Progetto CLARA (H2020-SC5-2016-2017/H2020-SC5-2016-TwoStage)

Analisi del trasporto solido di fondo del Fiume Parma mediante l'applicazione di diverse tecniche

RELAZIONE FINALE

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1. INTRODUCTION

Within the European project "CLARA" the Parma river basin Water Assessment (Pwa) has been developed by Arpae. Pwa aims to model the hydrological response of the Parma River catchment to different scenarios of climate change considering different types of responses. One of the model output is the coarse transport active along streams in response to hydrological constrains.

In coarse-bedded rivers, episodic coarse transport is one of the most significant factors controlling morphodynamic processes (Church, 2006; Church & Ferguson, 2015). For this reason, a reliable estimation of this process is a key issue for each attempt to model the river behavior over different time scales. Coarse material transport estimation is notoriously hard to achieve (Ferguson, 2007), especially in the context of large rivers, where direct sampling is unfeasible and theoretically based formulas often provide incongruent results (Martin and Ham, 2005). The virtual velocity approach represents a viable tool to achieve reliable estimates of coarse transport in these river contexts (Ferguson, 2007; Mao et al., 2017). It is a hybrid estimation method based on a theoretical framework (Wilcock, 1997) and substantial field-data collection about the sediment mobility in function of the dimensionless shear stress (τ^*) induced by water flow on the streambed (Mao et al., 2017; Brenna et al., 2019a).

The task of the Department of Geosciences of the University of Padova (UniPd) was applying the virtual velocity approach and other techniques (i.e. theoretically-based transport formulas) for providing the relationships between τ^* and the unit coarse transport locally induced by the water flow at different cross-sections representative of five waterbodies of the Parma and Baganza rivers. Such relationships allow to address the coarse transport estimates at river cross-sections during a competent "flood event" or for longer time scales.

2. STUDY AREA

This work focuses on the Parma River catchment, which is located in the northern Apennines (Italy) and covers a total area of 815 km^2 with an elongated North-South shape (Figure 1). Specifically we focused on the hilly and high-plain sectors of the Parma River and its major tributary, the Baganza River. Three and two waterbodies have been identified along the study sectors of the Parma River and Baganza River, respectively. For each waterbody we selected one or two representative river cross-sections (Figure 1 and Table 1) where developing the relationships between τ* and the unit coarse transport required for the transport estimates.

