

DOMINANT DISCHARGE – AN OUTLINE OF THEORY AND A CASE STUDY FROM THE RABA RIVER

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Abstract. Designing hydraulic structures engineers has only theoretical flows, calculated using formulas based on statistics. Knowledge of the dominant discharge could help determine designers who are interested in changes of the morphology of river channels, especially in terms of sediment transport. It was observed that the designing of a stable channel in the river is possible when defining characteristic of flow in the river which is the most frequently present in the river and in the same time it carries the sediment. That is the dominant discharge. It is this movement can represent both the hydraulic system and the geometry of the river cross-sections. The dominant discharge (also called river shaping channel discharge) is considered by many authors as a discharge that transports the largest amount of sediment, it takes a long time and has an impact on the formation of the shape of the river bed. Observations of Wolman and Miller showed that low but frequent flows of water might be responsible for new shape of the river channel, erosion of the riverbed, sediment deposition and consequently changes in river morphology. The paper presents Wolman method for dominant discharge use for the Raba River for chosen gauge cross section. Along in the paper we discuss the obtained results and the consequences of using dominant discharge for the practice. In six cross sections on the Raba River, Q_{dd} was calculated values, which range from $31 \text{ m}^3 \cdot \text{s}^{-1}$ (for the section in Rabka) to $395 \text{ m}^3 \cdot \text{s}^{-1}$ (in Proszówki). These flows occur

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every two years (for the upper sections of the river), and every four years (for cross-sections located in the lower section of the river).

Key words: dominant discharge, the Raba River, sediment transport, Wolman method, flow frequency

INTRODUCTION

Riverbeds are formed by the movement of water and sediment. It is therefore necessary to create a definition of flow, which might be recognized as a flow responsible for channel forming processes and at the same time a flow which allows engineers to “see” and to “feel” the river. For the alluvial river bed some could distinguish, except for flows with a characteristic probability of occurrence (the t -years flows), so-called flows affecting the formation of the river bed. The first is the bankfull discharge, which includes the flow of water to the border line of flood terraces. The second concerns the flow of shaping river bed in terms of multiple flows with characteristic interval, and usually the flow is between the average annual flows of a five-year peak. The third flow is the effective flow, which carries the largest amount of the average annual sediment/debris [Copeland et al. 2000, Radecki-Pawlik 2015]. In the Polish nomenclature the last two flows are describes as “dominant discharge”.

The definition of the dominant discharge might be determined by many scientists. Bankfull is often invoked as the most effective flow because this represents the maximum flow that occurs within the confines of the channel, hence exerts the largest stresses on the channel boundaries, whilst rarer overbank flows have negligibly more severe effect within the channel. However, there is no consistent correlation between flow frequency and bankfull nor, in fact, between flood frequency and effectiveness in creating morphodynamic change [Church 2015]. Significant correlations have been demonstrated between plant communities and elevation above normal water levels, hence usual duration of inundation [e.g., Woodyer 1968,] and between certain invertebrates and elevation [Radecki-Pawlik and Skalski 2008]. The “lower limit of continuous terrestrial vegetation” is a significant channel boundary that is more or less well-defined on most stream banks and is interpreted as the limit of the “active channel”. In many jurisdictions, this is also the legal limit of the river channel, though it may not correspond with the morphologically determined “bankfull” stage [Church 2015].

The volume of water that flows through the channel – in particular, the magnitude of flows that mobilize channel-bed sediments and thereby shape the channel – sets the scale of the channel [Church 2015]. Since runoff, including peak flows, varies with the size of the contributing drainage basin, river channel scale varies systematically through the drainage basin [Leopold 2005]. It is widely supposed that flood flow of some relatively frequent recurrence – in the range 1.5–2.5 years (that is, approximately the mean annual flood [cf. Wolman and Miller 1960]) – is the dominant or “channel forming” flow in the sense that it is the flow that creates the greatest degree of morphodynamic change (Church 2015). That way dominant discharge could turn out as a very important information for not only fluvial geomorphologists but also for hydraulic engineers working with river training and river channel maintained. Knowledge of

