The extent of partial transport in a wide gravel-bed river (Tagliamento river, Italy)

Etude du charriage partiel dans une grande rivière caillouteuse (Tagliamento, nord-est de l'Italie)

Mao L.[1], Picco L.[2], Surian N.[3], Lenzi M.A.[2]

[1] Pontificia Universidad Católica de Chile, Santiago, Chile, lmao@uc.cl
[2] Department of Land and AgroForest Environments, University of Padova, Italy, lorenzo.picco@unipd.it; marioaristide.lenzi@unipd.it
[3] Department of Geography, University of Padova, Italy, nicola.surian@unipd.it

RÉSUMÉ

Le transport de sédiments est le plus important des facteurs qui affectent l'habitat d'un système-rivière et il est essentiel de comprendre les changements morphologiques que ce phénomène provoque au niveau du lit des rivières. Il est cependant très difficile de mesurer directement le processus en utilisant des pièges, surtout pour des cours d'eau importants, complexes ou dispersés. Dans cet article, l'estimation de la mobilité des matériaux du grand lit caillouteux d'une rivière (Tagliamento, nord-est de l'Italie) constitue un premier pas vers la quantification du transport de sédiments en utilisant la méthode de la « Vitesse virtuelle ». Les mesures ont été effectuées au niveau de trois sections transversales de la rivière après avoir coloré des placettes sur le fond de celle-ci. La taille des éléments de la charge solide mobilisée et la distance parcourue par ces éléments ont été relevées après des crues. Les résultats montrent qu'un charriage partiel se produit avec un effort de coupe sans dimension qui varie entre 0.015 et 0.039, alors que le fond du lit se déplace complètement avec des efforts de coupe > 0.045. L'analyse de la longueur du déplacement des éléments de la charge solide a révélé qu'en cas de charriage partiel, la distance parcourue par les éléments d'une taille donnée augmente avec l'accroissement de l'effort de coupe et qu'il est possible d'identifier une valeur seuil de l'effort séparant conditions de déplacement des éléments indépendant de leur taille et conditions de déplacement sélectif et corrélé à leur taille.

ABSTRACT

Sediment transport is the most important factor affecting the physical habitat of a riverine ecosystem and is essential to understanding the morphological changes occurring in rivers. Unfortunately, it is exceedingly difficult to measure it directly using sediment traps, especially in large and complex braided rivers. Here we present an attempt of assessing sediment mobility in a large gravel-bed river (Tagliamento River, north-eastern Italy) as a first step to the quantification of sediment transport rate using the Virtual velocity approach. The analyses were carried out on three cross-sections where a number of areas were painted and the size and travel distance of the mobilized particles were measured after flood events. The results show that partial transport occurs with dimensionless shear stress ranging between 0.015 and 0.039 while with stresses > 0.045 the bed experiences full mobility. The analysis of the particle displacement length revealed that under partial transport conditions the travel distance of a certain size particle increases with the shear stress, and that a certain threshold between equal-mobility and size-selectivity conditions can be identify.

KEYWORDS

Bedload, displacement length, Italy, partial transport, Tagliamento river, tracers.

1 INTRODUCTION

Sediment transport is an essential component of river dynamics as it is responsible for the erosion and creation of bed forms, and lateral–vertical channel changes, especially in wide and complex gravel-bed river systems. The threshold for particle entrainment needs to be quantified in order to estimate the bedload sediment transport. However, such threshold is complex to quantify and subject to a number of variables. Moreover, evidences suggest that, counterintuitively, the coarser grains are more easily transported if surrounded by finer grains because they are more exposed to entraining forces. A further complication in a mixed-size bed is due to the condition of partial transport during which some surface sediments in a certain area remain immobile during a transport event (Wilcock and McArdell, 1997). A certain grain size is in a state of partial transport if only a percentage of surface grains of that size are transported (Wilcock and McArdell, 1997). On the contrary, if all the surface grains of a certain size are transported, the condition has been defined as a state of full mobility (Wilcock and McArdell, 1997). Later on, Haschenburger & Wilcock (2003) redefined the partial transport condition relative to the bed as a whole instead of a certain grain size. Therefore, the partial transport condition can be identified in a portion of the river bed where some grains remain immobile (regardless of their diameter) while others are transported. In this paper we report on a field study conducted on the Tagliamento River (north-eastern Italy), a large gravel-bed river where various portions of three cross-sections were spray painted during 2010 to gain information on the extent of partial transport and travel distance of coloured particles. The occurrence of five flood events allowed the assessment of the increasing morphological effects, from the deposition of fine sediments to the entrainment and transport of painted particles and to the complete erosion of the bed surface layer.

