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

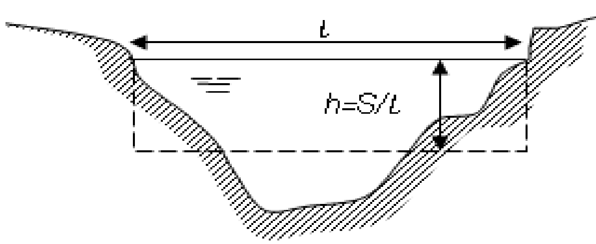
Advection-diffusion in turbulent regime

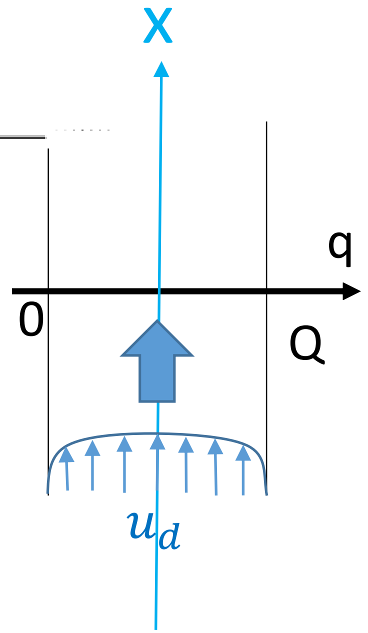
$$\frac{\partial c}{\partial t} + \overline{u_i}\,\frac{\partial c}{\partial x_i} = D\,\frac{\partial^2 c}{\partial x_i^2} + \frac{\partial\left(\varepsilon_{ti}\frac{\partial c}{\partial x_i}\right)}{\partial x_i}$$

- D = molecular diffusivity
- ε_{ti} = turbulent diffusivity
- $\overline{u_i}$ = 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 ➔ D<< ε_t

* **Uniform 1D horizontal** flow ➔ depth averaging: $\overline{\boldsymbol{U_x}} = \boldsymbol{u_d}\ (\boldsymbol{z})$ and U_z=U_y=0

* **Vertical mixing** >> transverse mixing ➔ vertical dispersion neglected

* Considering the **averaged** transverse mixing coefficient E_z

Streamtube model equation

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

-> u_d = local streamwise velocity – h = local depth
-> c_d = depth average concentration
-> z = transverse position
-> ε_z= transverse mixing coefficient

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

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)

-> 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 : $c_d(x,q,t=0) = c_d(x,q,t=+\infty) = 0$

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

$\int dt$

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

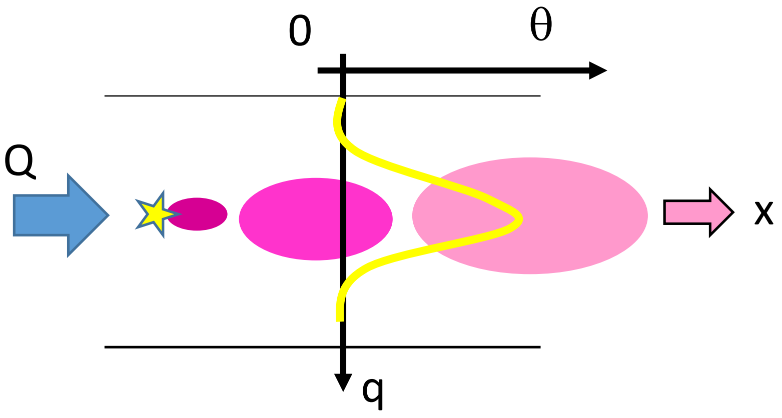
Local dosage θ :

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

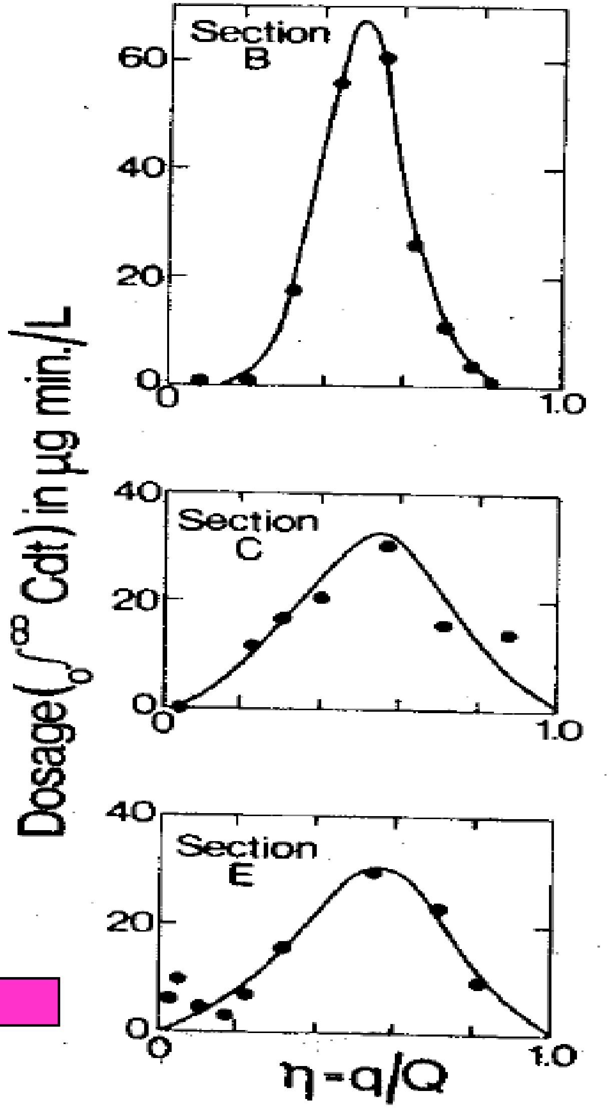
General solution : $\theta_u(x,q) = \frac{M}{\sqrt{4\pi E_z \psi U H^2 x}} exp\left[\frac{q^2}{4 E_z \psi U H^2 x}\right]$