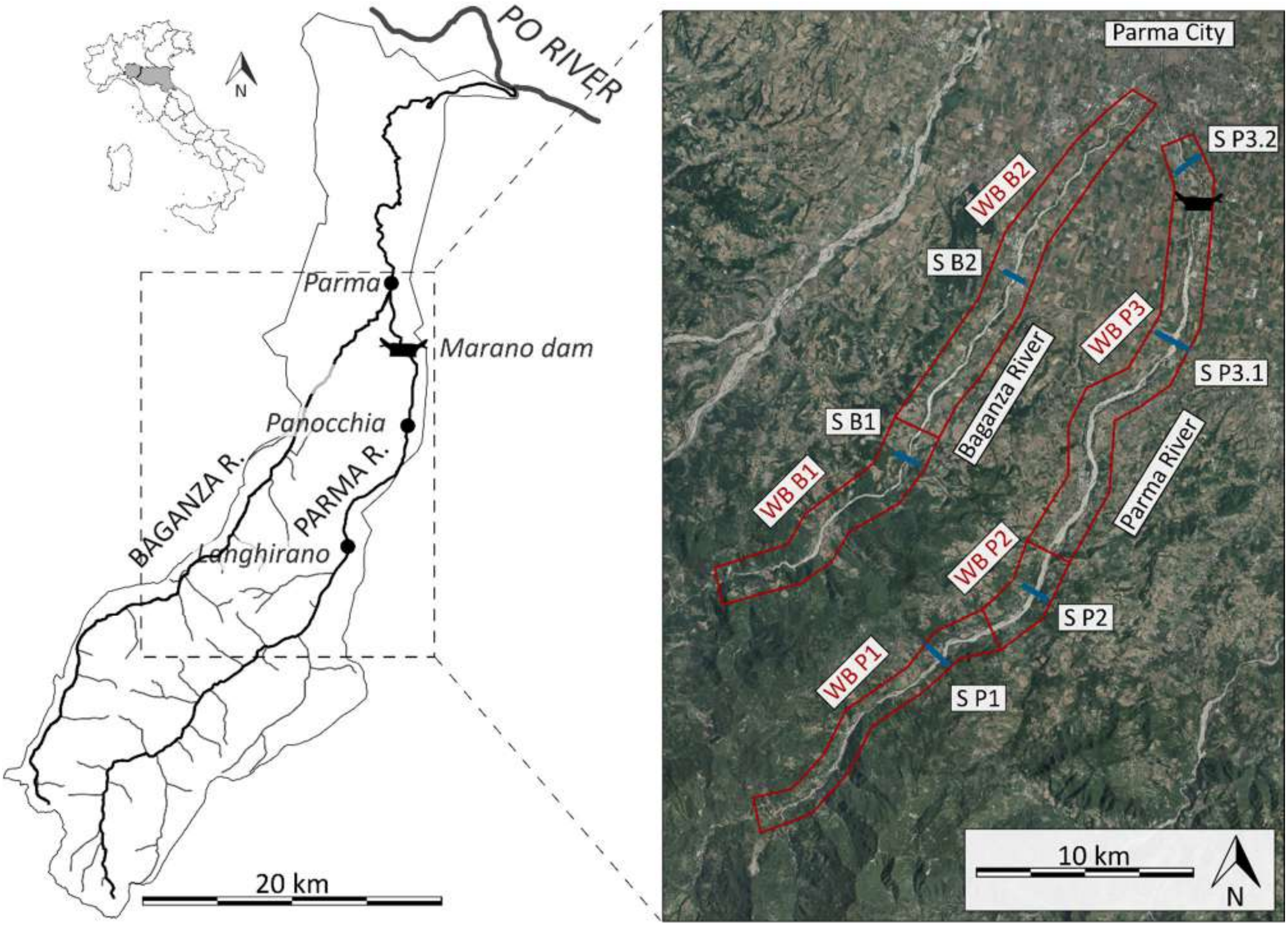

Figure 1. General setting of the study area. In red are identified the water bodies. Blue lines refer to the selected study sections.

River	Waterbody	Channel morphology	Min and max active channel widths (m)	Study section	Section location	Mean channel slope
Parma River	WB P1	Sinuous - Braided	50 - 260	S P1	Mulino Vecchio	0.012
	WB P2	Braided	190 - 330	S P2	Chiastrone	0.011
	WB P3	Sinuous - Braided	40 - 380	S P3.1	Panocchia	0.010
				S P3.2	Valle cassa Marano	0.005
Baganza River	WB B1	Sinuous - Braided	20 - 200	S B1	Marzolara	0.014
	WB B2	Wandering - Braided	30 - 240	S B2	Sala Baganza	0.013

Table 1. Characteristics of the water bodies and selected cross-sections. Mean channel slope was averaged considering 400-800 m of channel centered on each section.

3. METHODS

3.1 Geomorphic units and grain size characterization

For each selected cross-section the grain size of the surface material have been defined. During the fieldwork, the active channel near the sections was classified in two main geomorphic units (i.e. channels and bars) (see Mao and Surian, 2010, for an overview of the criteria).

We selected two sites on each geomorphic unit type at each cross-section and took digital orthogonal photographs (area of 0.8 * 0.6 m) of the surface sediments. The photos were processed by the Digital Gravelometer software (Graham et al., 2005, 2010) deriving the surface grain-size distribution characterizing each site with a lower truncation of 6 mm due to camera resolution. That data have been used for calculating the D_{50} and D_{84} of channels and bars surface material at each cross-section.

3.2 The Virtual Velocity Approach

In order to develop relationships between the dimensionless bed shear stress (τ^*) and the unit coarse transport (q^u), we adopted the virtual velocity approach based on the framework developed by Wilcock (1997), since it takes into account several site-specific aspects that control transport processes. The framework requires determining empirical relationships between calculation parameters (i.e. thresholds among mobility conditions; percentage of the mobilized streambed surface in case of partial transport; thickness of the active layer in case of full transport; virtual velocity of moved grains) and the τ^* induced by the water flow over the streambed. Those relationships are site-specific (i.e. reach-specific, as described in Brenna et al., 2019a, or section-specific for this application case), depending by the local characteristics (e.g. grain size, sediment fabric etc.) of the streambed material.

