



**HAL**  
open science

## River Flow 2020 Estimation of the transverse mixing coefficients in shallow gravel-bedded rivers

L. Gond, Emmanuel Mignot, J. Le Coz, L. Kateb

► **To cite this version:**

L. Gond, Emmanuel Mignot, J. Le Coz, L. Kateb. River Flow 2020 Estimation of the transverse mixing coefficients in shallow gravel-bedded rivers. RIVERFLOW 2020 - 10th Conference on Fluvial Hydraulics, IAHR (International Association for Hydro-Environment Engineering and Research), Jul 2020, DELFT, Netherlands. cea-02972575

**HAL Id: cea-02972575**

**<https://cea.hal.science/cea-02972575>**

Submitted on 20 Oct 2020

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

The logo for CEA (Commissariat à l'énergie atomique et aux énergies alternatives) is displayed in white on a red background. It consists of the lowercase letters 'cea' in a stylized font, with a horizontal green line underneath.

DE LA RECHERCHE À L'INDUSTRIE

# Estimation of the transverse mixing coefficients in shallow gravel-bedded rivers

RiverFlow 2020



INRAE



L. Gond<sup>1,2,3</sup>, E. Mignot<sup>1</sup>, J. Le Coz<sup>2</sup> & L. Kateb<sup>3</sup>

<sup>1</sup> CNRS-Université de Lyon, INSA Lyon, LMFA, Villeurbanne, France

<sup>2</sup> INRAE Lyon-Grenoble, UR RiverLy, Villeurbanne, France


<sup>3</sup> CEA, DEN, Cadarache, DTN, SMTA, Laboratoire de Modélisation des Transferts dans l'Environnement, Saint-Paul-Lez-Durance, France

## Goals:

- Understanding the contribution of mixing processes in a reach due to turbulent diffusion, secondary currents dispersion
- Determining a predicting formulation to estimate the mixing efficiency in a reach

## Applications:

- Predicting the spatial distribution of pollutants in a river downstream a disposal area
- Determining the «perfect transverse mixing length »



Fischer, 1979:  $L_y = \alpha \frac{UW^2}{E_y}$

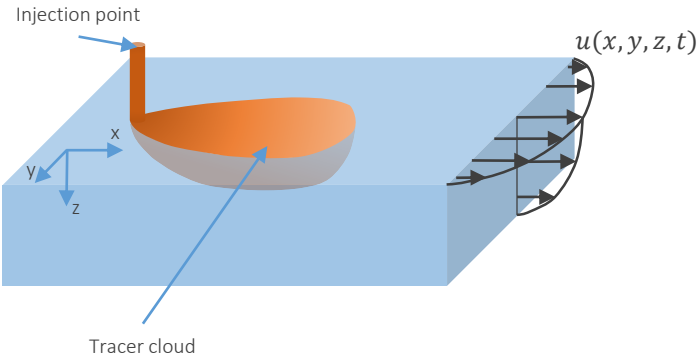
$L_y$ : perfect transverse mixing length

$U$ : bulk velocity of the stream

$W$ : width of the stream

$E_y$ : reach-averaged transverse mixing coefficient

When a cloud of particles is introduced in a stream, it spreads along the three spatial directions with increasing time:



For wide, shallow, uniform and stationary flows:

- velocity is mainly one directional ( $u = u(y)$ ,  $v = w = 0$ )
- vertical mixing is rapidly complete
- streamwise mixing is negligible
- we focus on transverse mixing



Simplified 1D depth-averaged advection-diffusion equation:

$$\frac{\partial hc}{\partial t} + u \frac{\partial hc}{\partial x} = uh \frac{\partial \left( uh^2 \varepsilon_y \frac{\partial c}{\partial q} \right)}{\partial q} \quad \text{①}$$

Yotsukura & Cobb (1972)

With:

- $h$  = local flow depth (m)
- $u$  = local depth and time-averaged velocity (m/s)
- $q = \int_0^y u(\delta)h(\delta)d\delta$  = cumulative discharge (m<sup>3</sup>/s)
- $\varepsilon_y$  = local mixing coefficient (m<sup>2</sup>/s)
- $c$  = local depth and time-averaged concentration (kg/m<sup>3</sup>)

In the case of a slug injection of a mass of tracer, we can integrate Eq.1 over the time following Beltaos (1980, 1984):

$$\frac{\partial \theta}{\partial x} = E_y \psi U H^2 \frac{\partial^2 \theta}{\partial q^2} \quad \text{②}$$