the dominant discharge value might be very useful for determining the initial size of hydraulic structures for the hydraulic design project [Radecki-Pawlik 2015]. In determining the dominant discharge should be remembered that certain factors are “sensitive” in relation to the methods used. Depending on the material with which we face, we must apply the method of logarithmic (for sand) or arithmetic (for gravel). Another sensitive parameter is appropriately selected sediment transport. From the viewpoint of comparison it is important to analyze data which are homogenous. The data that should be used must be concentrated in time. If, therefore, the data that we have are not enough, there is no possibility to determine the dominant discharge. Problems also arise when we expect changes in hydrology of the catchment for example by rapid changes in land use [Copeland et al. 2000]. Observations done by Wolman and Miller [1960] allowed to conclude that dominant discharge is a low but frequent flow of water in relation to these catastrophic shaped river bed still mobilizing the sediment to move but so intensively that after the time being its changing the river channel morphology [Radecki-Pawlik et al. 2014].

In the following paper we analyzed the dominant discharge for the Raba River. Having the 30 years long series of hydrological data for gauging stations of the Raba River we applied the Wolman method for dominant discharge. For sediment transport calculations we used BAGS model. In six cross sections on the Raba River, Q_{dd} was calculated values, which range from $31 \text{ m}^3 \cdot \text{s}^{-1}$ (for the section in Rabka) to $395 \text{ m}^3 \cdot \text{s}^{-1}$ (in Proszówki). As results we present the dominant discharge data for the whole gauging stations for the Raba River.

MATERIAL AND METHODS

Raba River is a right tributary of the Vistula. Raba collects the waters of the northern slope of the Western Carpathians. The length of the watercourse is 132 km and its drainage basin covers an area of 1537 km². Its sources are located near the village of Sieniawa (approx. 785 m a.s.l.) in southern Poland in Beskid Orawsko-Podhalański. The river flows into the Vistula River in the town of Ujście Solne (180 m a.s.l.) [Plesiński et al. 2014]. The alluvial river bed of the Raba River is mostly gravel, and sand (in the mouths of the River). Narrow valley, waterfalls and a high stream power define the Raba River as a mountain river. The average slope of its upper course is 8.5‰ (the Beskidy Mont.). Its middle section runs within the foothills of the lower course of the Sandomierz Basin [Wyźga 1993].

Along the Raba River are located 6 gauging cross-sections: 4 upstream the dam in Dobczyce (in the villages of: Rabka-Zdrój, Mszana Dolna, Kasinka Mała, Stróża) and 2 downstream of the dam (in Dobczyce and Proszówki villages).

To find dominant discharge value for the Raba River we applied the Wolman and Miller concept [1960]. The method is using the relationship between the sediment transport and frequency of occurrence of discharges in rivers. For our calculations we used discharges values for the Raba River from last 30 years for all gauging stations also we calculated sediment transport for all those years and discharges. The dependence between sediment load and frequency of floods presents Fig. 1.

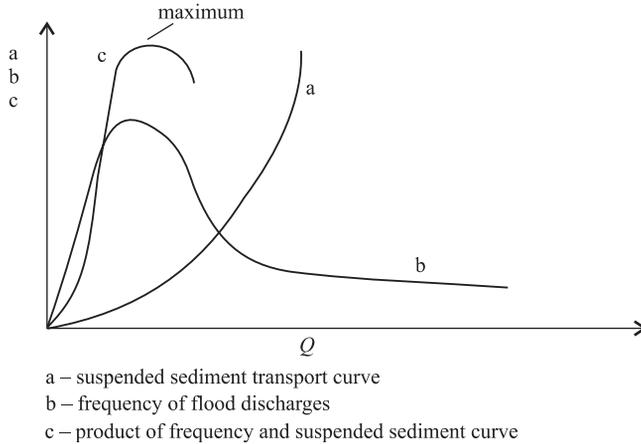


Fig. 1. Dominant discharge value according to Wolman and Miller [1960]

Wolman and Leopold [1957] concluded that the most significant movement of the morphology is such that both creates and maintains the channel shape. They compared it to the annual water 1.5, which they considered to be very close to bankfull discharge [Benson and Thomas 1966].