The Department of Geosciences of UniPd and Arpae collected field data at one water body of the Parma River (i.e. WB P3) monitoring 6 - 9 competent events during the period 2015 - 2017 at sections S P3.1 and S P3.2. Field monitoring mainly consist in installing two types of tracers (i.e. painted clasts and Passive Integrated Transponders) and scour chains and performing topographic surveys. After each flood event we monitored data about sediment mobility at the installed study sites (see Brenna et al., 2019a). Taking errors and variability into account, we applied the equations to calculate fractional transport (Wilcock, 1997) and the derived empirical relationships to determine the total unit mass transport rate (q^u) occurring for a specific τ^* (time resolution = 30 min) on a cross-section unit (spatial resolution = 1 m). For practical reasons affecting the tracers approaches, the estimates of the coarse fraction of transport consider clasts larger than 6 mm (b axes). Four final relations $q^u = f(\tau^*)$ have been calculated for channels and bars at sections S P3.1 and S P3.2 using the virtual velocity approach.

The application of the section-specific $q^u = f(\tau^*)$ relations allows to calculate the local (i.e. 1 m-wide) and instantaneous (i.e. 1 hour) q^u induced by the water flow, based on the τ^* which depends by the local water depth, the mean section slope and the local surface mean grain size (i.e. depth-slope approach, see Mueller et al., 2005). For estimating the coarse transport occurring during an entire competent event at a specific river cross-section it is sufficient to integrate over the space (i.e. the section extension) and over the time (i.e. the hydrograph duration and shape) the local (i.e. 1 m-wide) and instantaneous (i.e. half hour) $q^u{}_s$ calculated using the $q^u = f(\tau^*)$ relationships.

3.3 Theoretically based transport formulas and selection of the appropriate calculation formula

For sections S P1 and S P2 (Parma River) and S B1 and S B2 (Baganza River) the field-data for applying the virtual velocity approach were not available. For this reason, the adoption of an adequate theoretically based transport formula was the only way for defining section-specific relation between τ^* and q^u at these sections.

It is widely recognized that the application of different theoretically based transport formulas at the same section for the same event often provides incongruent results (Martin and Ham, 2005;

Lopez et al., 2014) so it was crucial to select the most appropriate formula for estimating the coarse transport at the selected study-sections. In order to select the most appropriate formula, we identified four potentially applicable theoretically-based approaches for calculating the coarse transport at section S P3.1 (Panocchia section) during a representative flood event (i.e. January 2016) for which the reliable estimates obtained through the virtual velocity approach were also available. Through the comparison of the results obtained using the four selected formulas with the virtual velocity estimate we selected the more reliable theoretical approach.

The section S P3.2 is located downstream from the Marano retention basin dam, so its sediment mobility is strongly impacted by the human-induced limitation of mobile sediments (Brenna et al., 2019b). The sections located at water bodies WB P1 (S P1), WB P2 (S P2), WB B1 (S B1) and WB B2 (S B2) have streambed sediments characteristics more comparable with those of section S P3.1, so the comparisons made at this location and the derived conclusions about the best-fitting formula can be considered valid also for the other study-sections.

The tested theoretically based formulas, all developed for estimating transport in coarse-bedded rivers so potentially applicable in this context, are:

- The Meyer-Peter and Mueller equation (Meyer-Peter and Mueller, 1948)
- The Wong and Parker relation (Wong and Parker, 2006)
- The Wilcock and Crowe model (Wilcock and Crowe, 2003)
- The Recking formula (Recking, 2010; Recking et al., 2012)

4. RESULTS

4.1 Grain size of surface sediments

The results obtained from the grain size analysis are reported in Table 2 and Figure 2. Channel sediments are coarser than bars ones at all considered sections excluded the section B S2 where channel and bar sediments are similar.