With:

- $H$  = reach-averaged flow depth (m)
- $U$  = reach-averaged velocity (m/s)
- $E_y$  = reach-averaged coefficient (m<sup>2</sup>/s)
- $\psi = \frac{\frac{1}{Q} \int_0^Q \bar{u}(q) h(q)^2 dq}{UH^2}$  = velocity-shape profile
- $\theta$  = local depth-averaged dosage (kg.s/m<sup>3</sup>)

Solving Eq.2 in a reach from cross-section  $S_i$  to  $S_{i+1}$ :

$$\theta_0(x_{i+1}, q) = \int_0^Q \frac{\theta(x_i, q_0)}{\sqrt{4\pi E_{y,i,i+1} \psi U H^2 (x_{i+1} - x_i)}} \exp\left[\frac{-(q \pm q_0)^2}{4E_y \psi U H^2 (x_{i+1} - x_i)}\right] dq_0$$

Seo et al. (2006)

And using the mirror method to model the reflection at the banks:

$$\theta(x_{i+1}, q) = \theta_0(x_{i+1}, q) + \theta_0(x_{i+1}, q) + \sum_{n=1}^{\infty} \theta_0(x_{i+1}, 2n \pm q) \quad \text{③}$$

- Many field and laboratory studies since 1960 (Elder, 1959; Fischer, 1969; ... ; Seo et al, 2016)
- Attempts to find correlation between the transverse mixing coefficient and parameters:  
$$\frac{E_y}{Hu^*} = f\left(\frac{U}{u^*}, \frac{W}{H}, S_n\right)$$
 with  $U/u^*$  the friction factor,  $W/H$  the aspect ratio and  $S_n$  the sinuosity
- Problem:
  - no clear correlation is yet found and the quantification of the transverse mixing coefficient remains an open question
  - most studies consider that the studied reaches follow the 1D model hypotheses, but natural reaches generally present significant longitudinal hydraulic and geometric variations (Jackson et al, 2013)
- Proposed solution:
  - Delineate a natural reach in smaller sub-reaches that would better follow the 1D hypotheses

➔ Choose a longitudinally varied reach, delineate it in sub-reaches with quasi-homogeneous roughness elements by measuring concentration cross-profile at each two ends

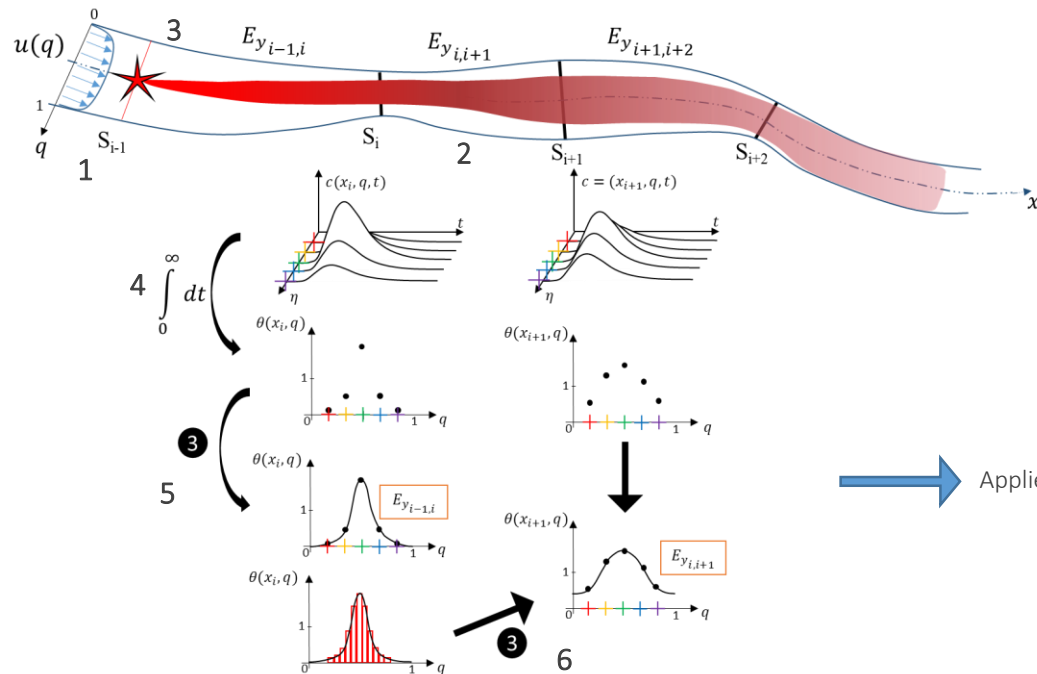
➔ Highlight the variability of the mixing coefficient in a short reach usually disregarded in past studies