Solution with mirror : $\theta(x,y) = \theta_u(x, q+q_0) + \theta_u(x, q-q_0) + \sum_{n=1}^{N} \theta_u(x, 2n\mathrm{Q} \pm q \pm q_0) + \theta_u(x, 2n\mathrm{Q} \pm q \pm q_0)$

(Seo & al. (2016))



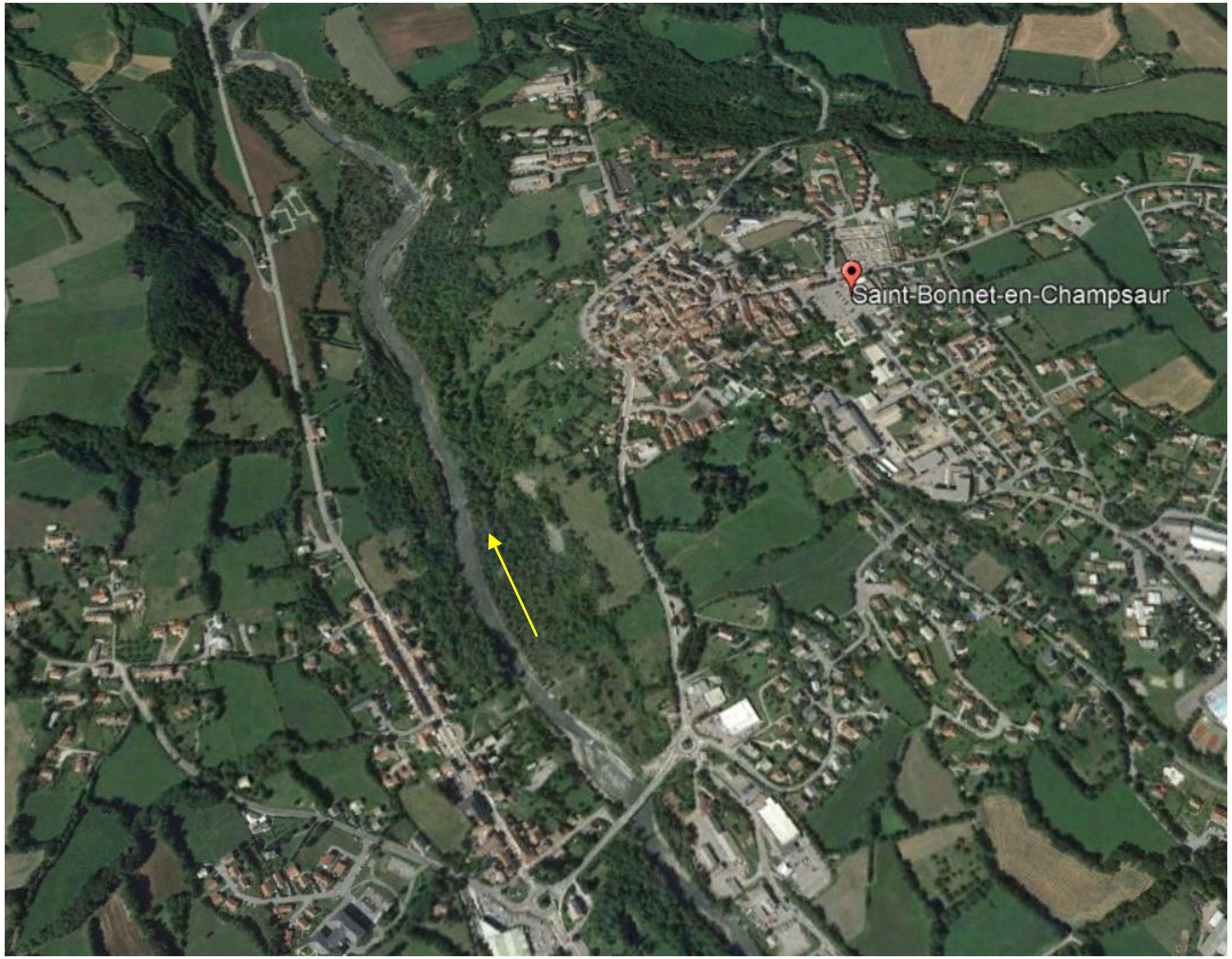
E_z = best fit

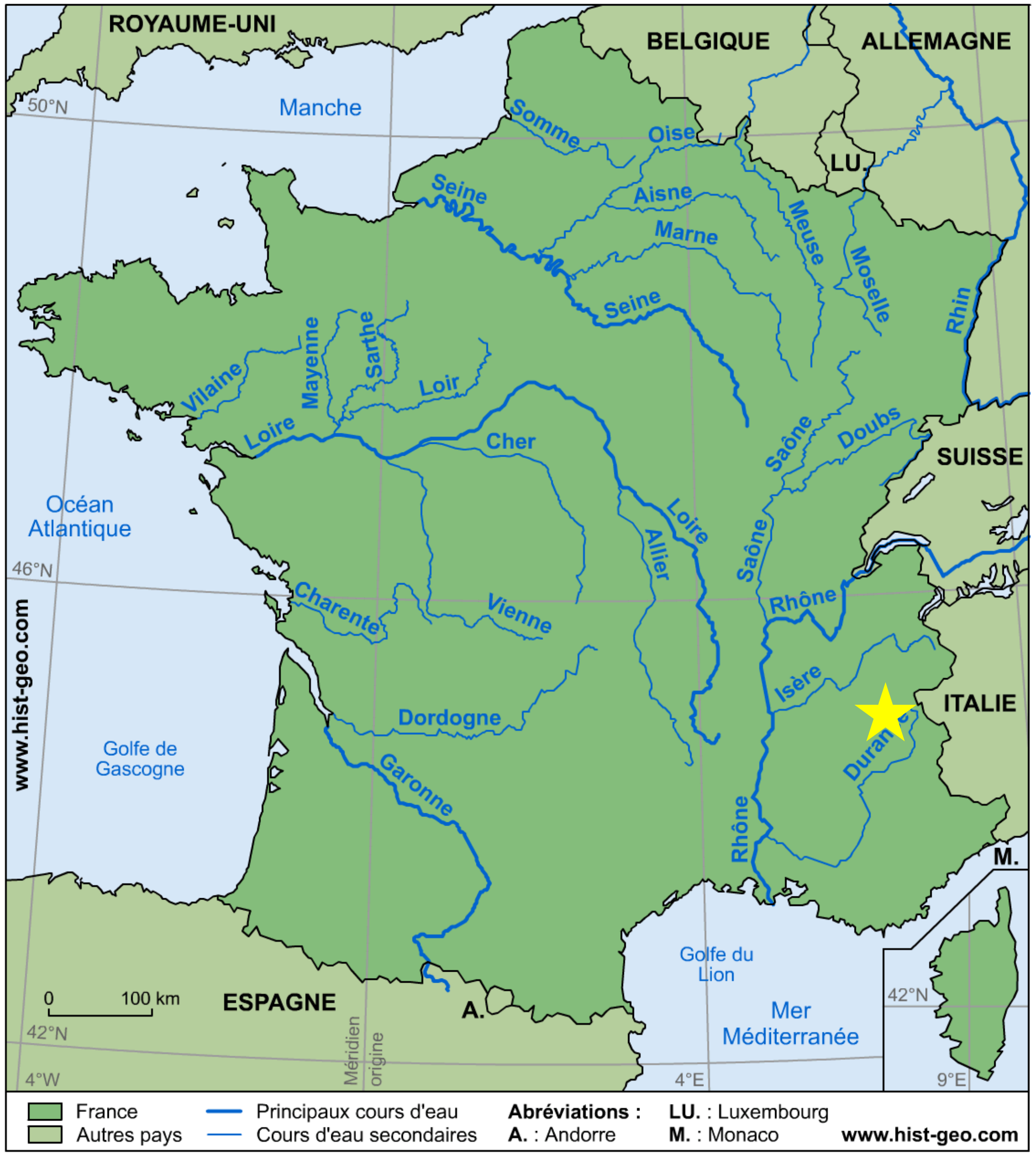


