Value of bedload movement in alluvial rivers using analysis of sand bar migration

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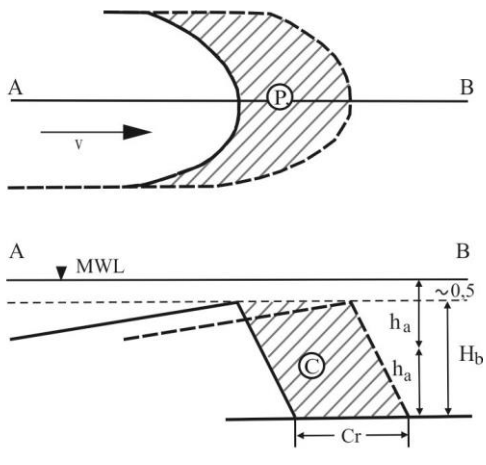
ABSTRACT: The channel mesoforms dynamics was conducted of the lower Vistula river (Poland). Movement of bars was determined on own measurements carried out at the three characteristic sections: unregulated channel, strong transformation channel below dam and regulated reach. Studies showed that each increase in flows corresponds to a proportional increase in the mesoforms dynamics. The size of bedload movement was determined based on the dynamics of bars, their movement rate and the layer thickness of these forms. Studies showed that bedload in the unregulated section on average amounted to nearly 2.2 million tons per year, whereas in the regulated section it did not exceed 1.0 million tons per year.

1. INTRODUCTION

Mesoforms are of major importance in the study of channel processes, defined by Popov (1977) as an unsteady continuous movement of the river channel bed under the influence of flowing water (Van Rijn, 1984). Kurpianov and Kopaljani (1979), suggest that the channel process is chiefly conditioned by a mechanism for fluvial transport and they establish certain relationships between them. These relationships have also been built up by Schumm (after Shen 1982) and by Winkley et al. (1984). From these data it can be inferred that a channel pattern (channel process) and an adequate system of mesoforms, depend on the quantity and quality of the bed-load transport. Continuous bed-load transport leads to the formation of dunes and sand ripple marks, i.e. microforms, whereas discontinuous transport results in central and lateral bars (islands), i.e. mesoforms (Carling et al., 2000; Rodrigues et al., 2014). The term channel mesoforms refers to forms, the size of which corresponds with the channel width and high stability of which is determined by hydraulic geometry of a stream. They usually comprise single large sand-gravel waves and fixed lateral bars, the surface of which lies in a zone of average water stages although they are formed at high water stages (Babinski, 1987).

2. SUDY AREA AND METHODS

Research on channel mesoforms dynamics was conducted in the years 1981–2014 over a 200 km-long section of the lower Vistula (Northern Poland) (Babiński, 1992a). The research posts were located at specific sections of the river which is partially regulated and features a single dam. In recent years, the researchers constantly monitored pools located along the line of a new road bridge over the Vistula river near Toruń. Both horizontal and vertical movement of bars was determined on the basis of own measurement methods, including geodetic measurements carried out at the unregulated Vistula reach near Warsaw (Fig. 1), as well as at the section being subject to strong transformation caused by the dam in Włocławek (Habel 2013). The third selected reach had been regulated to a constant width in the second half of the 19th century (Babiński 1992b). Both cross– and longitudinal sections of the channel proved to be extremely helpful when preparing the bathymetric maps of the channel (bars and pools morphometry). The study was supplemented with measurements of mechanical composition of the bars and pools.



$$T = P \cdot H_b = P\,(2h_a - 0,5)$$

Figure 1. Ideogram of bed-load transport value (T) based on measurements of alternate sand bars dynamics at the regulated Vistula reach. Explanations: H_b – average thickness of sandbar, Cr – velocity of movement, P – surface rate of movement.

The following bars were identified on the lower Vistula in the course of field research and aerial photographs analysis: at the unregulated section of the Vistula – lateral sand bars and mid-channel bars, elevation of which corresponds with average annual water stages, linguoid bars, whose elevation coincides with average low water stages and occasionally (mostly at the regulated, straight section) diagonal bars that in terms of elevation fall between the abovementioned forms. The lateral and mid-channel bars are approximately 550 – 750 m long and 200 – 300 m wide, the linguoid bars reach an average length of 450 m and width of up to 200 m, whereas the diagonal bars reach on average 800 – 1200 m and 300 m respectively. Pools, erosion forms that can be found together with bars and which are at the same time commensurate with their size, reach a depth (measured at average water stages) of 4.0 – 4.5 m, 5.5 m locally in the case of braided channel, and 5-7 m with local depressions of up to 12 m at the regulated section of the lower Vistula.

