Bedload transport capacities along the Rhone river (France): a spatio-temporal overview

Capacités de transport par charriage dans le Rhône (France) : une perspective spatio-temporelle

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RÉSUMÉ

Un siècle et demi d'intenses modifications humaines ont modifié drastiquement les capacités de transport par charriage dans le Rhône. Nous combinons ici de la modélisation hydraulique 1D, des équations de transport par charriage et une large base de données granulométriques et bathymétriques pour estimer les capacités de transport à l'état actuel tout au long du chenal principale du Rhône (France). Nous comparons ces estimations avec celles obtenues pour un régime hydraulique non aménagé et une granulométrie de lit plus fines. Ces résultats apportent une vision générale sur la variabilité spatiale des capacités de transport par charriage dans le Rhône et une comparaison avec les capacités de transport avant les grandes phases d'aménagement du fleuve.

ABSTRACT

A century and a half of human modifications have drastically altered transport capacities along the Rhone River. We are using 1D hydraulic modelling and bedload computations coupled with an extensive dataset of measured grain sizes and channel bathymetry to estimate present-day transport capacities along the entire length of the Rhone River (France). We compare these to pre-management estimates based on model runs for an unimpeded flow regime and computations based on finer (pre-armouring) grain sizes. The results provide an overview of how transport capacities vary along the Rhone and how they compare to pre-management rates.

MOTS CLES

Bedload transport, hydraulic modelling, hydropower dams, grain-size distributions, river training, Rhône river

1. INTRODUCTION

The present-day Rhône River (France) owes its geomorphic character to several major periods of human modifications carried out in the main channel over the past 150 years. The first, in the late 1900s, consisted of classic river training aimed at improving navigation. The second, starting in 1948, involved the construction of a series of canals that bypass the main channel, diverting flow to dams for hydroelectric production. Finally, gravel mining was widespread from the 1950s until the 1990s. The net result of these works is an incised channel characterized by almost continuous embankments along the lowermost 300 km and multiple segments of by-passed channel characterized by reduced flood frequencies and reduced average discharges.

We present results of a study carried out within the framework of the Rhône Sediment Observatory (OSR) aimed at estimating present-day bedload transport capacities along the Rhône river and determining how these rates have been affected by management works. Mean annual bedload transport capacities are estimated by coupling a 1D hydraulic model (MAGE) and grain size data with empirical bedload transport equations. We compare these rates to pre-dam estimates based on model runs under an unimpeded flow regime (discharge and slope). We calculate bedload transport capacities for finer grain sizes present in gravel bars compared to those in the main channel. A comparison of transport capacities based on different characteristics grain sizes allows to test the sensitivity of transport capacity to grain size and determine how armouring may have contributed to the low mobilities that characterize the present-day system.

The results of the study provide a global overview of transport capacities along the Rhone at different discharges and shed light on how these differ from historical transport capacities.

2. MATERIALS AND METHODS

This study uses a 1D hydrodynamic model (MAGE) developed by IRSTEA for the entire French Rhone. The model is based on recent cross-sections of channel bathymetry at 500 m intervals measured by the CNR (Compagnie National du Rhone) and incorporates the operating rules for each of the canals that divert flow to the hydropower plants. The model has been calibrated and validated for each reach over a wide range of discharges using water surface profiles provided by the CNR (Dugué et al., 2015). Grain sizes used in this study were measured as part of a large-scale sampling campaign (2012-2013) conducted by the OSR (Parrot, 2015) in which the bed was sampled approximately every 5 km along the entire length of the Rhone.

Flow duration curves were constructed for entire Rhône based on gauge records at hydrometric stations located along the main channel. Based on these curves, the 1D-hydraulic model was used to obtain water surface slopes and velocities for discharges with different recurrence intervals. These were used to estimate the skin shear stress component of the basal shear stress and introduced into the Recking's bedload transport formulae along with measured grain sizes in order to compute bedload transport capacities. Grain sizes were interpolated linearly between samples in order to generate a continuous series.

3. RESULTS

The present-day hydraulics of the Rhône river is strongly compartmentalized by dams. Water surface profiles based on model outputs highlight the presence of backwater upstream of the dams diverting flow into the canals even at high flows (Figure 1). Estimates of transport capacities show a strong reduction in transport capacities associated with this these backwater zones. The maximum grain sizes estimated as potentially mobile based on average basal shear stresses are typically finer than the median grain sizes measured in the bed, pointing at the low bed mobility in the present-day Rhône (Figure 2).

