Observation and modeling of sand fluxes in the Rhône River during a flood

Guillaume Dramais, B. Camenen, Jérôme Le Coz, G. Pierrefeu, C. Peteuil, T. Fretaud

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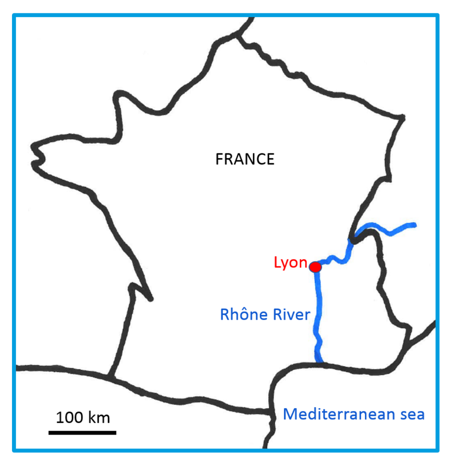
Abstract

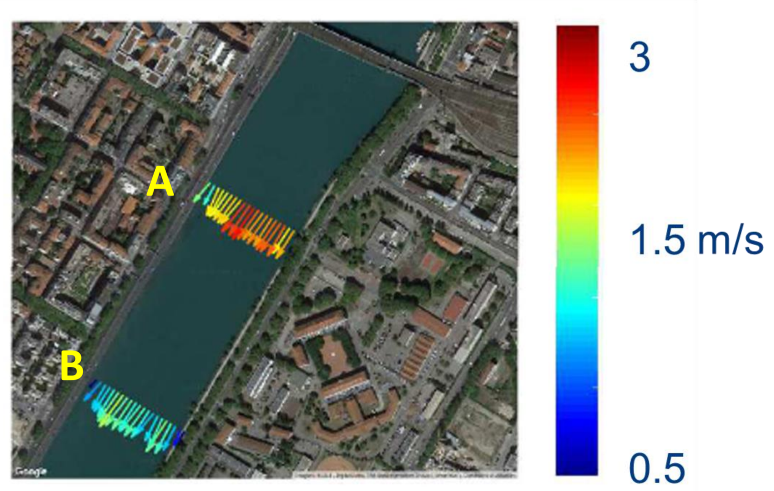
The estimation of sand fluxes in large rivers is an important issue because of its significant role in the river morphodynamics. However, these fluxes are very difficult to measure and compute because of their large spatial and temporal variability. Equations can be used to compute the sediment transport capacity but the actual sediment transport may be lower than this capacity when sand supply is limited, especially for gravel bed rivers like the Rhône River, France. This study presents the results of a comparison between recent flux measurement surveys on the Rhône River in Lyon and a simple physically based model for computing the sand transport capacity.

The Rhône River

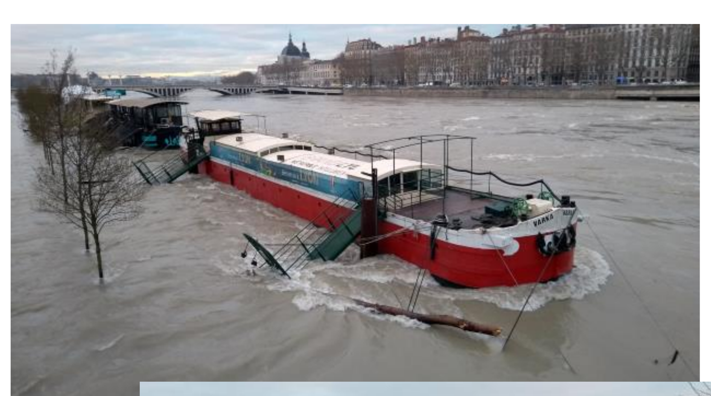
The Rhône river drains a catchment of about 95000 km² . The mean annual discharge downstream is 1700 m³/s. The river has been largely modified since the middle of the 20th century (sediment dredging, levees, dams on the river and on its tributaries). However the Rhône River remains currently the main tributary of the Mediterranean sea in terms of sediment fluxes. The study site is located in the city of Lyon.

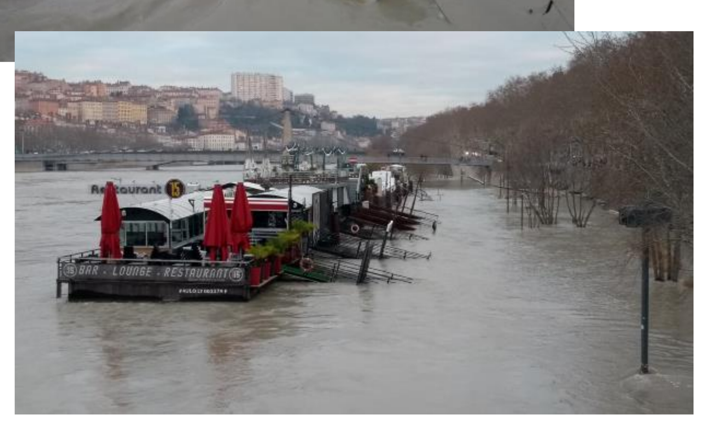


Location of the study site



Location of the measurement cross-section and depth average ADCP velocities and direction in color scale (USGS VMT software).