As we had 30 years of observed flows for all gauging station, for bed load transport we used equation of Wilcock and Crowe [Wilcock et al. 2003], where we applied Manning coefficients according to Chow [1959]. For calculations we used BAGS model. In this model we have chosen Wilcock formula. In the formula, we shear stress. Initially we used dimensionless Shields stress for mean size of bed surface τ_{rm}^* :

$$\tau_{rm}^* = \frac{\tau_{rm}}{(s-1)gD_m} \quad (1)$$

Using F_s – proportion of sand in surface size distribution, we can change the relation as:

$$\tau_{rm}^* = 0.021 + 0.015 \exp(-20F_s) \quad (2)$$

To calculate the transport we use the formula:

$$W_i^* = \begin{cases} 0.002\varphi^{7.5} & \text{for } \varphi < 1.35 \\ 14 \left(1 - \frac{0.894}{\varphi^{0.5}}\right)^{4.5} & \text{for } \varphi \geq 1.35 \end{cases} \quad (3)$$

Where:

$$\varphi = \frac{\tau}{\tau_{ri}} \quad (4)$$

and

$$\tau_{ri} = \tau_{r50} \left(\frac{D_i}{D_{50}} \right)^b \tag{5}$$

D_m – mean grain of bed surface.

The exponent b in formula (5) is calculated as:

$$b = \frac{0.67}{1 + \exp\left(1.5 - \frac{D_i}{D_m}\right)} \tag{6}$$

where:

D_i – grain size of fraction i ;

D_{50} – median grain size;

Values of W_i^* (7) are calculated for each size fraction, then weighted by the proportion of that size fraction on the bed surface F_i . Those values are summed over all sizes to get the total instantaneous (width-integrated) bed load transport rate:

$$Q_{b_i} = \frac{W_i^* F_i B u_i^* \rho_s}{(s - 1)g} \tag{7}$$

RESULTS AND CONCLUSIONS

The results obtained from our calculations we present below in the graphical form, according to Wolman and Miller postulates [1960].