(Beltaos, 1980)

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

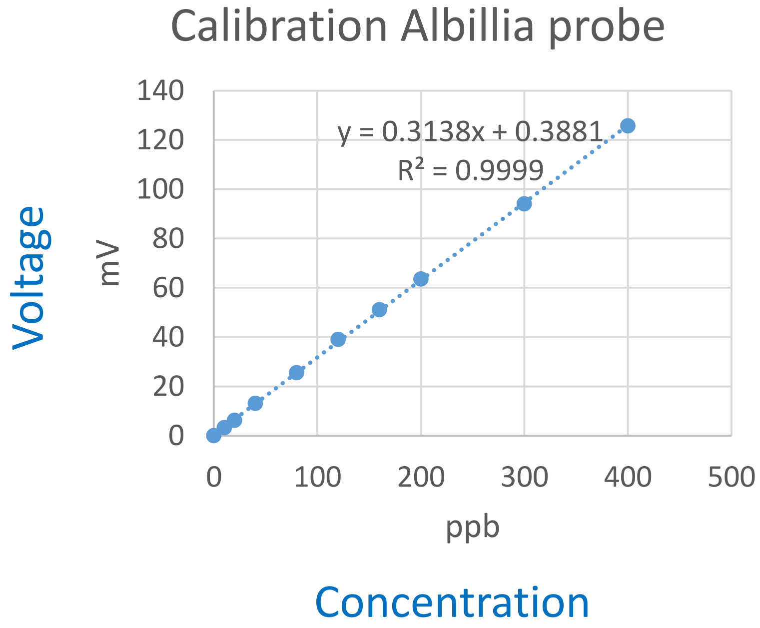
Fluorescence probes :

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

Calibration with several controled Rhodamine concentration

+ Temperature corrections

(EDF)