➔ See if the delineation method gives useful correlations between the dimensionless mixing coefficient and hydraulic or geometric factors in order to use it for a predictive formulation

➔ Usually  $\frac{E_y}{Hu^*} = f\left(\frac{U}{u^*}, \frac{W}{H}\right)$

With:

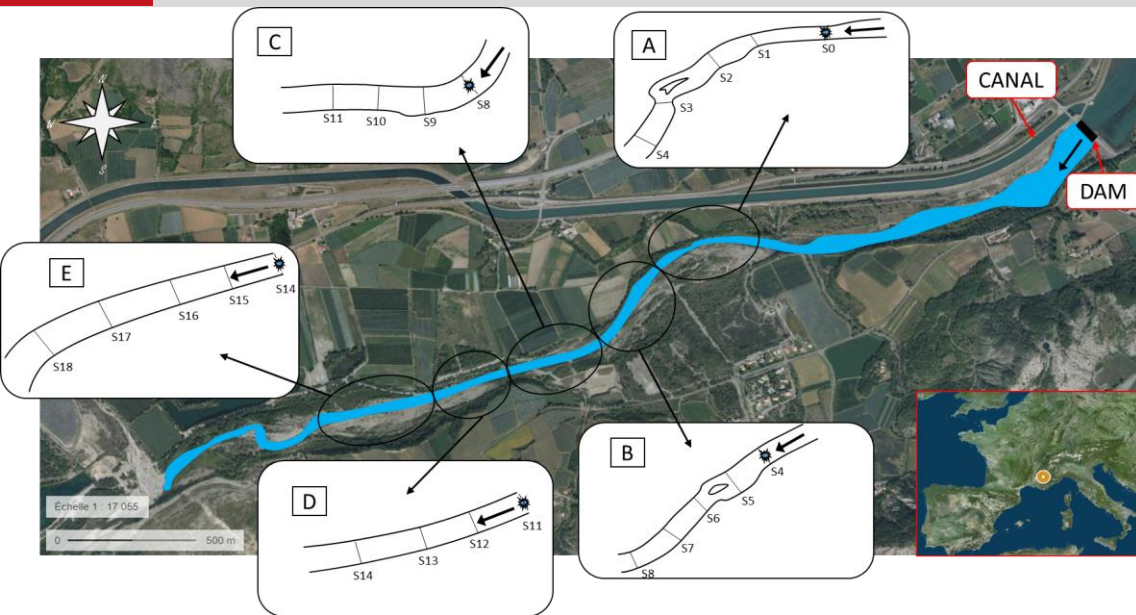
- $U/u^*$ : friction factor
- $W/H$ : aspect ratio



Applied to the Durance river, France

1. Position an injection point upstream
2. Measure hydraulics and position sensors along two successive cross-sections downstream
3. Inject a tracer
4. Gather data and integrate concentration profiles over time
5. Fit solution Eq.3 to determine  $E_y$  between the injection and the sub-reach's upstream cross-section
6. Discretize upstream profile and fit solution Eq.3 to determine  $E_y$  between the two cross-sections