River	Section	Geomorphic unit	Surface D_{50} (mm)	Surface D_{84} (mm)
Parma River	P S1	Channel	114	264
		Bar	48	82
	P S2	Channel	107	167
		Bar	58	133
	P S3.1	Channel	49	93
		Bar	42	93
	P S3.2	Channel	107	192
		Bar	63	118
Baganza River	B S1	Channel	105	208
		Bar	50	99
	B S2	Channel	48	93
		Bar	48	107

Table 2. D_{50} and D_{84} defined for the two considered geomorphic units at the six study-sections.

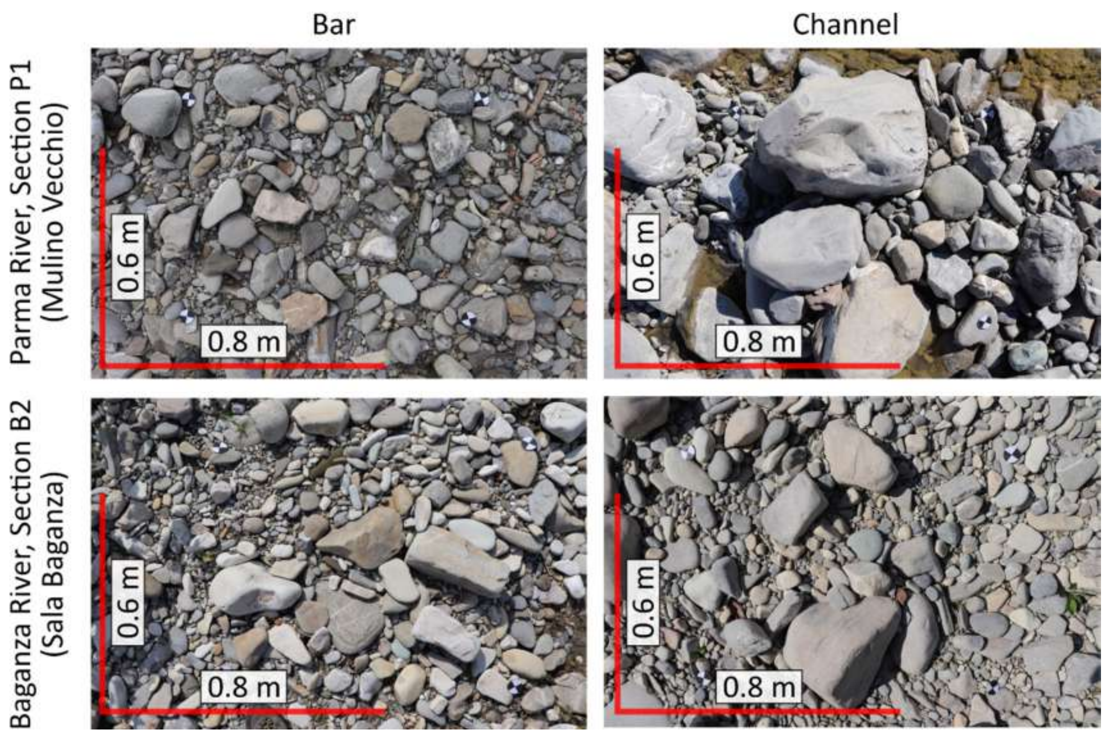

Figure 2. Examples of bar and channel surface sediments at two sections of Parma River and Baganza River.

4.2 The Virtual Velocity Approach applied at two sections of the Parma River

At sections S P3.1 and S P3.1 (waterbody WB P3 of the Parma River) the field-monitoring allowed us to define the section-specific relationships between q^u and τ^* for channel and bar sediments. Using the empirical relation between τ* and calculation parameters and the equations provided by the Wilcock's framework (1997), the final $q^u = f(\tau^*)$ were obtained. Figure 3 summarizes the results.

