Largeur du transport sédimentaire et morphologique des rivières à lit de gravier : variabilité à différentes échelles de temps

Bedload and morphological active widths of gravel-bed rivers: variability among timescales

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RÉSUMÉ

La largeur active, la portion d'un chenal fluvial impliquée dans le transport sédimentaire, est un indicateur crucial de la dynamique des rivières alluviales, reliant le transport sédimentaire à l'évolution morphologique de la rivière. Cette étude examine la variabilité temporelle et spatiale de la largeur active de la charge de fond (BAW) et de la largeur active morphologique (MAW) dans les rivières à lit de graviers, en simulant différent types de rivière en laboratoire. Les expériences ont simulé différentes morphologies fluviales (tressée, transitionnelle, vagabonde et à barres alternées) avec des puissances spécifiques variées (dimensionless stream power). Les résultats montrent que la MAW sous-estime systématiquement la BAW d'environ 30 %, quel que soit le type de rivière, remettant en question les hypothèses pour les systèmes en tresse. Les expériences en laboratoire mettent également en évidence la relation existante entre la MAW cumulative et l'échelle de temps d'analyse, intégrant la magnitude et la durée des crues. L'analyse de changements morphologiques des rivières Tagliamento (Italie) et Sunwapta (Canada) sont cohérents avec les observations en laboratoire, permettant une analyse quantitative entre ces changements morphologiques en fonction de la magnitude et la durée des crues. Ces perspectives améliorent la compréhension du transport sédimentaire et de la réponse des rivières aux événements hydrologiques, avec des implications pour la gestion fluviale et l'évaluation des risques d'inondation. Les travaux futurs exploreront les régimes d'écoulement non stationnaires et les effets d'un confinement réduit.

ABSTRACT

Active width, the portion of a river channel involved in sediment transport, is a crucial indicator of alluvial river dynamics, linking sediment transport to river morphological evolution. This study examines the temporal and spatial variability of bedload active width (BAW) and morphological active width (MAW) in gravel-bed rivers, by simulating different river types in the laboratory. The experiments simulated different river morphologies (braided, transitional, vagabond and alternating bar) with varying dimensionless stream powers. The results show that MAW systematically underestimates BAW by around 30%, whatever the river type, calling into question the assumptions for braided systems. Laboratory experiments also highlight the relationship between cumulative MAW and the time scale of analysis, in function of flood magnitude and duration. Analysis of morphological changes in the Tagliamento (Italy) and Sunwapta (Canada) rivers are consistent with laboratory observations, enabling quantitative analysis of morphological changes as a function of flood magnitude and duration. These perspectives improve understanding of sediment transport and river response to hydrological events, with implications for river management and flood risk assessment. Future work will explore non-stationary flow regimes and the effects of reduced confinement.

MOTS CLÉS

Changements morphologiques, Echelles de temps, Largeur active, Modélisation analogique, Transport sédimentaire

Active width, Morphological changes, Physical modelling, Sediment transport, Timescales

1 INTRODUCTION

Active width, the portion of a river channel actively participating in sediment transport at any time or during a given time period (Ashmore et al., 2011), is a key indicator of alluvial river dynamics. It is strongly correlated with morphodynamic processes, serving as a meaningful link between sediment transport and channel evolution. In braided gravel-bed rivers, active width becomes an essential predictor of bulk sediment transport rates and morphodynamic thresholds (Middleton et al., 2019; Peirce et al., 2018). Additionally, active width simplifies field data collection and improves the predictive capacity of numerical models, supporting informed river management decisions such as flood risk assessments, infrastructure protection, and ecological restoration. Understanding the temporal and spatial evolution of active width is thus crucial for interpreting how rivers respond to natural and anthropogenic pressures (e.g. flood regime and sediment supply), and to improve our capability to predict future river evolutionary trajectories in the context of global changes.

Despite its straightforward definition, active width is subject to varying interpretations, primarily influenced by the techniques employed but more importantly the timescale of analysis (i.e. instantaneous, flood events, decades etc). The instantaneous bedload active width, reflecting the area actively transporting sediment at a given moment, is often substituted with the time-integrated morphological active width due to the difficulty of direct measurement in the field. This approach is known to underestimate the instantaneous active width and both active widths are expected to be comparable at sufficiently short-time intervals (Lindsay & Ashmore, 2002). However, the difference between these two metrics has never been quantified, leaving a key gap in understanding the temporal dynamics of sediment transport and morphological change in gravel-bed rivers.