3. RESULTS OF STUDY

Results analysis of the geodetic measurements of the bars and the channel sections against the Vistula river flows showed a dependence between the mesoforms dynamics and the hydrological regime of the river. The relation was the greater, the smaller was the impact of non-hydrological factors, such as channel morphology, ice phenomena and anthropogenic activity (bridges, channel regulation). Generally, each increase in flows corresponds to a proportional increase in the mesoforms dynamics and vice versa. The analysis of reaches featuring different channel development levels shows that the heads of bars of the same kind move at similar rate, however, this tends to change the more the bars differ in terms of, among others, elevation of their surfaces. Thus, the highest bars, i.e. lateral and mid-channel bars, have the lowest movement rate (Fig. 2), in the range of 0.2 – 1.27 m per day (on average 0.6 – 0.8 m per day), diagonal bars – alternate (occurring mostly at the regulated sections) – from 0.4 to 2.4 m per day (on average 1.1 – 1.2 m per day), whereas linguoid bars, being the lowest (corresponding to mean low water flows) and most dynamic forms (Fig. 2), move at a rate of 0.6 to 4.3 m per day (on average 1.7 – 1.8 m per day).

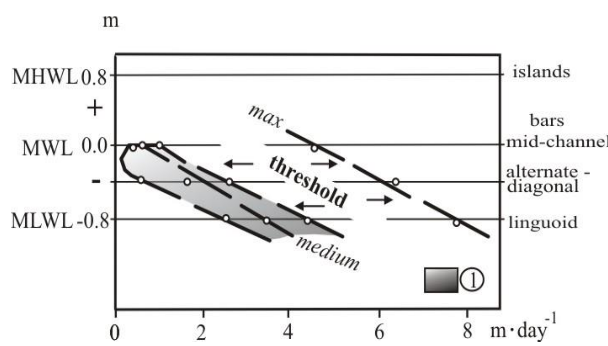


Figure 2. Mean diurnal rate of bar shifting on the unregulated and regulated sections of Vistula: 1 — zone of average velocities of bar shifting, MHWL — average high water stage, MWL — average water stage, MLWL — average low water stage.

4. CONCLUSIONS

The size of bedload movement was determined based on the dynamics of bars, their movement rate and the layer thickness of these forms. Studies showed that bedload in the unregulated section (reservoir backwater area) on average amounted to nearly 2.2 million tons, whereas in the regulated section, in the hydrological years of 1971/1995, it did not exceed 1.0 million tons. During a wet year 1975, the lower Vistula can transport up to 4 million tons of bedload at the braided and anastomosing section (unregulated channel) and more than 1.5 million tons at the regulated reach in the profile of Toruń, with the minimum of, respectively, nearly 1.0 and 1.5 million tons. The above data show that the smallest differences in bedload movement between these two sections occur in dry years (twofold), and the largest during wet periods (2.7 times). This spatial differentiation of bedload movement arises from: (a) the impact of the 19th century regulatory works, which transformed the braided and anastomosing channel (currently above the backwater of the Włocławek reservoir) into a straight, slightly winding one with a system of diagonal bars, and (b) limited capacity to collect bedload below the dam as a result of bed erosion (geological structure), which prevents the river from reaching the value of the section upstream of the water body (Babiński, 1992a). The bedload movement anomaly that occurs below the erosion zone is associated with the moment when the river becomes "saturated" with bedload (eroded from the bottom and banks), which is then temporarily discharged before entering into the regulated section of the Vistula (Figure 2 - Babiński, 1992a, 2002). The obtained results correspond to the findings of research conducted at the site of the road bridge construction in Toruń in the years 2011-2015 (Babiński, 1992a), albeit certain differences have been indicated. These involve a slight reduction in the rate of movement of pseudo-curved bars above the pillar of the bridge, and vice versa – the rate tends to increase down the river (Babiński et. al. 2014).

5. ACKNOWLEDGMENT

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