A comparison of present-day bedload transport capacities with estimates based on model runs under an unimpeded flow regime shows transport capacities to be on average 20 times higher prior to dam regulation. In addition, bedload transport estimates based on grain sizes measured in bars are one order of magnitude higher than estimates based on grain sizes measured in the channel. The combination of these estimates suggests that transport capacities today are one order of magnitude lower than pre-management capacities. This result suggests that incision in response to management works has resulted in a less mobile armoured bed with a more simplified uniform cross-section characterised by fewer gravel bars.

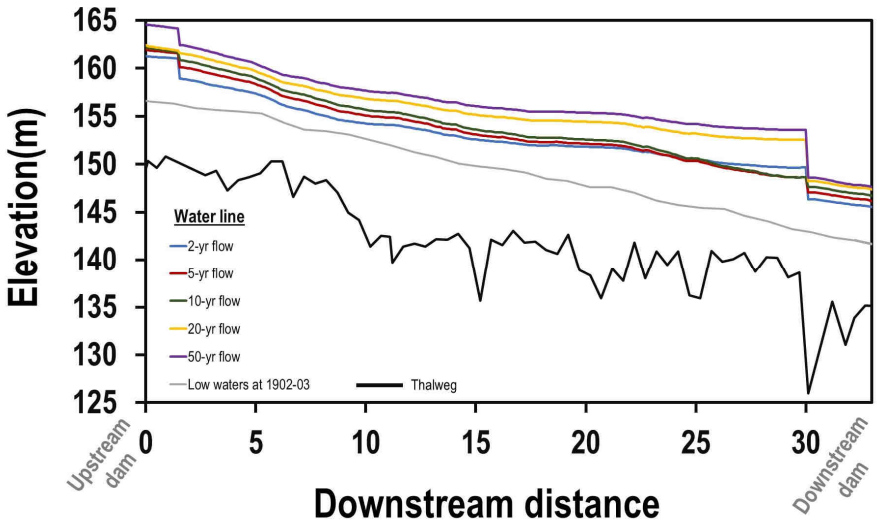

Figure 1. Water surface profile obtained from the 1D Hydraulic model for the Rhône (example from the Péage de Roussillon reach)

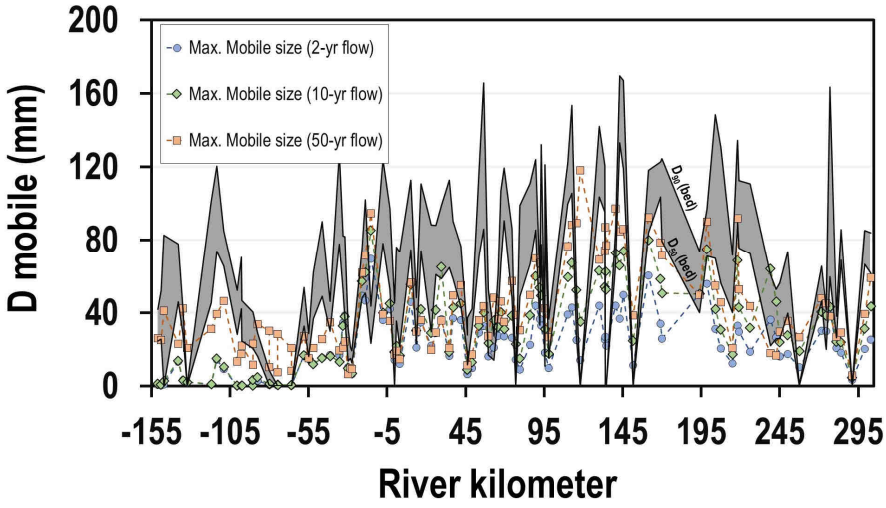

Figure 2. Potential mobile grain sizes estimated for several discharges and the D50 and D90 measured in the bed.

4. CONCLUSIONS

- Bed mobility and transport volumes in the present-day Rhone are strongly controlled by the hydraulic effects of dams diverting flow to hydropower plants: dams reduce water slope and as a result bedload transport capacities and volumes.

- Overall, bed mobility along the Rhône's main channel is low: potentially mobile grain sizes are typically finer than the median grain sizes measured in the bed.

- The results of our analysis suggest that a combination of flow regulation and coarsening of the bed due to armouring associated with sediment deficits and incision could have resulted in up to 1-2 orders of magnitude decreases in bedload transport capacities

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