Flooded left dock in Lyon on January 24th, photo courtesy of Raphaël ANDRE (Métropole de Lyon).

The flood

Occurred in January 2018, this event was a 10-year flood.

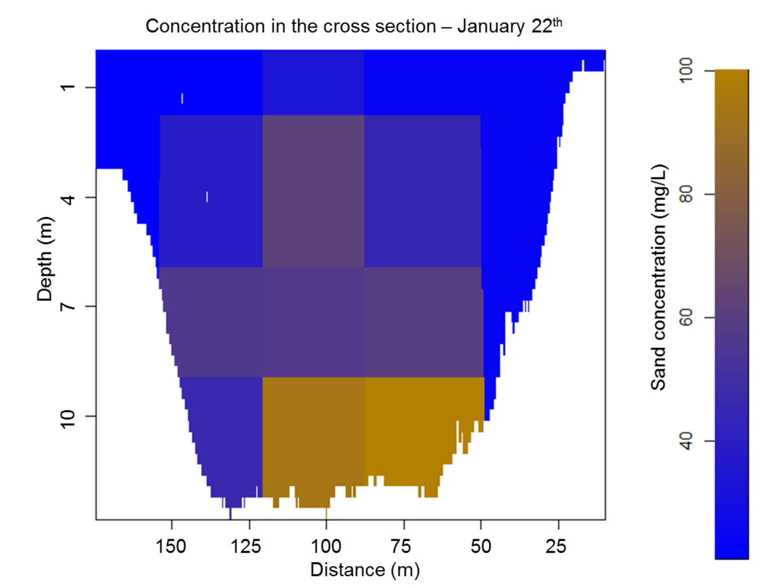
The range of investigated discharges varies from 900 m³/s to 2700 m³/s during different phases of the flood.

This flood carries "large" amounts of sand probably mainly supplied by the Ain River.

Experimental method

- Flux measurements were achieved combining ADCP measurements and direct sampling using a Niskin sampler. Seven field surveys were carried out.
- Each experiment is made of a set of 12 samples distributed on a cross section, velocities and bathymetry being acquired with an ADCP.
- Sand concentration analyses were carried out by sieving (63µm) before filtering (Dramais, 2018).
- An R code is used to compute ADCP data and concentration data to calculate sediment fluxes in the cross section.

CNR vessel mounted ADCP for mobile deployments and Niskin bottle ready to be used.



The measured sand concentration divided in sub-sections according to the sample positions and ADCP data.

Modeling method for sand rating curve

- Hydraulic model based on stage-discharge relationships to estimate main hydraulic parameters (flow velocity, bed shear stress, etc.).
- This model was implemented on two measurement cross-sections.
- Sediment transport estimated using a semi-empirical sediment transport formula for suspended load (Camenen and Larson, 2008).

$$q_{ss} = UC_R \frac{\epsilon_v}{W_s}\left[1 - \exp\left(-\frac{W_s h}{\epsilon_v}\right)\right]$$

U : Mean velocity

$\sigma = 1$: Turbulent Schmidt number

W_s : Settling velocity

$$d_* = \sqrt[3]{g\,(s-1)/\nu^2}\, d$$

τ_{Ht}: bed shear stress including form roughness

$u_{*H} = \sqrt{\tau_{Ht}/\rho}$: shear velocity

Turbulent diffusion

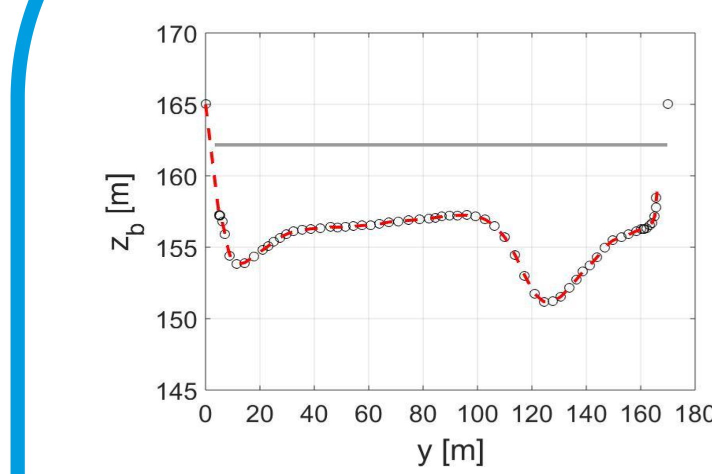
$$\epsilon_v = \frac{\sigma}{6}\kappa u_{*H} R_{hH}$$