This study aims to address this gap by employing a physical modelling approach to investigate the variability of both reach-scale bedload and morphological active widths, with respect to the timescale of analysis and river type. Specifically, we seek to bring new insights in the following questions: (i) what is the instantaneous bedload active width as a function of river type? To our knowledge, the 2D spatio-temporal evolution of the instantaneous bedload active width has never been assessed before, despite it is a critical component of numerical models. (ii) How do time-integrated bedload and morphological active widths vary with to both the river type and timescale of analysis? and (iii) how does the morphological active width vary with the timescale of analysis in relation to flood magnitude and duration?

2 METHOD

To address these questions, we performed physical modelling with a 25 m long and 3 m wide flume to model various river types and processes in a controlled environment. The physical model has been designed to monitor the spatio-temporal evolution of sediment transport and riverbed. The flume is equipped with two cameras allowing to take photos of the riverbed every minute with a resolution of about 1 mm, allowing instantaneous sediment transport mapping using a time-lapse technique developed by Redolfi et al. (2017). Moreover, a laser scanner allows to monitor the bed elevation with a grid spacing of 50 and 5 mm in the longitudinal and transversal directions respectively. The experiments were carried out with a fixed longitudinal slope of 0.01 m/m, a fixed corridor width of 0.6 m filled with a well-sorted sand with a median diameter of 1 mm. Before starting each experiment, a narrow rectangular channel of 0.15 m was built at the centre of the corridor to facilitate the channel bed evolution.

In total, five experiments were performed with a constant input water and sediment flux (

Table **1**). The timescale of each experimental duration has been set so that it remains similar in terms of morphological evolution of the riverbed under various conditions. This timescale refers to the conservation of sediment mass equation (the Exner equation) and is expressed as:

$$T_{xnr} = (1 - p) \cdot \frac{D \cdot W_w^2}{Q_b} \tag{1}$$

where p is the porosity equal to 0.37, D the mean water depth, W_w the mean wetted width and Q_b the mean output sediment flux in m^3/s.

Table 1: Input parameters for each experimental run.

	Q05	*Q07*	*Q10*	*Q15*	*Q20*
Q [l/s]	0.5	0.7	1.0	1.5	2.0
Qsin [g/s]	0.25	0.39	1.14	2.46	3.58
Txnr [min]	109	74	48	30	20
Dimensionless stream power	0.07	0.11	0.14	0.20	0.25
Planform style	Braided	Braided	Transitional	Wandering	Alternate bar

Each experiment duration has been divided in two parts. First, a 'regime' part performed for 15 Txnr to leave the river rework the entire corridor area, and then a second part performed for 4.5 *Txnr* where the experiment was stopped every 0.5 *Txnr* to carried out topographic surveys of the dry riverbed (9 runs in total). The resulting dataset of each experiment is a set of bedload transport occurrence maps every minute, digital elevation models (DEM) of the riverbed and a set of morphological changes maps using DEM of difference technique (DoD). Each map can be sum up to the others defining an envelope of sediment transport or morphological changes for a given period (Figure 1.a), allowing to perform analysis at different time scales. Both bedload and morphological active widths are expressed in term of ratio with the maximum mean wetted width (active width ratio) to be comparable.

3 PRILIMINARY RESULTS AND DISCUSSION

The experiments led to four different riverbed morphologies from the lowest to the highest discharge: braided, transitional, wandering and alternate bar with a dimensionless stream power ranging from 0.07 to 0.25. To our knowledge, it is the first time that the 2D spatio-temporal evolution of the instantaneous bedload transport is shown. First, results show that the mean reach-scale instantaneous BAW has a positive relationship with the dimensionless stream power increasing from 20% to 75% of the wetted width as previously observed for the MAW (Garcia Lugo et al., 2015; Peirce et al., 2018).