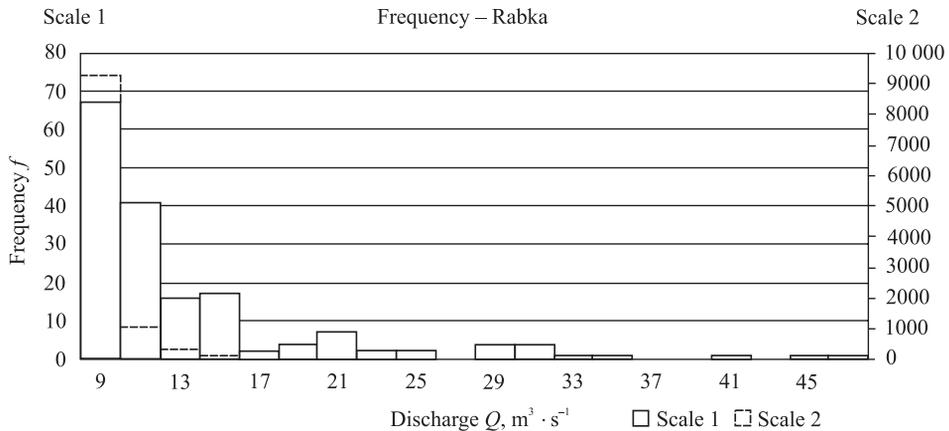


Fig. 2. Frequency of discharge in Rabka gauge station

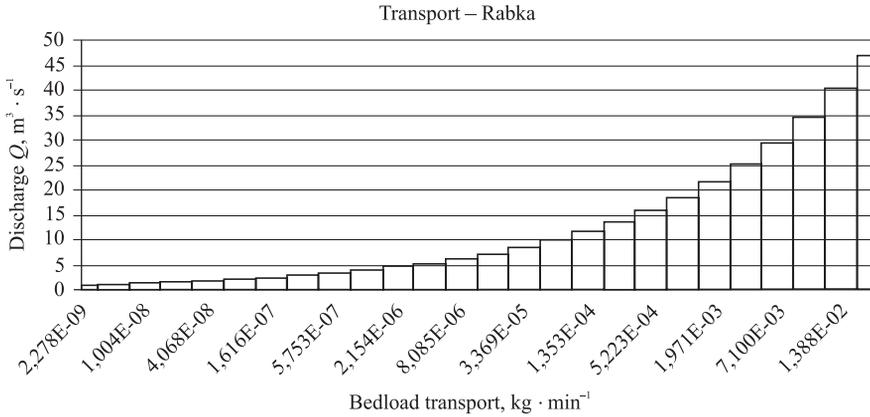


Fig. 3. Bedload transport in Rabka gauge station

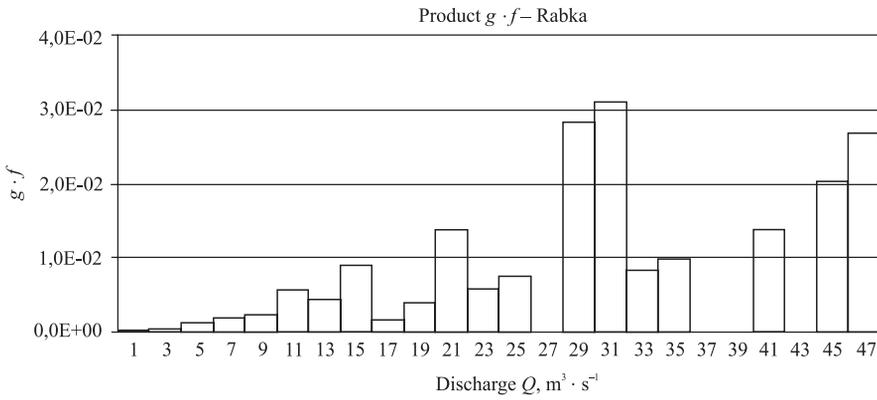


Fig. 4. Product $g \cdot f$ in Rabka gauge station

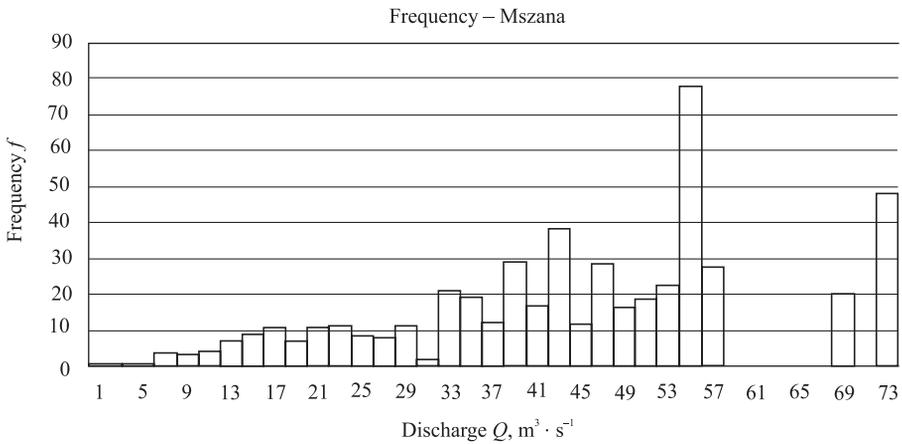


Fig. 5. Frequency of discharge in Mszana gauge station