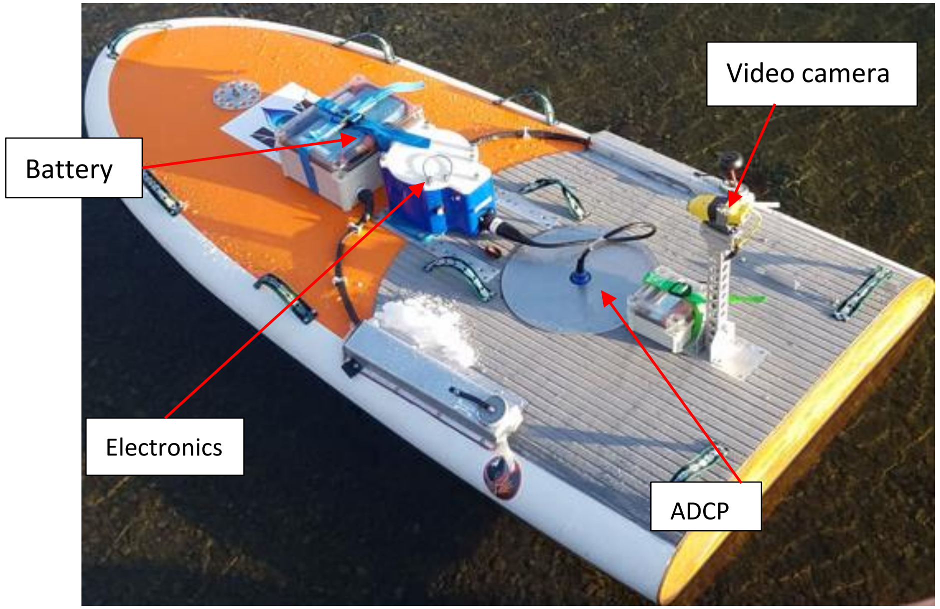


Albillia

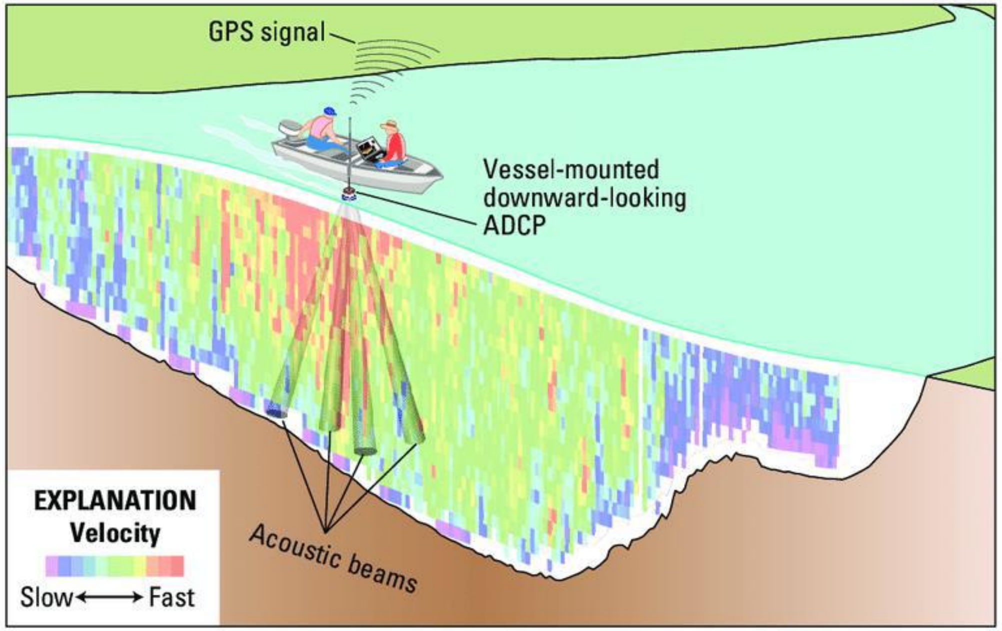
TQ-tracer

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

ADCP (Acoustic Doppler Current Profiler)

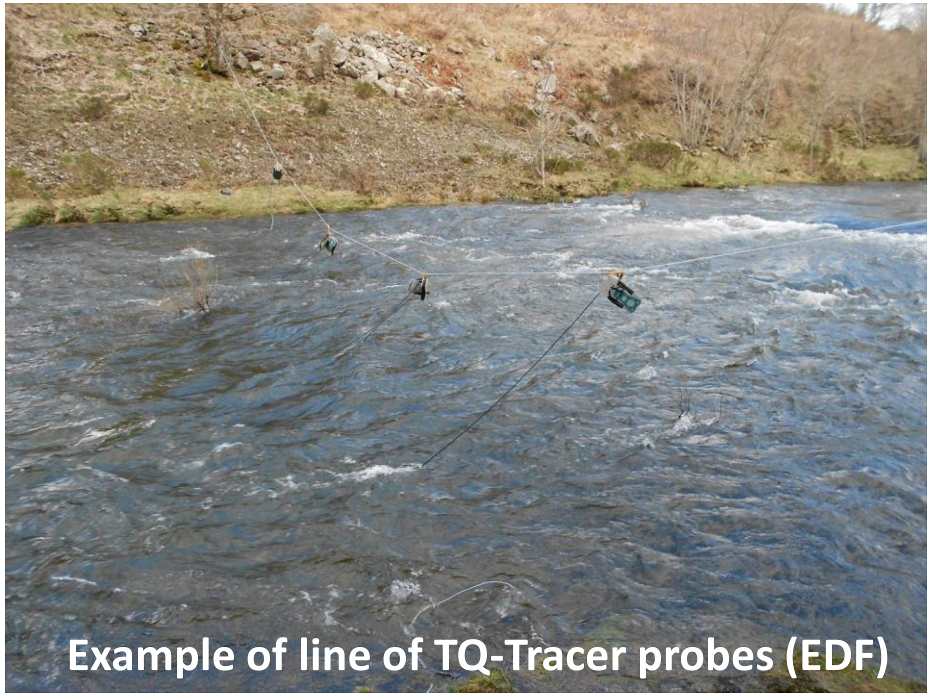


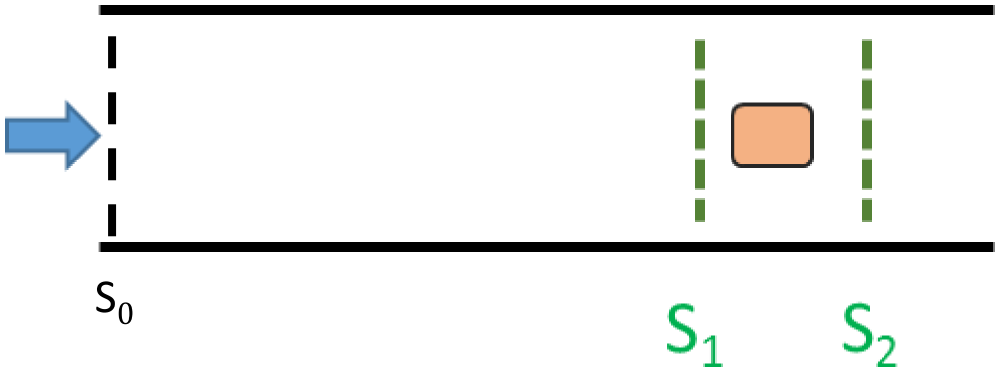
ADCP installed on a River-Drone



ADCP system (from Muller & Wagner, 2013)