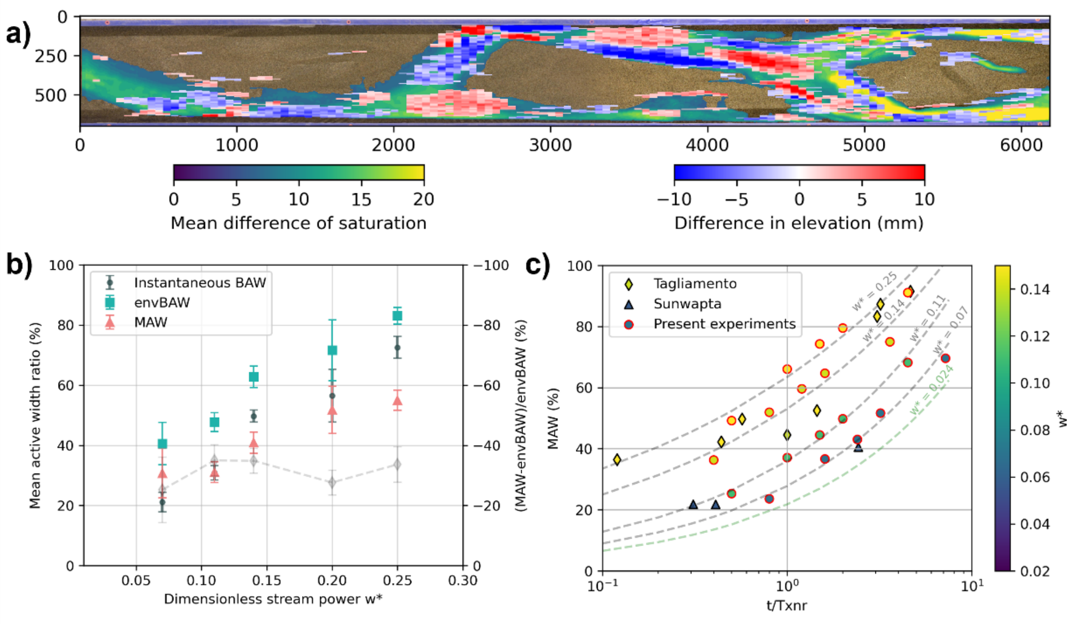

Figure 1*:* Resulted bedload and morphological active widths from flume experiments. A) Example of envelop maps of sediment transport intensity and the associated DoD at the end of a run (Q10 Table 1), b) Comparison between the envelope-based active width ratio (envBAW) and the morphological active width ratio (MAW) after a period of 0.5 Txnr, c) Relationship between MAW and the t/Txnr ratio as a function of the dimensionless stream power (w∗), where t represents the time (in minutes) during which sediment transport occurred.

The comparison between the BAW envelope and the MAW shows that the latter tends to systematically underestimate the active width of bedload transport of about 30% of the BAW regardless of the river type (Figure 1.b)). This result differs from what is expected for braided system, where it is assumed that in braided rivers, most of bedload transport is accommodated by morphological changes. We explored how this difference varies changing both the topographic survey frequency (i.e. the timespan between two DEMs), and cumulative envelops of MAW from DoDs with the highest temporal resolution (the latter is shown in Figure 1.c)). Results show that increasing the temporal resolution of DoDs does not lead to a better estimation of the BAW at the finest temporal scale but improve its estimation when integrated in time (i.e. summing the envelops through time). These results have been obtained from highly confined river systems (> 75%) which may have an impact on the relationship between BAW and MAW due to compensation effect. However, we have estimated the proportion of the compensation effect for each experiment, and it is not sufficient to explain most of observed differences.

Since the mean reach-scale active width depends on the timescale of analysis, we investigated how the cumulative MAW evolves as a function of the timescale, expressed as the t/Txnr ratio (Table 1) for each river type (or dimensionless stream power; Figure 1.c). We focused on the MAW instead of the BAW because it is much easier to measure in the field. This plot can be interpreted as the time required for the river to rework n% of a reference area (in this case, the maximum wetted width) during the analysis period. Given the definition of Txnr (Equation (1)), the t/Txnr ratio integrates the combined influence of flood magnitude and duration. Measurements of the MAW on Sunwapta (Ashmore et al., 2011) and Tagliamento rivers align with the trends observed in the laboratory. This result has the potential to provide valuable insights into the timescales of morphological change in response to the frequency, duration, and magnitude of flood events.

4 CONCLUSION AND PERSPECTIVES

This study provides new insights into the variability of both reach-scale bedload and morphological active widths in gravel-bed rivers, emphasizing the critical role of timescale and river type in their temporal evolution. Through physical modelling, we quantified for the first time that the commonly used morphological active width tends to underestimate the instantaneous bedload active width, with differences of up to 30%, even in braided systems. This result enhances our understanding of the relationship between the temporal dynamics of sediment transport and morphological change in gravel-bed rivers. Moreover, the relationship between morphological active width and the timescale of analysis, particularly in relation to flood magnitude and duration, reflected in the value of *Txnr*, offers valuable insights into the timescales of morphological change and the response of rivers to flood events. We also showed that a similar trend seems to be observed in real river systems. However, further investigations are needed to confirm these results. Future experiments will investigate the relationship between bedload transport and morphological changes by modelling flood events using unsteady input water discharge. Also, experiments with a larger corridor width will be performed to compare the insights of the present study with a lower degree of confinement of the river system.

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