2 MATERIALS AND METHODS

The study was conducted in the Tagliamento River, located in the Friuli region in northeastern Italy. Being one of the few European gravel-bed rivers still retaining a highly dynamic nature and eco-morphological complexity from a relatively low human impact, the Tagliamento River has been extensively studied as to its ecological properties, dynamic habitat changes, invertebrate communities, large woody debris, riparian vegetation, and island dynamics. The mean annual precipitation ranges around 2000 mm and the regime is basically flashy pluvionival.

The study has been conducted on three cross-sections located in the braided portions of the Tagliamento, near the Cornino village, where the active channel is about 1 km wide and the slope is about 0.0034 m m^{-1}. The cross-sections were surveyed with a DGPS in June 2010 and than resurveyed 5 times after major floods that occurred until the end of 2010 (Figure 1).

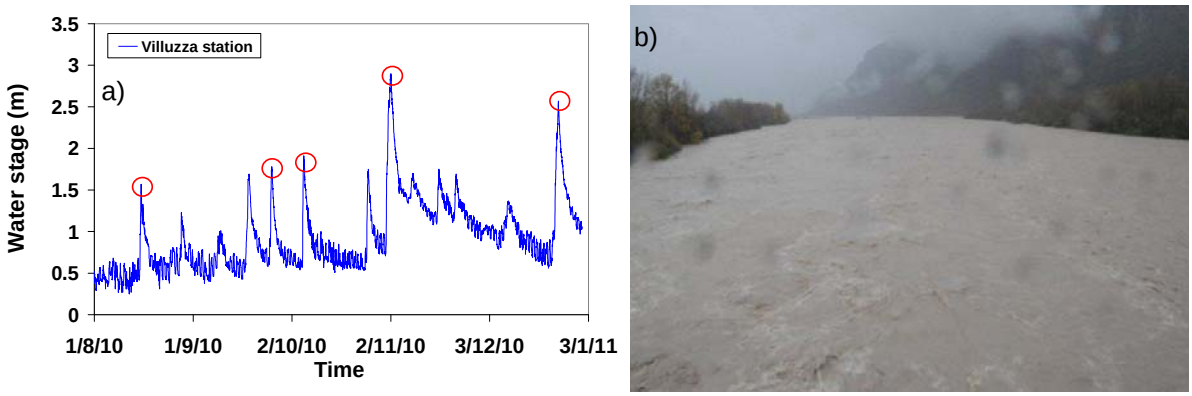

Figure 1. Water stage measured from August to December 2010 at the Villuzza gauging station (relatively close to the study reach). The analyzed floods are highlighted with a red circle. On the right the Tagliamento during the 25/12/2010 flood.

Along the three cross sections surveyed, a number of 0.8×0.8 m areas were selected as representatives of each morphological unit and vertical digital photographs of the bed surface were taken. The collected photos were processed with the Digital Gravelometer software to derive the surface grain size distribution of each site. After the photographs were taken, the surface of the same photographed area was painted using a spray paint All the painted areas were visited immediately after each flood event during the study period (July 2010-January 2011). During each visit, the painted sites were photographed again and the size and the travelled distance of all the painted particles found in the downstream direction were measured. The morphological effects of flood events on the coloured areas were classified as no motion of gravel particles (NM), deposition of fine sediments

above the coloured area (FD), partial transport (PT) and gravel deposition or full removal of the whole coloured area. The partial transport class is intended here sensu Haschenburger and Wilcock (2003), which identifies the condition where some surface-painted grains (irrespective of their diameter) moved whereas other particles remained immobile in a certain area of the streambed throughout a flood. To estimate the shear stress acting on the flooded sites, at each visit the maximum flow depth over each painted area was estimated from field evidence. Shear stress was calculated through the slope-depth approach, and dimensionless shear stress (τ^*) was calculated using the local D_{50} derived from the grain size photographic analysis of the same coloured area.