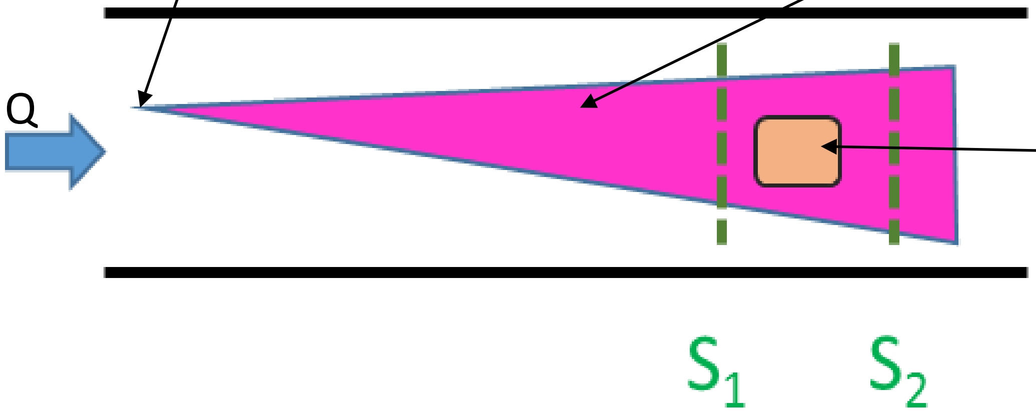
Step 4 : Install sensors along 2 cross sections (near-bed)


Example of line of TQ-Tracer probes (EDF)



