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# Sand dynamics at the Isère-Rhône confluence

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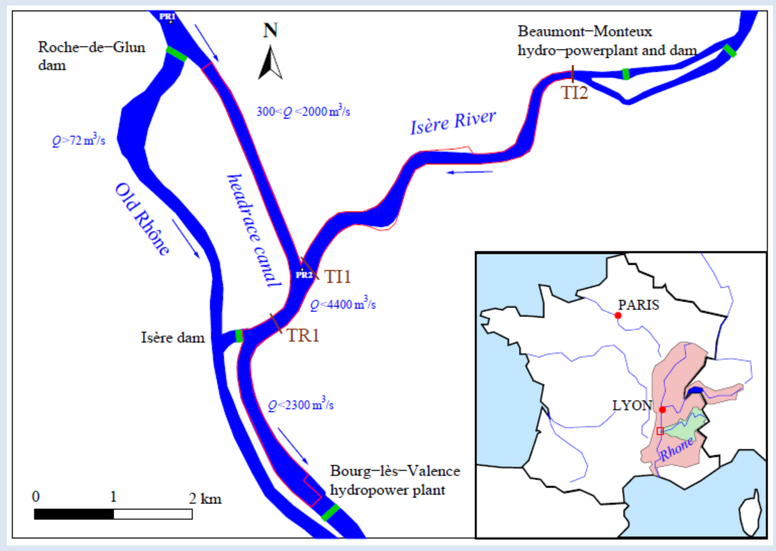
## Evaluation of the sand dynamics in a complex enineered river system

- **Main issues in European piedmont rivers** are related to two characteristics:
  - a poorly sorted grain size distribution with particles from cobbles to clay;
  - a high anthropogenic level including dikes and dams .
- As a consequence, many of these rivers, initially considered as gravel-bed rivers, lost most of their dynamics, are often paved (Kondolf, 1997), and more impacted by fines sediments (Owens et al., 2005).
- Sand dynamics is particularly difficult to estimate in such rivers due to sampling limits (high velocities, sand-gravel mixture, etc.) and temporal and spatial variability especially in term of supply due to the presence of dams.
- **Objectives of the study**
  - To evaluate sand dynamics in an engineered piedmont river system by focusing on two critical periods: (i) dam flushing events for which a significant sand input is introduced in the system, and (ii) periods following dam flushing events for which sand is gradually evacuated downstream.
  - To provide a methodology to overcome the lack of measurements based on sediment budgets, the use of sediment rating curves and numerical modelling.

## Study site: the Isère-Rhône confluence

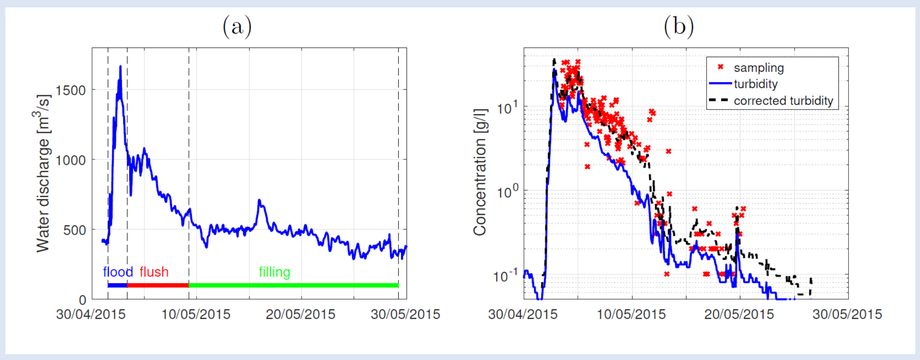
- **Highly engineered system with a chain of dam on the Isère River and a confluence in a headrace canal**
  - Necessity for EDF (Electricity of France) to maintain a capacity for their dam chains
  - Necessity for the CNR (Compagnie National du Rhône) to maintain navigation in the headrace canal and to limit flood risk in the downstream part of the Isère River
  - Several problems occurred the two last flushing events in 2008 and 2015 (after 7 years without flush) due to large deposits of sand at the confluence




*Geometrical characteristics (location PK, usual water elevation zw, capacity V at usual water elevation) of the river dam reservoirs in the Lower Isere River and sediment budgets after the 2008 and 2015 flushing events, respectively*

| Dam name | PK (km) | $z_w$ (m NGF) | $V$ ($10^6$ m$^3$) | $\Delta V_{2008}$ ($10^6$ m$^3$) | $\Delta V_{2015}$ ($10^6$ m$^3$) |
|---|---|---|---|---|---|
| St-Egrève | 94.0 | 205.50 | 6.80 | – | – |
| Beauvoir | 51.2 | 172.50 | 11.80 | -1.59 | -1.94 |
| St-Hilaire | 39.4 | 161.00 | 6.80 | -0.33 | -1.34 |
| Pizançon | 24.5 | 149.75 | 13.75 | – | -1.34 |
| La-Vanelle | 14.7 | 137.00 | 3.90 | – | 0.09 |
| Beaumont-Monteux | 7.9 | 128.60 | 3.30 | – | -0.23 |