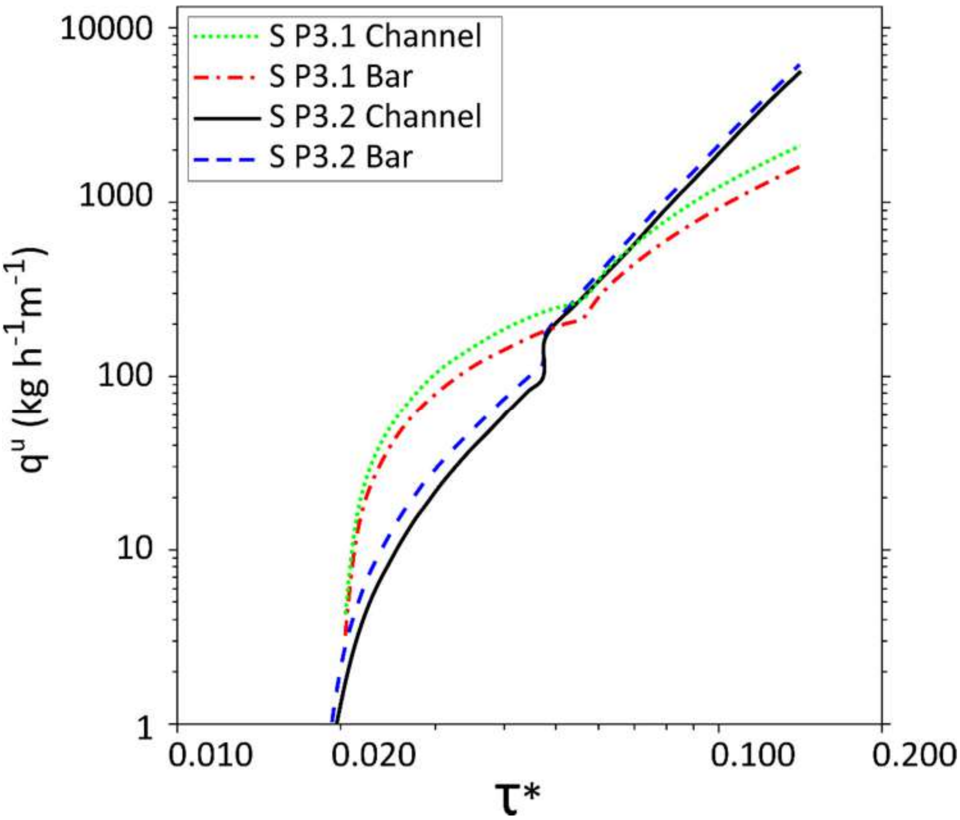

Figure 3. $q^u = f(\tau^*)$ obtained through the Virtual Velocity Approach at the two sections of the waterbody WB P3 on the Parma River. Two geomorphic units (channels and bars) are considered.

4.3 Selection of the most appropriate transport formulas

To select the most appropriate theoretically-based formula for estimating the coarse transport at sections S P1, SP2, SB1 and SB 2, we compared the estimates of coarse transport occurred at section S P3.1 during the January 2016 event (maximum discharge = 124 $m^3 s^{-1}$, return interval ≈ 1 yr) (Figure 4) provided by the four tested formulas and the Virtual Velocity Approach.