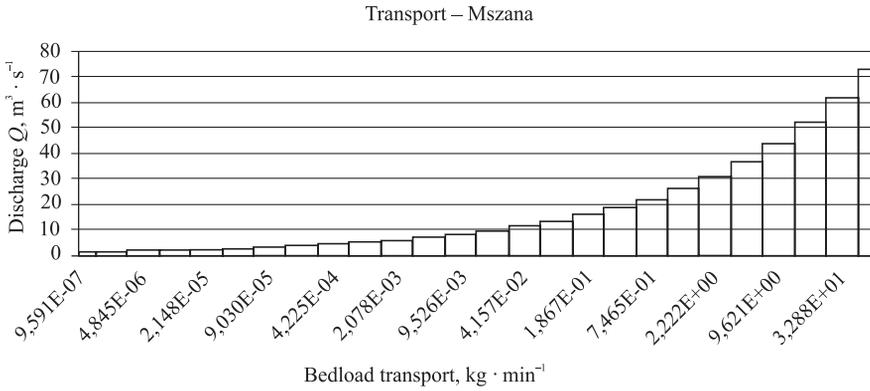


Fig. 6. Bedload transport in Mszana gauge station

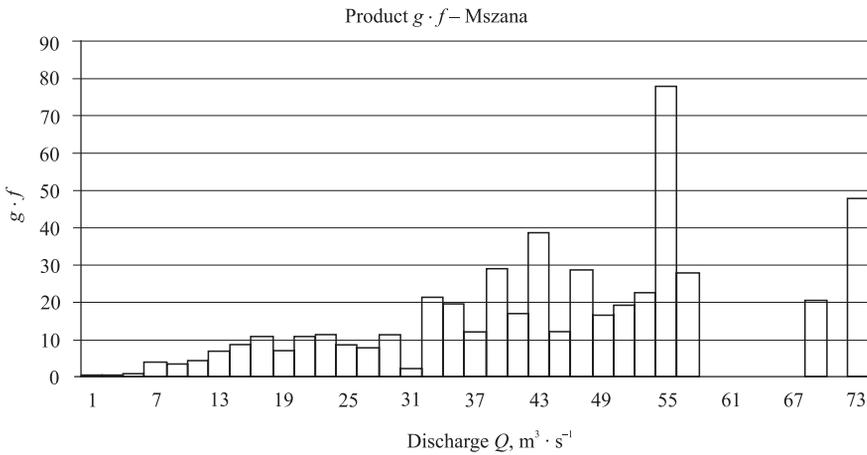


Fig. 7. Product $q \cdot f$ in Mszana gauge station

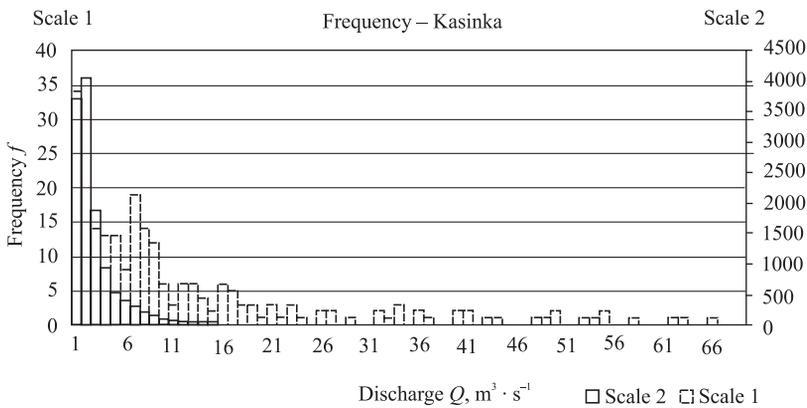


Fig. 8. Frequency of discharge in Kasinka gauge station

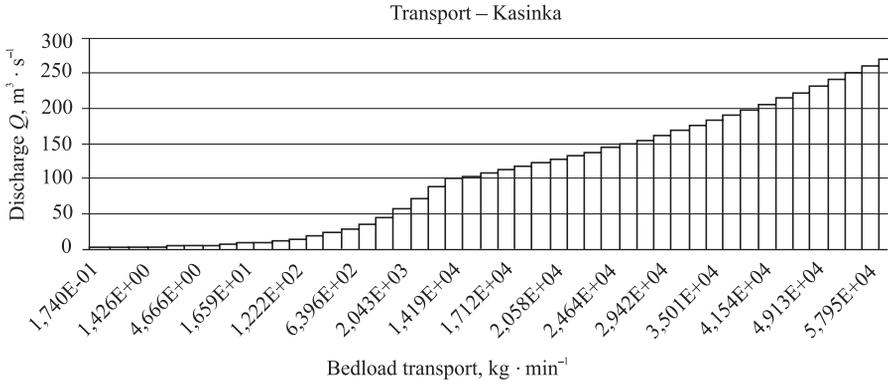


Fig. 9. Bedload transport in Kasinka gauge station