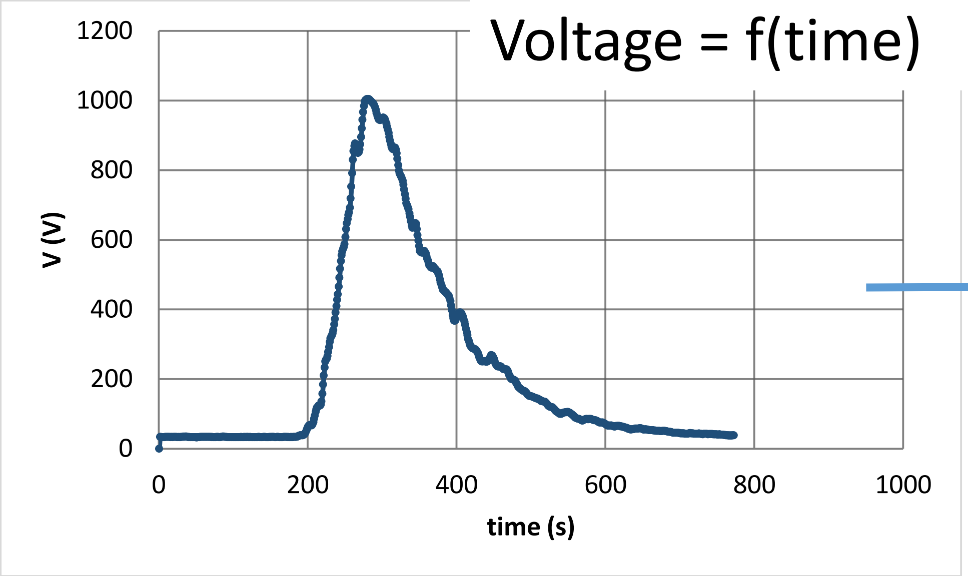
Survey cross-sections

Step 5 : Sudden Rhodamine injection upstream

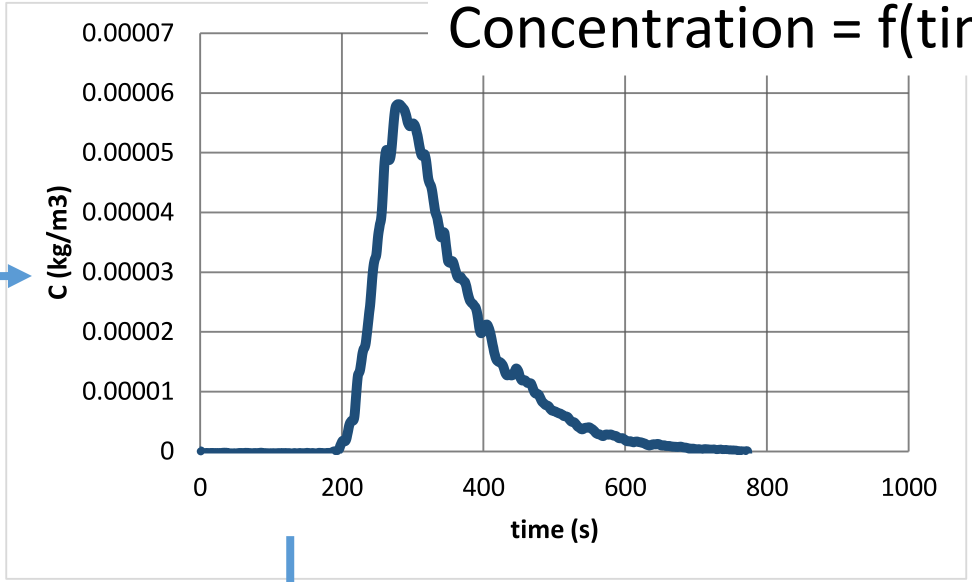


Survey cross sections

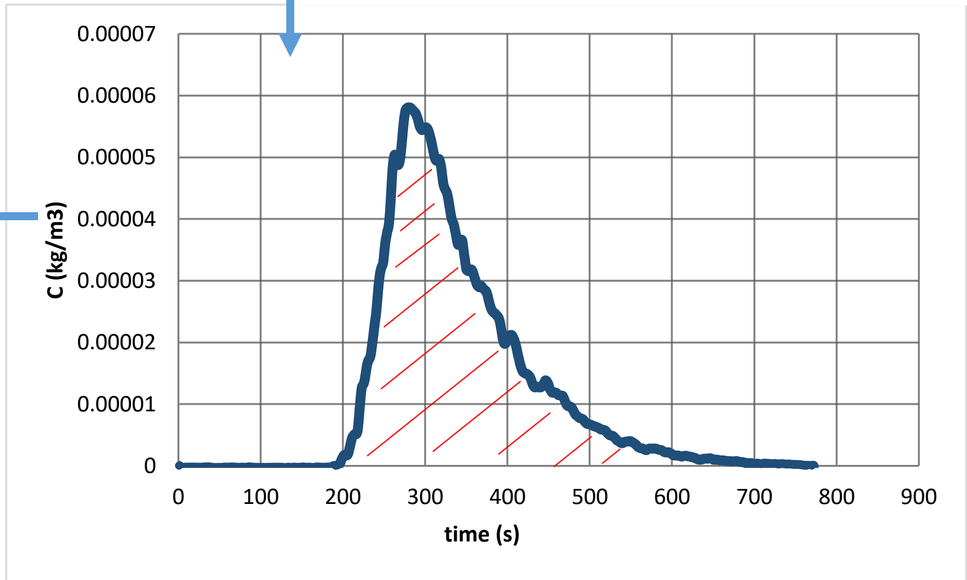
Step 6 : Measure C(t) on each probe, evaluate θ, θ=f(q)



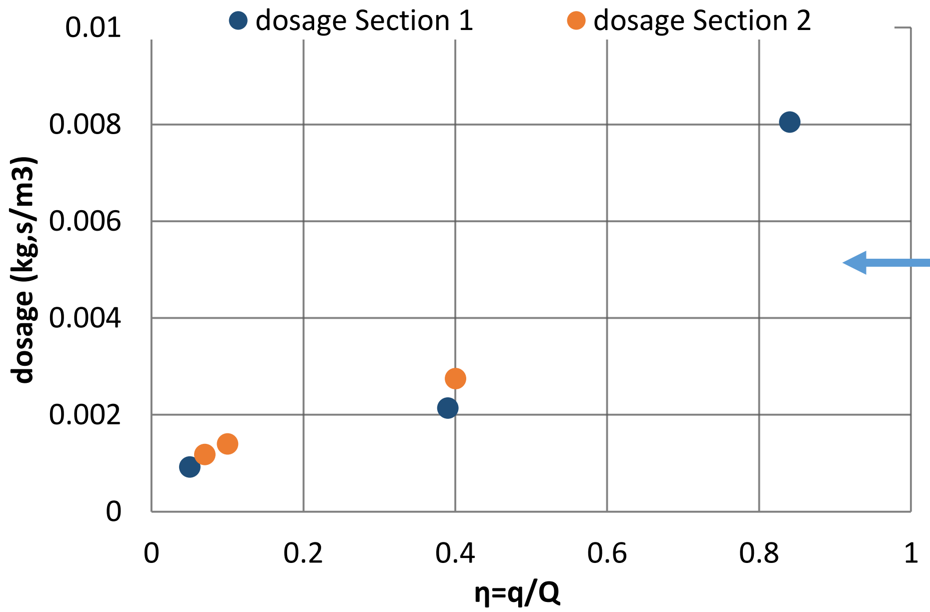
Using Calibration + temperature correction