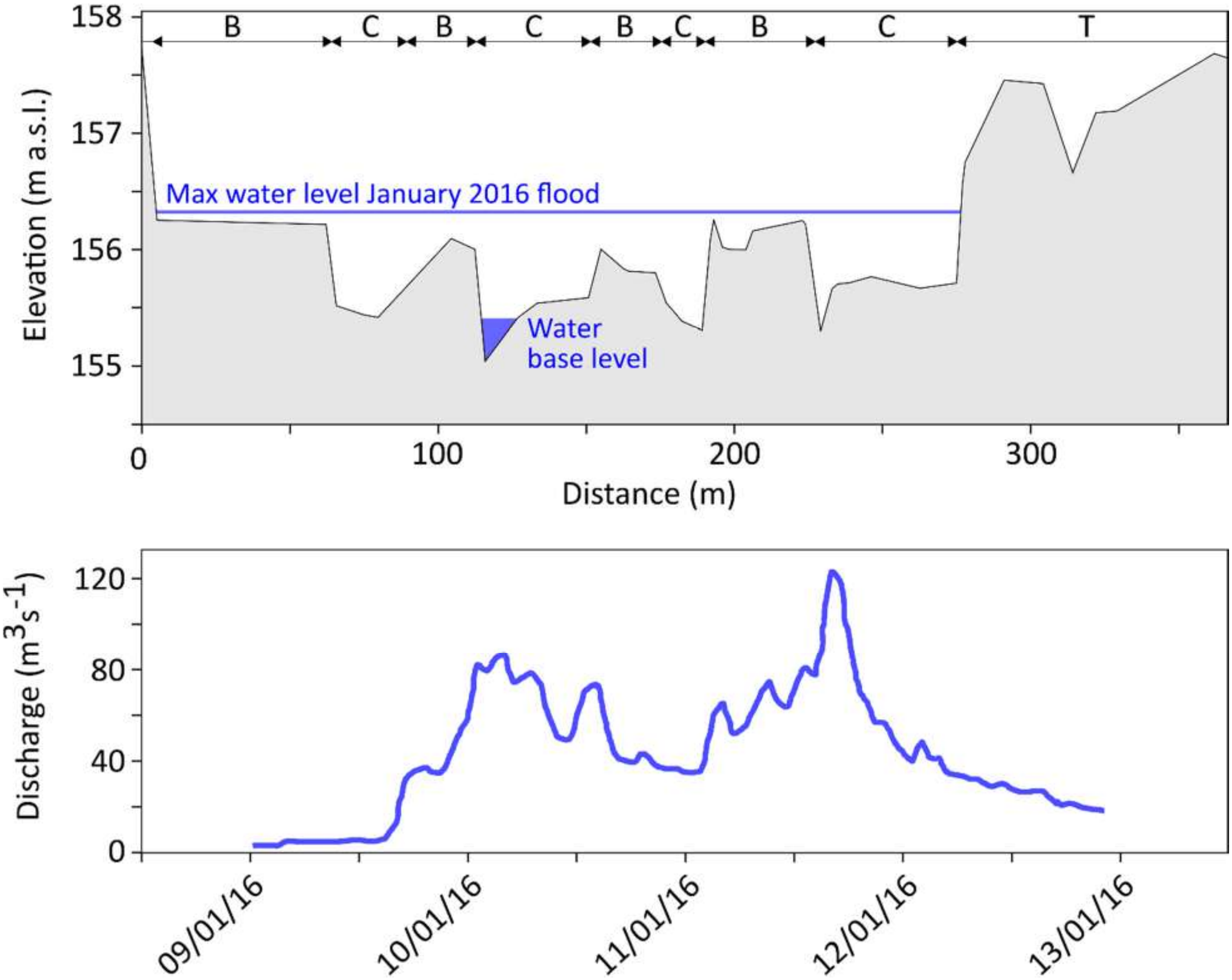

Figure 4. Section S P3.1 and hydrograph of the January 2016 flood event.

Considering the section and streambed features (mean slope, D_{50} and D_{84}, as reported in Table 1 and Table 2) and the data collected in the field during the two-years monitoring, we defined the section-specific relationships between τ^* and q^u using the four tested theoretically based formulas and the Virtual Velocity Approach (Figure 5).

