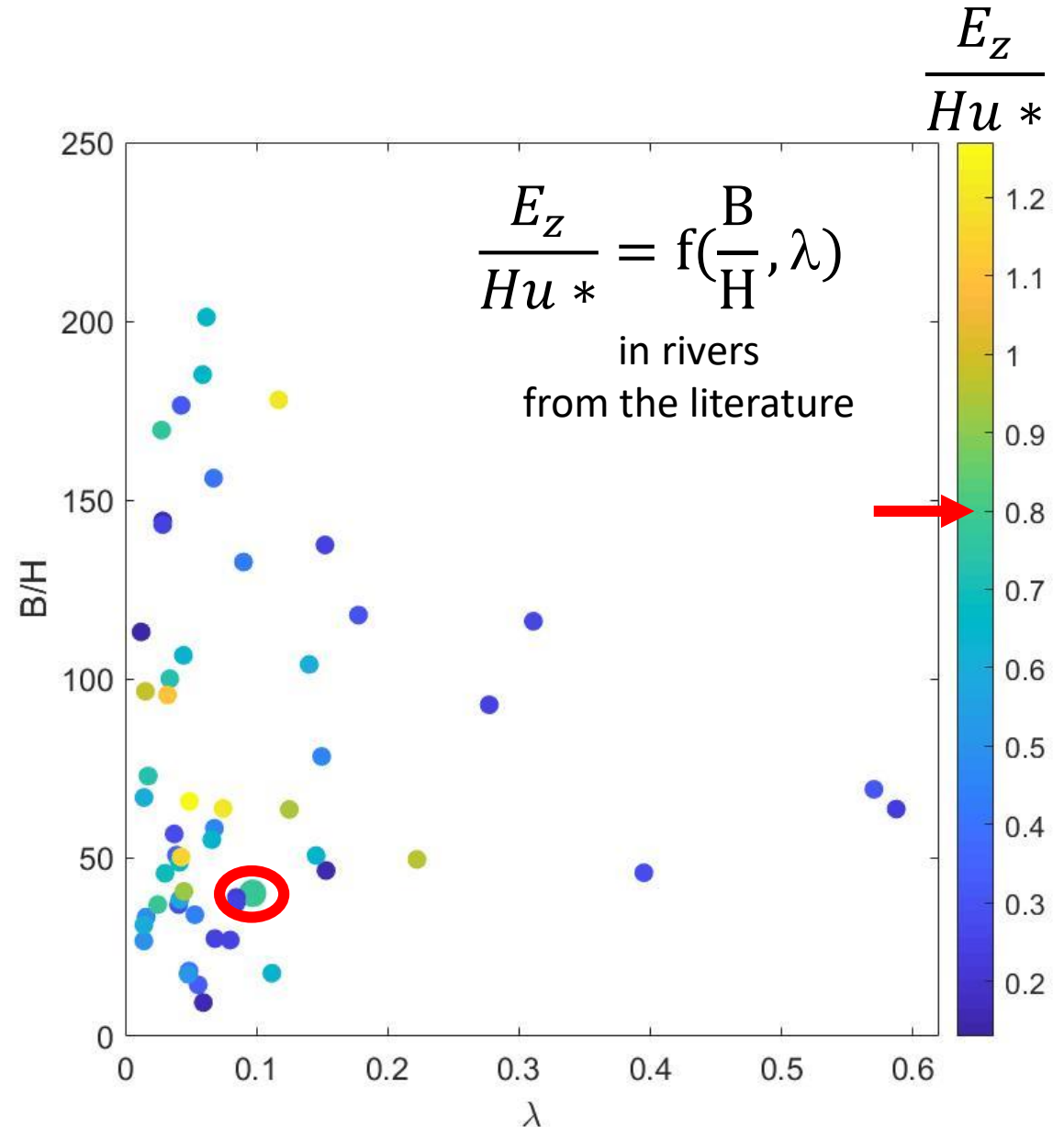
Impervious emerging bloc strongly increase the transverse mixing coefficient

Comparison of E_{z1} with literature data



$$\frac{E_{z1}}{Hu^*} = 0.8$$

B/H = channel aspect ratio
 λ = Darcy friction coefficient



3.2 Application to the Durance river



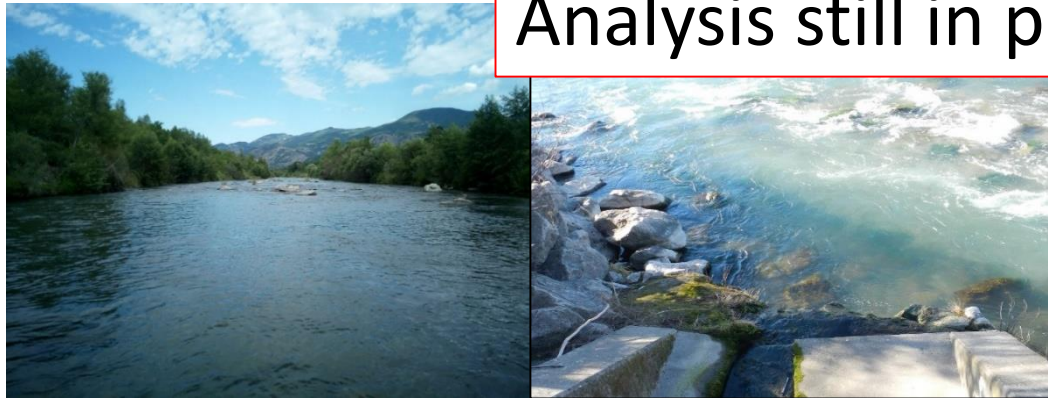
Many different bed conditions on a small area :



Shallow waters with rocks



Boulders



Channel with boulders


Analysis still in progress !



Deep and slow waters


Perspectives :

- Reproduce hydraulic conditions in laboratory (LMFA – INSA Lyon)

 Study of different flows with rough beds

 Effect of roughness height on the mixing coefficient

- Presentation of the results at RiverFlow 2020

 Scientific paper

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