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

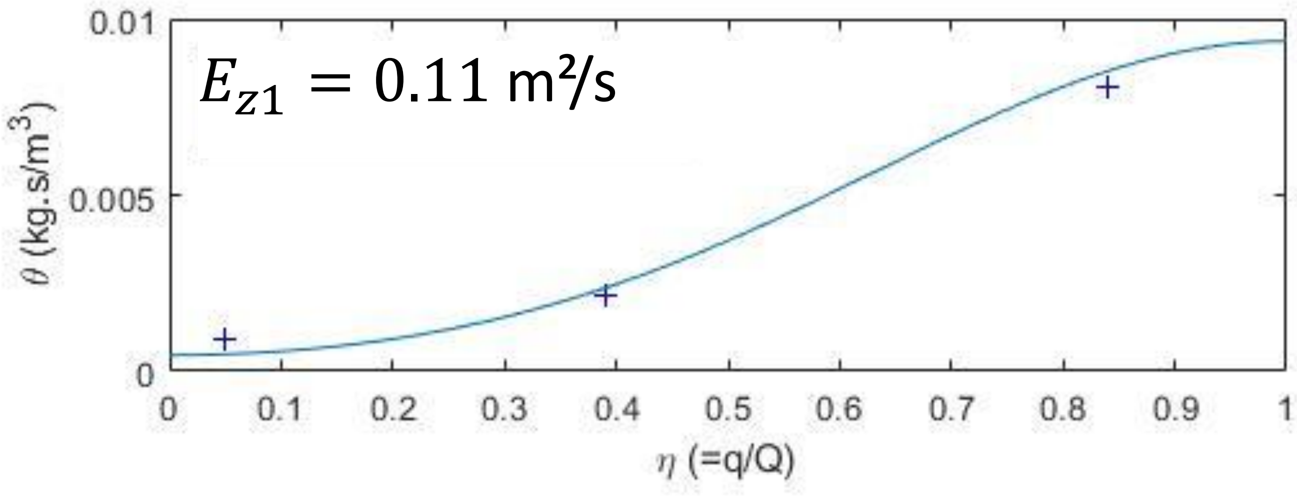


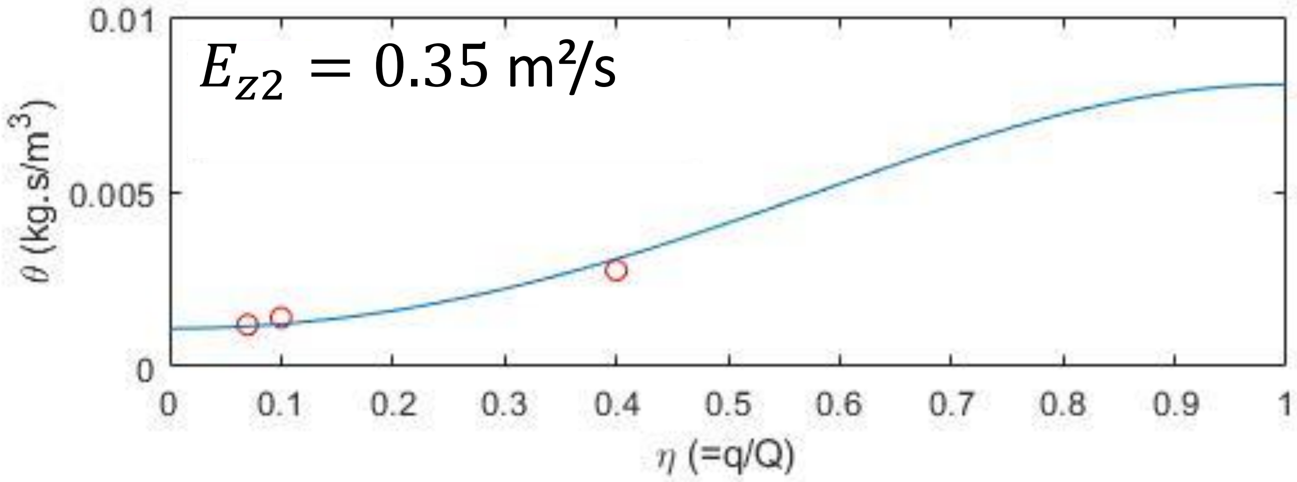
Aggregate all data

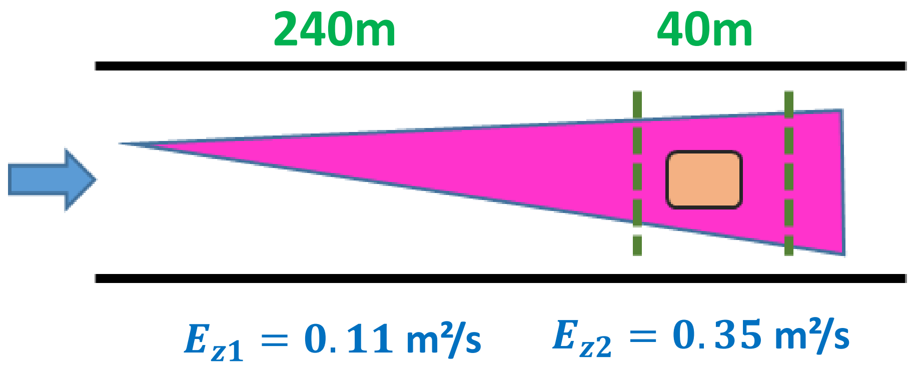


Step 7 : Fit analytical model & estimate E_z

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







From injection to S1 : $E_{z1} = 0.11$ m²/s
From S1 to S2: $E_{z2} = 0.35$ m²/s

⇩

Impervious emerging bloc strongly increase the transverse mixing coefficient

Comparison of E_{z1} with literature data

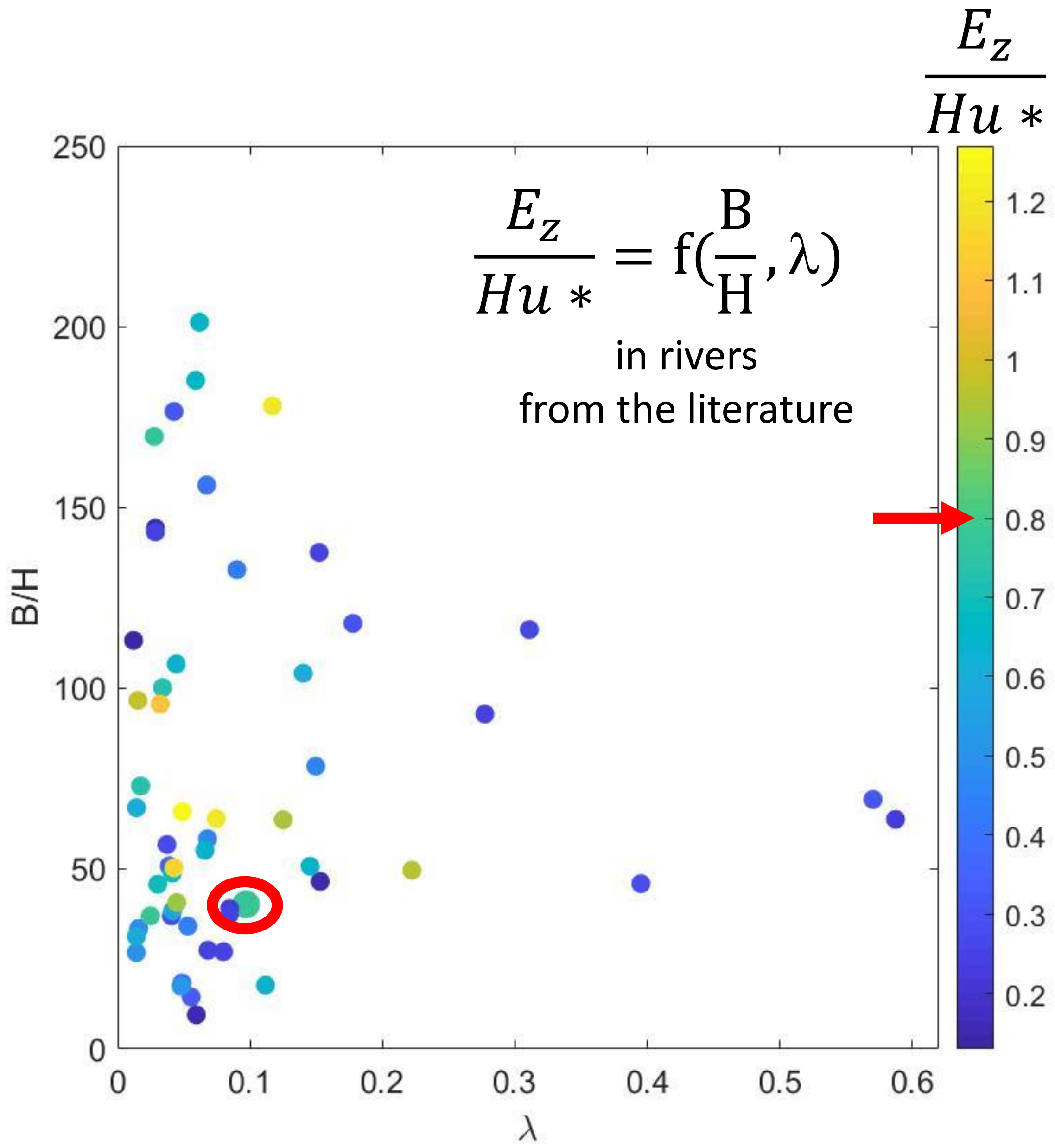
ADCP

$u^* = 0.106\ m/s$
$Q = 15\ m^3/s$
$B = 24\ m$
$\mathrm{H} = 0.6\ m$
$U = 0.95\ m/s$