- **Data available**
  - Hydrosedimentary stations upstream and downstream of the dam series;
  - Regular bathymetry of the dam reservoirs (EDF) and of the Isère and Rhône rivers around the confluence (CNR) but with large uncertainty (density of mixtures);
  - Punctual measurements of bedload and/or suspended during the 2015 flushing event and later.




*Discharge (a) and concentration (b) measured on the Isère River at the Beaumont-Monteux station during the 2015 flushing event.*

- **Sediment budget over the Lower Isère and Isere-Rhône confluence after the 2008 and 2015 events**

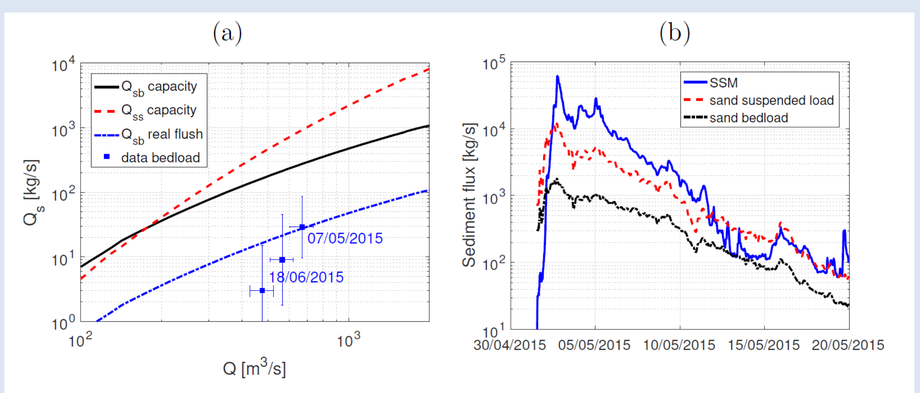
*LI: Lower Isère; BM: Beaumont-Monteux; IR: Isère-Rhône). M : mass passed through a river section or deposited in a river reach during the flushing period, and $u_M$: corresponding uncertainty.*

| Site (measurements) | Budget 2008 $V$ ($10^6$ m$^3$) | $M$ ($10^6$ t) | $u_M$ ($10^6$ t) | Budget 2015 $V$ ($10^6$ m$^3$) | $M$ ($10^6$ t) | $u_M$ ($10^6$ t) |
|---|---|---|---|---|---|---|
| Tullins (SPM flux) | - | 5.1 | 1.0 | - | 2.7 | 0.5 |
| LI dams (bathymetry) | 2.8 | 3.6 | 2.0 | 4.8 | 6.3 | 2.5 |
| BM (SPM flux) | - | 7.0 | 2.0 | - | 7.6 | 1.5 |
| BM (sand model) | - | 5.4 | 5.0 | - | 3.5 | 1.0 |
| IR confluence (bathymetry) | 0.5 | 0.8 | 0.2 | 3.5 | 5.6 | 1.0 |

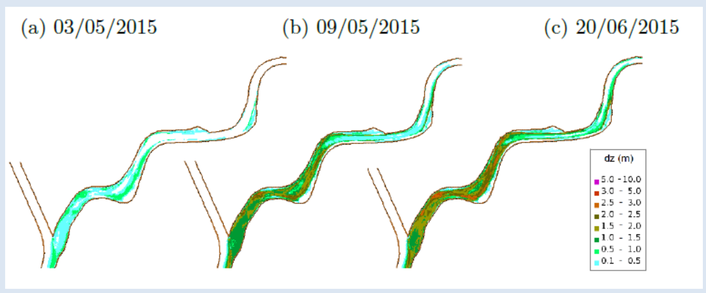
## Evaluation of sand input during flushing events

- **Estimation of the sand input**
  - Sediment rating curve based on a stage-discharge rating curve (Camenen et al. 2011, 2014); exponential decrease of the sand supply during the filling period;
  - Errors in bedload measurements ? Not consistent with the deposit volume.