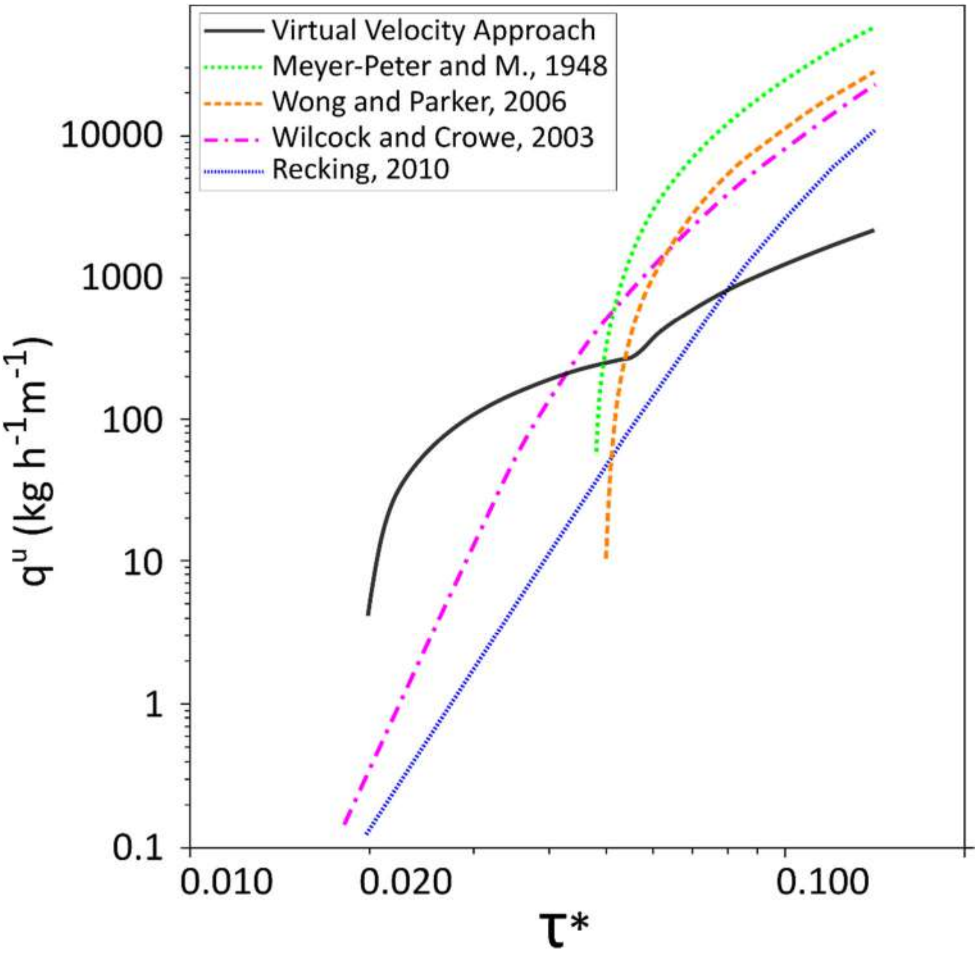

Figure 5. $q^u = f(\tau^*)$ obtained through the Virtual Velocity Approach and tested theoretically based formulas at section S P3.1 for the geomorphic unit "channels". Similar relationships have been determined also for the geomorphic unit "bars".

Finally, the total coarse transport occurred at section S P3.1 during the January 2016 flood event has been estimated as described in the Method section by applying the four $q^u = f(\tau^*)$ relationships obtained by the tested theoretically based formulas and the $q^u = f(\tau^*)$ relationship gave by the Virtual Velocity Approach. Transport estimates, expressed in m^3 of coarse sediment mobilized during the entire event, are:

- Meyer-Peter and Mueller (1948): **52959** m^3
- Wong and Parker (2006): **23593** m^3
- Wilcock and Crowe (2003): **19389** m^3
- Recking (2010): **5309** m^3
- Virtual Velocity Approach: **3842** ± 1309 m^3

Based on the comparison of the estimates results and looking at the obtained relationships between τ* and q (Figure 5), the Recking formula (2010) has been identified as the theoretically based approach that, in this case-study, better fits with the results provided by the Virtual Velocity Approach. For this reason, we adopted the Recking formula (2010) for determining the $q^u = f(\tau^*)$ relationships also at sections S P1 and SP 2 in the Parma River and SB 1 and S B2 in the Baganza River.

4.4 Recking's Formula results

Based on sections S P1, SP 2, SB 1 and S B2 features (mean slope, D_{50} and D_{84}, as reported in Table 1 and Table 2), the $q^u = f(\tau^*)$ relationships determined using the Recking formula (2010) for channels and bars of the four sections are reported in Figure 6.