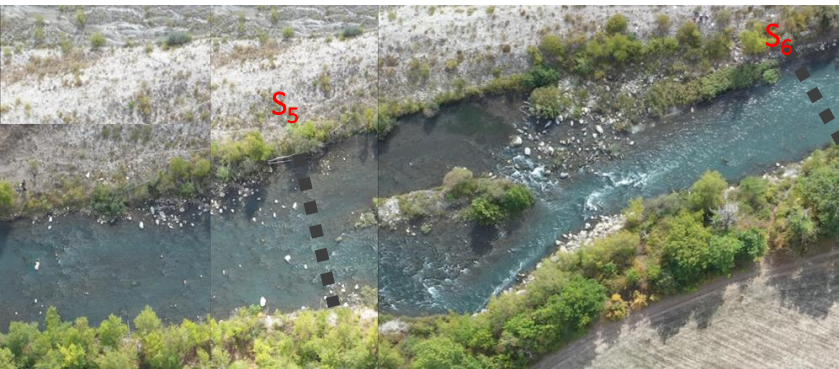




Location: La Saulce, France

Dates: September 23-27 2019

➔ 5 injection zones, 18 cross-sections and sub-reaches



Complex succession of emerging blocks, riffle with island, and pool



Long sand bedded pool with vegetation



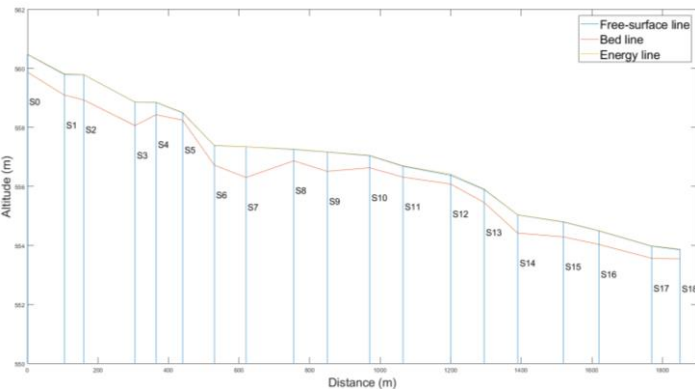
Patches of emerging blocks

ADCP measurements at every cross-sections: velocity field + bathymetry + sensors positioning



Gives  $U, H, \psi$  and sensors position in cumulative discharge

Free surface elevation measurements with a DGPS Leica along the left bank



Gives  $u^* = \sqrt{gHJ_e}$

With:

- $g$  = gravitationnal acceleration ( $m^2/s$ )
- $J_e$  = energy line slope ( $m/m$ )

Chosen tracer: Liquid rhodamine WT 20% → Fluorescent tracer, small quantities needed, low toxicity

Measured with:

GGNU-FL30 Albillia



TQ-tracer (Sommer Messtechnik)

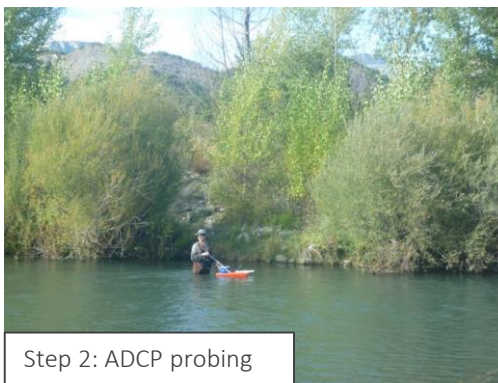


Positioned along the cross-sections every 7<sup>th</sup> of the total discharge

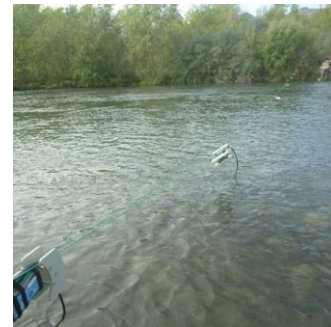




Step 1: Calibration



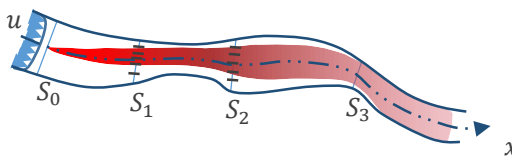
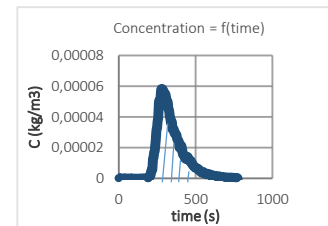
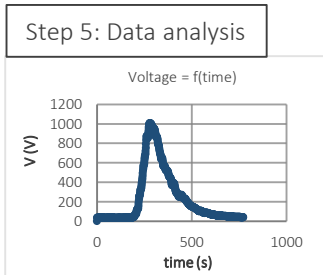
Step 2: ADCP probing