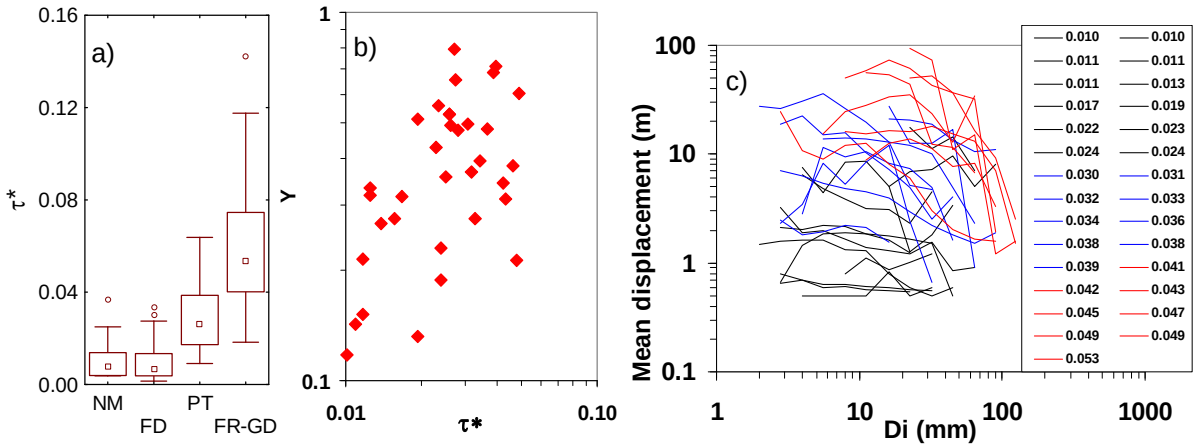

Figure 2. Range of shear stress that acted over the painted particles and induced morphological effects classified as no sediment motion nor deposition (NM), deposition of fine sediments (FD), partial transport (PT), full removal of the painted sediments or gravel deposition (FR-GD) (on the left). Extent of partial transport at different values of dimensionless shear stress (centre). Displacement length of particle of different size belonging to coloured areas experiencing partial transport conditions at different values of dimensionless shear stress (on the right).

3 PRELIMINARY RESULTS AND REMARKS

The analysis of the morphological effects over the coloured areas shows that the full mobility conditions (e.g. all surface sediments transported) are due to dimensionless shear stress higher than 0.045, which is generally in agreement with the more accepted value of critical Shields stress for the entrainment of the D_{50} (Figure 2a). Overall, partial sediment transport conditions are determined by dimensionless shear stress ranging between 0.015 and 0.039. An image analysis conducted on the post-event photos taken on the coloured areas experiencing partial transport conditions revealed that there is a rather weak but positive relationship between the dimensionless shear stress and the extent of partial transport (Y in Figure 2b). Looking at the mean particle displacement length from coloured areas experiencing partial transport, it appears that the travel distance of a certain size particle increases with the shear stress (Figure 2c). Also, for a given dimensionless shear stress a systematic decrease of particle displacement with grain size is evident beyond a certain size, and the position of this threshold coarsens as flow strength increases. Although these slope breaks are not easily recognizable in the curves for all the plotted coloured areas experiencing partial transport, on the left hand side of Figure 2c are the grain size that demonstrate an invariant displacement length which suggests sediment transport under equal-mobility conditions. Conversely, on the right-hand side of Figure 2c are the grain size which supposedly are transported under size-selectivity conditions.

Even if a preliminary attempt of calculating sediment transport is not presented here, the data collected has the potential of allowing the assessment of bedload transport rate using the so-called “virtual velocity” method, which considers the threshold between full mobility and partial transport conditions, the degree of partial transport which depends on the flow strength, and the displacement length of particles of different sizes (Wilcock, 1997).

LIST OF REFERENCES

Haschenburger, J.K. and Wilcock, P.R. (2003). *Partial transport in a natural gravel bed channel*. Water Resources Research 39 (1), 1020. doi:10.1029/2002WR001532.

Wilcock, P.R. (1997). *Entrainment, displacement and transport of tracer gravels*. Earth Surface Processes and Landforms 22, 1125–1138.

Wilcock, P.R. and McArdell, B.W. (1993). *Surface-based fractional transport rates. Mobilization thresholds and partial transport of a sand-gravel sediment*. Water Resources Research 29, 1297-1312