$\frac{B}{H} = 40$
$U/u^* = 9$
λ=0.097

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

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

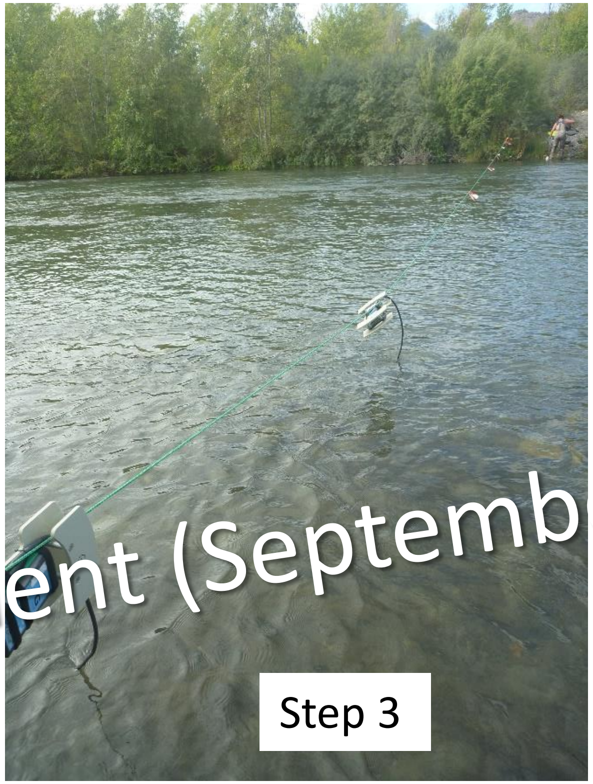


3.2 Application to the Durance river

Recent experiment (September 24th 2019)

Step 4

Step 1



Step 3

Step 2

18 transverse sections, 4 injection points :

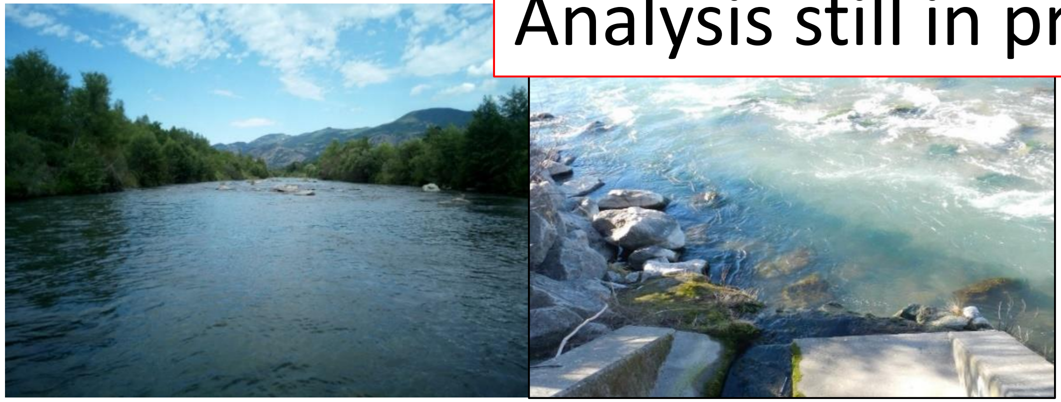
La Saulce, 05110

Many different bed conditions on a small area :

Shallow waters with rocks

Boulders

Analysis still in progress !



Channel with boulders

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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