*Estimation of the sand rating curve at Beaumont-Monteux station (a) and measured SPM flux and estimated sand bedload and suspended load during the 2015 flushing event.*




- **2D modelling of the sand dynamics**
  - Application of the Rubar20TS software (Irstea). Limitation of the modelling to the Isère River (3D structure of the flow and concentrations in the headrace canal)
  - The deposit started at downstream end of the Isère River and grew upstream until the Beaumont-Monteux dam is eventually closed; sand transport in suspension

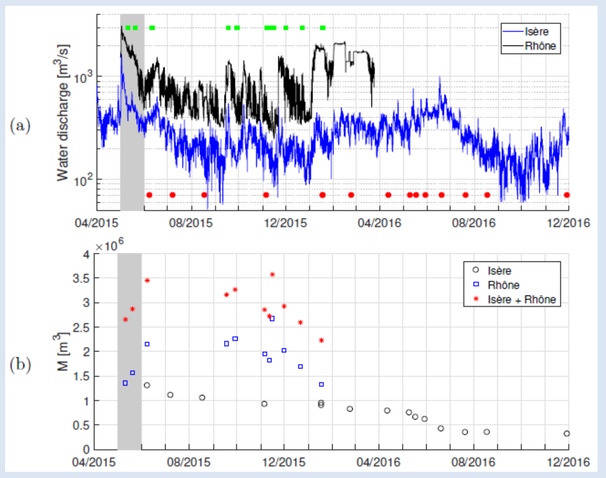



*Model results for the sand deposits in the downstream part of the Isère River during the 2015 event (a) after the flood peak at the beginning of the flushing event on 3rd May 2015, (b) at the end of the flushing event on 9th May 2015, and (c) at the end of the dam filling on 26th June 2015.*

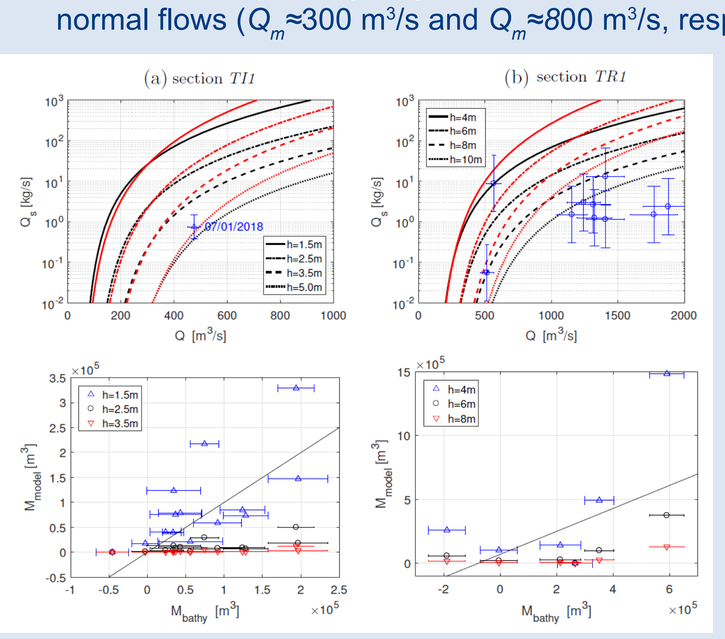
## Evaluation of sand input after flushing events

- **Evolution of the sand deposit**

*Water discharges in the Isère River at Beaumont-Monteux and in the Rhône headrace canal (green dots and red dots correspond to bathymetric surveys achieved on the Isere reach and headrace canal, respectively) after the 2015 flushing event (a) and estimated volumes of sand deposits in the Isere reach and headrace canal reach during the same period (b).*




- **Analysis of bathymetric surveys**
  - Application of the dune-tracking method between bathymetric surveys
  - Estimation of sediment rating curve in critical sections assuming a constant water level (imposed by the dam)
  - Significant effect of the deposit thickness on the sediment transport capacity; larger sediment transport capacity in the headrace canal compared to the Isère River for normal flows ($Q_m$≈300 m³/s and $Q_m$≈800 m³/s, respectively)




*Estimation of the sand rating curves (black lines correspond to bedload, and red lines to suspended load) at setion TI1 (Isère River, a) and section TR1 (headrace canal, b) and resulting calculations of the total sand mass transited through the sections TI1 and TR1 between bathymetric surveys.*

- Dune-tracking

$$q_{sb,DT} = (1-p)\ \alpha_d\ H_d \frac{D_d}{\Delta T}$$

- Estimation of the mass transiting though a river section

$$M_{bathy,S_i,T_i} = (1-p)\rho_s \left(V_{bathy,t_{i+1}} - V_{bathy,t_i}\right) + M_{input,T_i}$$

## Conclusions

- Dam series significantly affect sediment transport, especially sand. Sand is transported as suspended load during flushing event until the confluence, then as bedload; the Rhône River has a larger capacity to evacuate sand downstream compared to the Isère River for usual flows
- A combination of sediment rating curves, analyses of bathymetry measurements and sediment budgets, and modelling was useful to better understand the sand dynamics