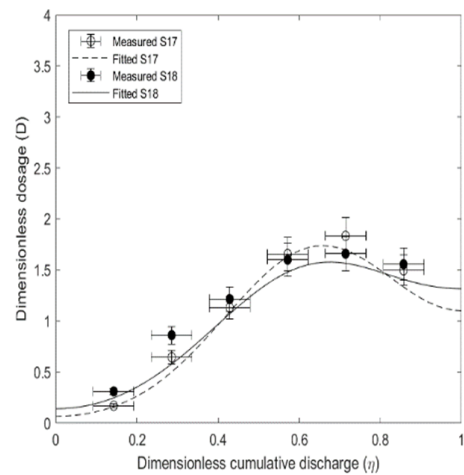
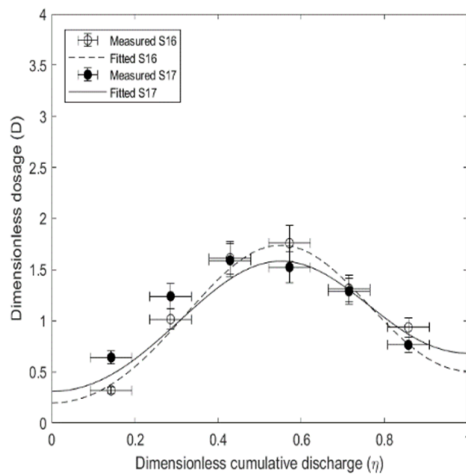
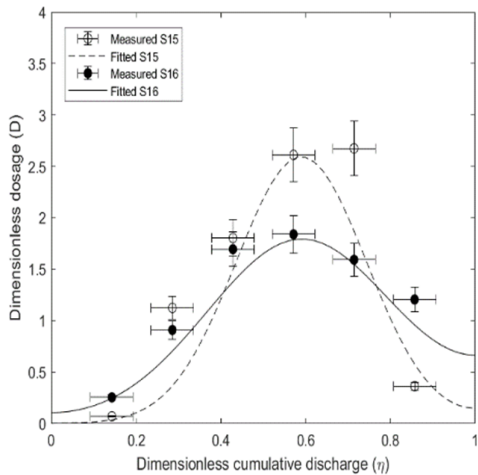
Step 3: Probes positioning on two consecutive cross-sections



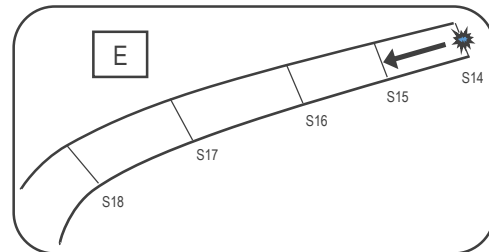
Step 4: Instantaneous injection of tracer (Rhodamine WT) and re-do steps 2,3 and 4 for the next sub-reaches

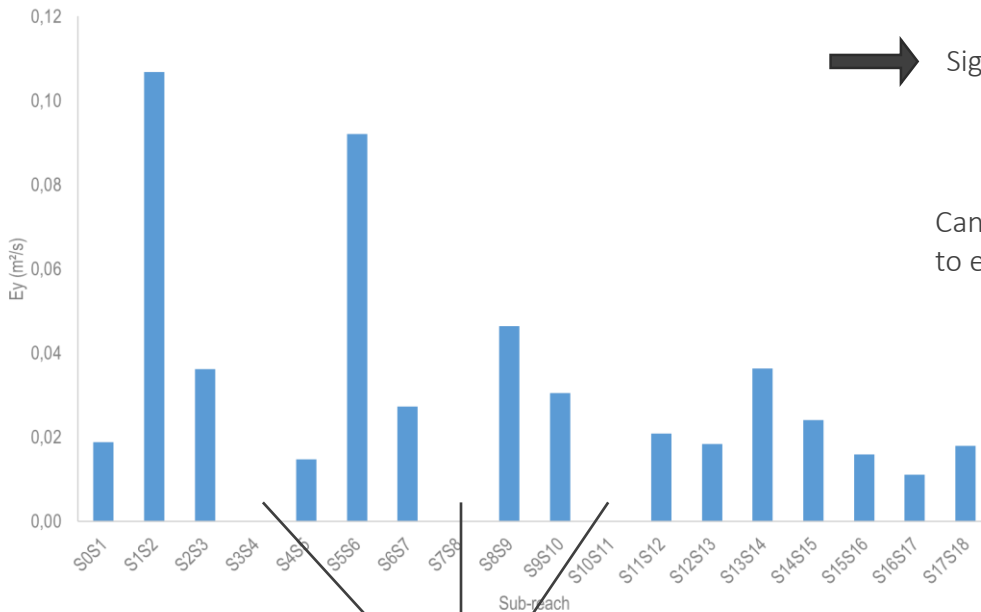


Integrate to get:  $\theta = \int_{t=0}^{t=\infty} c dt$



Example for injection zone E:  
(straight channel with patches of emerging blocks)