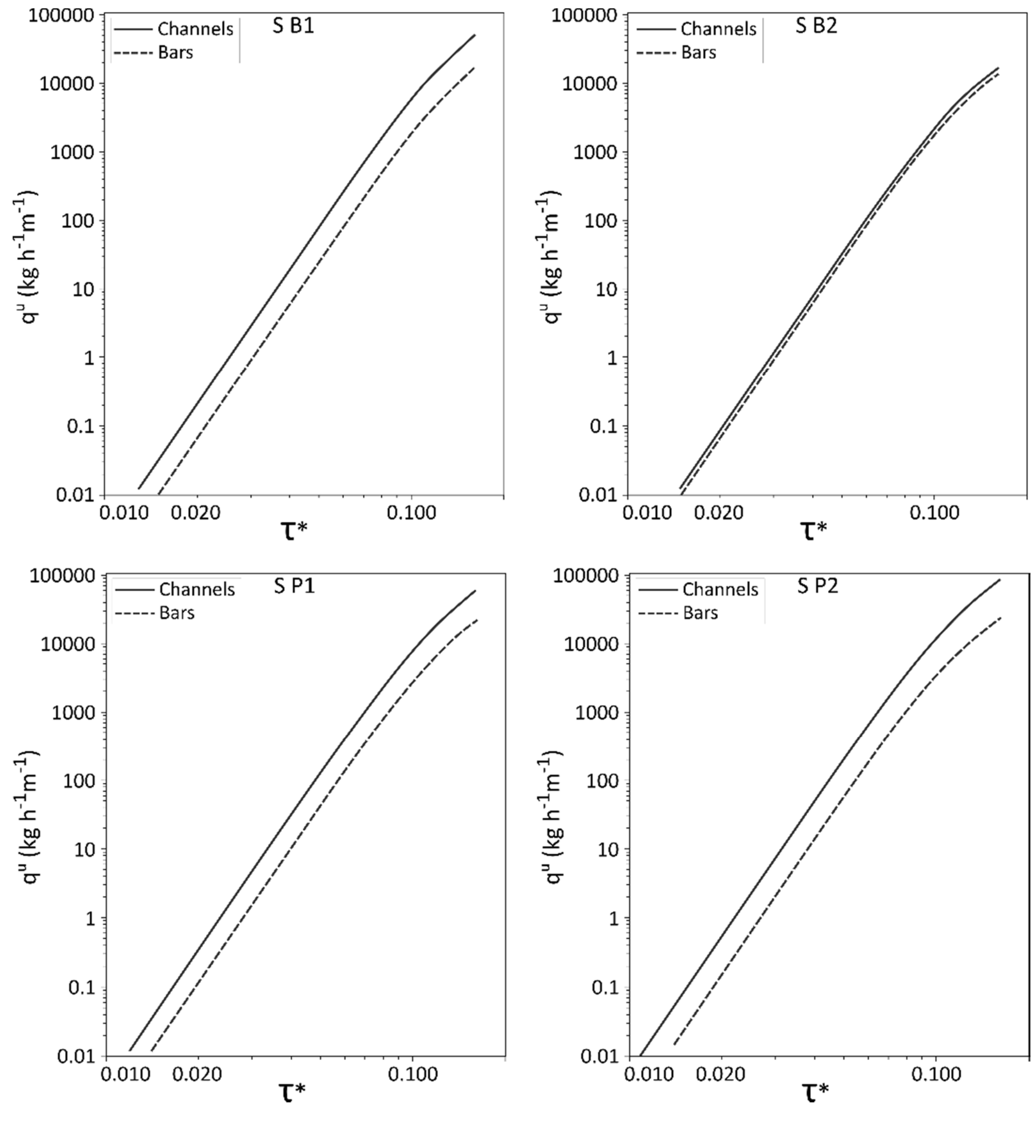

Figure 6. $q^u = f(\tau^*)$ obtained using the Recking formula (2010) at the four considered sections

5. APPLICABILITY AND LIMITATIONS OF THE RESULTS

The high reliability of the $q^u = f(\tau^*)$ derived using the Virtual Velocity Approach is discussed in some scientific works carried out during the last years (Mao et al., 2017; Brenna et al., 2019a). The choice of the Recking formula (2010) as the most appropriate theoretically based approach for estimating the coarse transport at some of the sections considered in this work is based on a single test conducted for this specific case-study.

The estimation of transport addressed in this work focuses only on the coarse material larger than 6 mm (b-axes) which moves as bedload transport. Fine gravel, sand and fine sediments are not considered in this work.

It is important to consider that each $q^u = f(\tau^*)$ relationship determined in this work is valid only for a specific location (i.e. cross-section) since both the Virtual Velocity Approach relationships and the Recking relationships are strictly controlled by the local characteristics of the streambed material. With this in mind, also their validity over time depends by the stability of the streambed conditions within the evolution of the rivers. In other words, the obtained relationships can be considered valid as long as the streambed sedimentological features remain unchanged. Significant variations in grain size or grain fabric at the study-sections would make obsolete the derived relationships.

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