Reference concentration

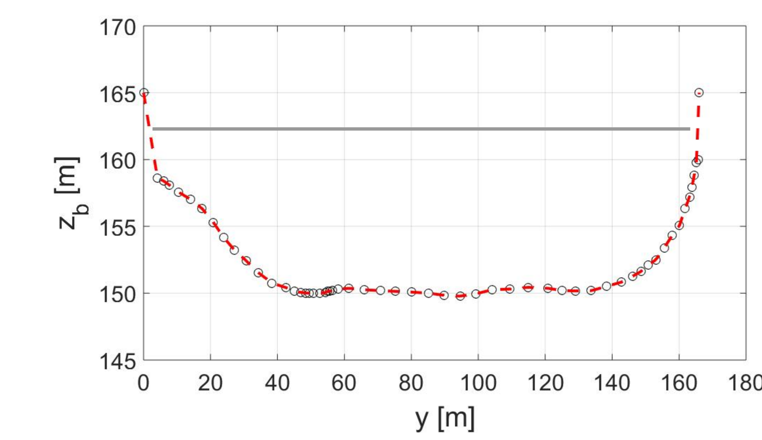
$$C_R = 1.5\times10^{-3}\exp(-0.2 d_*)\,\theta\,\exp\left(-4{,}5\frac{\theta_{cr}}{\theta}\right)$$

Results

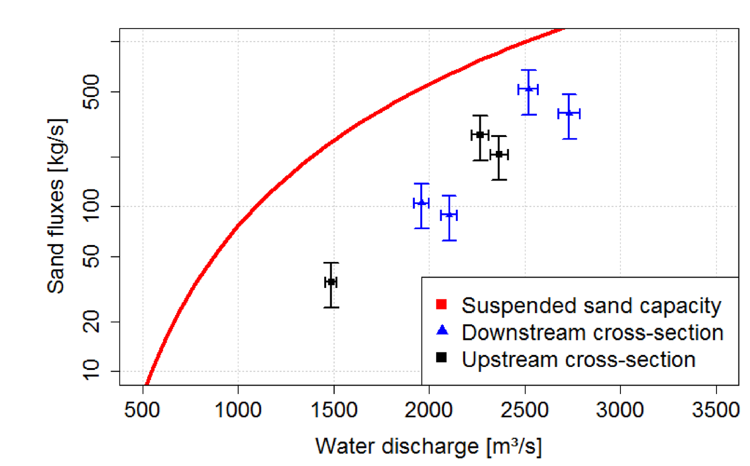
- Comparison of results obtained for the two river cross-sections



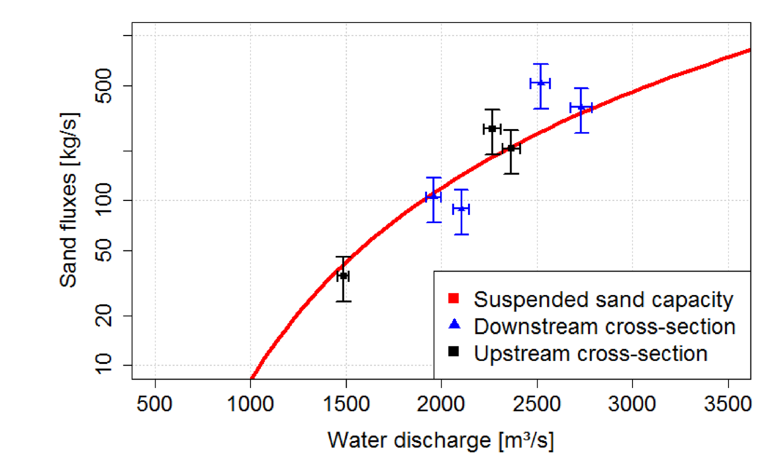
Bathymetry and water level for the upstream cross-section (A).



Bathymetry and water level for the downstream cross-section (B).



Modeling of the suspended sand discharge compared to experimental data, upstream cross-section (A).



Modeling of the suspended sand discharge compared to experimental data, downstream cross-section (B).

- In the upstream section (A) the transport capacity is not reached, in the more homogeneous section (B) the capacity is reached.
- There is a channel control for stage-discharge relation but a section control for sediment transport, as the deepest cross-sections limit the transport capacity along the reach.
- The importance of the section choice to establish a sand rating curve based on transport capacity is highlighted here.

Conclusions

We established a suspended sand rating curve for this 10 year-flood on the Rhône River and experimental results were correctly predicted by the model. The suspended sand transport in this reach is piloted by the less dynamic section. However some questions have to be investigate:

- Is this relation reliable for other flood events?
- Is the transport capacity always reach in high flow conditions? And how is it linked with the sediment supply from upstream?
- Then, uncertainties need to be evaluated before establishing reliable sand fluxes time series and budgets.

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