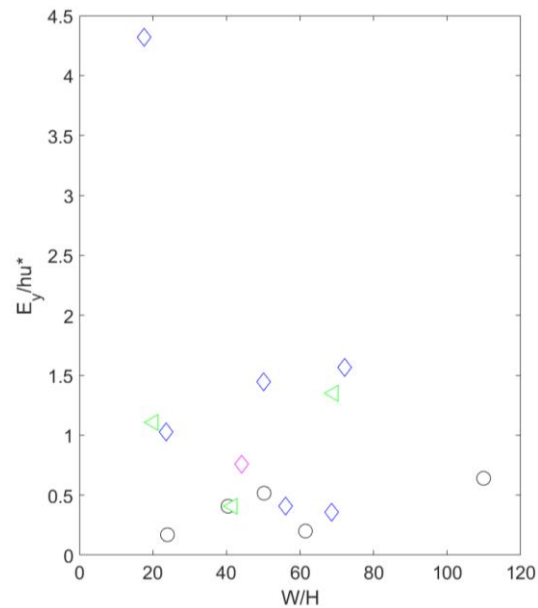
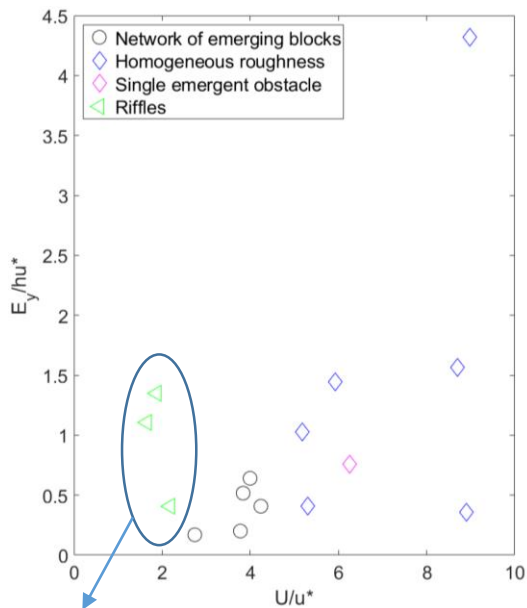
Significant longitudinal variability



Can we find interesting correlations to explain it?

Complete mixing reached

$$\frac{E_y}{Hu^*} = f\left(\frac{U}{u^*}, \frac{W}{H}\right)$$



Values of  $Hu^*$  poorly representative of the riffles hydraulics (measurements upstream and downstream of it)

➔ No clear correlation observed even when a reach is delineated in quasi-homogeneous sub-reaches



- We applied tracing experiments in a river presenting strong variations in bed morphology; we delineated the chosen reach in sub-reaches with quasi-homogeneous roughness elements
- We used a simple 1D-diffusion model with simplificative hypotheses to determine the transverse mixing coefficient of each sub-reaches and show significant variations of the mixing coefficient in a natural reach
- We found no clear correlation of the dimensionless mixing coefficient against the usual factors defined in the literature

## Perspective:

- A new parameter seems needed to explain the variations in our data, and eventually explain those in the literature; a new analysis of the data considering the non-uniformity of the flow may reveal interesting results
- Laboratory measurements are planned to study the influence of the relative roughness height on the transverse mixing (including emerging obstacles)

Beltaos, S. 1980. Transverse mixing tests in natural streams. *J. Hydraul. Div.*, 106(10), 1607–1625.

Elder, J. W. 1959. The dispersion of marked fluid in turbulent shear flow. *J. Fluid Mech.*, 5(12), 544–560.

Fischer, H. B. 1969. The effect of bends on dispersion in streams. *Water Resour. Res.*, 5(2), 496–506.

Fischer, H. B., List, E. J., Koh, R. C. Y., Imberger, J., and Brooks, N. H. 1979. *Mixing in inland and coastal waters*, Academic Press, New York.

Jackson, T. R., Haggerty, R., & Apte, S. V. 2013. A fluid-mechanics based classification scheme for surface transient storage in riverine environments: quantitatively separating surface from hyporheic transient storage. *Hydrology and Earth System Sciences*, 17(7).

Seo, I. W., Choi, H. J., Kim, Y. D., & Han, E. J. 2016. Analysis of two-dimensional mixing in natural streams based on transient tracer tests. *J. Hydraul. Eng.*, 142(8), 04016020.

Yotsukura, N., and Cobb, E. D. 1972. *Transverse diffusion of solutes in natural streams*. USGS, Washington, DC.