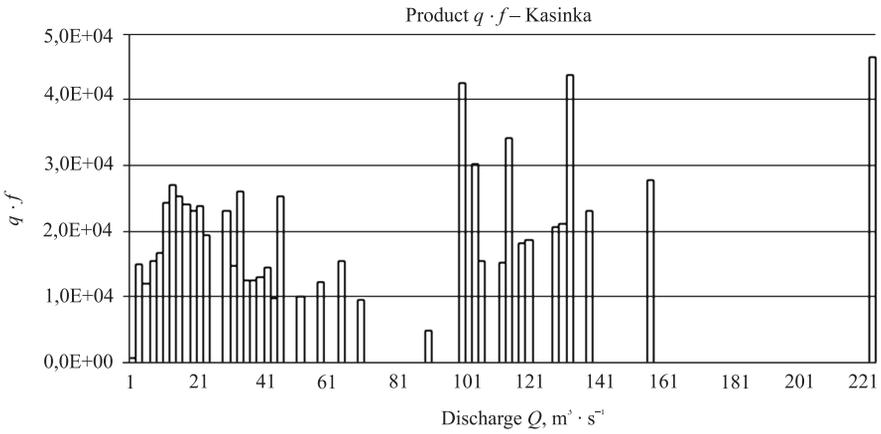


Fig. 10. Product $q \cdot f$ in Kasinka gauge station

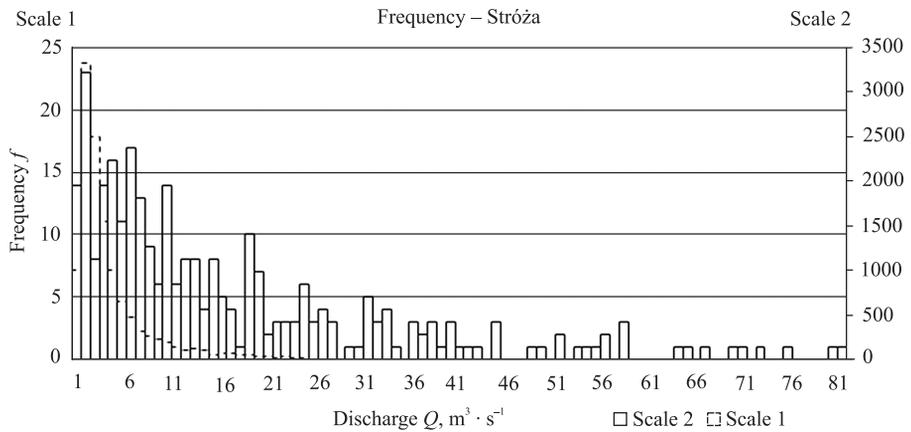


Fig. 11. Frequency in Stróża gauge station

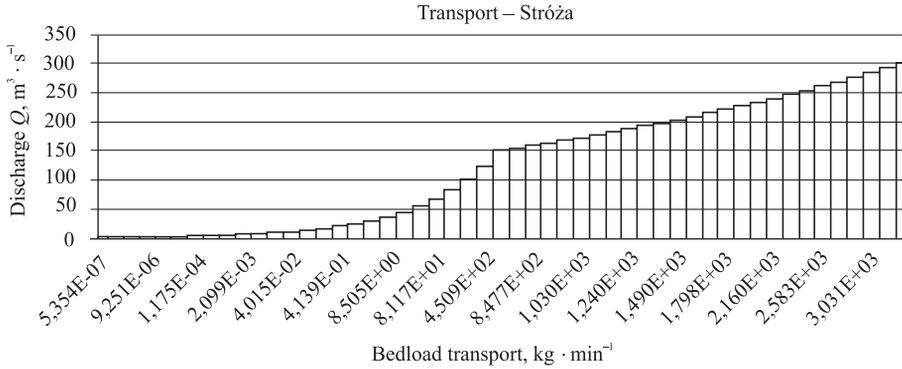


Fig. 12. Bedload transport in Stróża gauge station

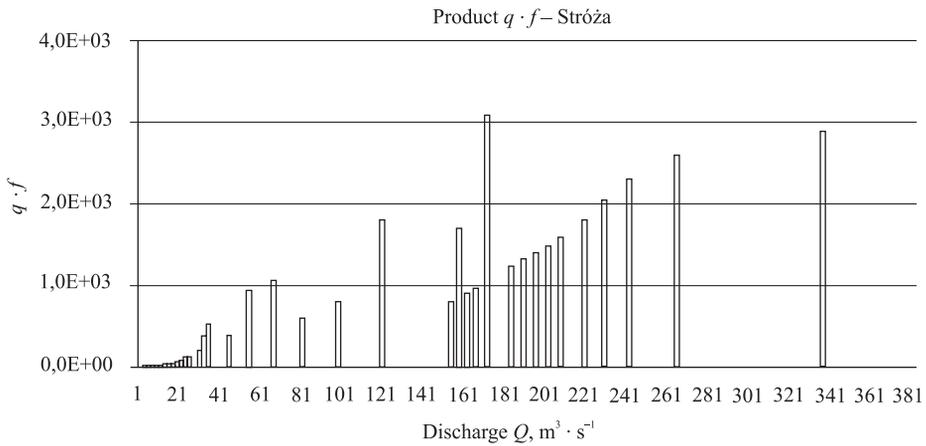


Fig. 13. Product $q \cdot f$ in Stróża gauge station

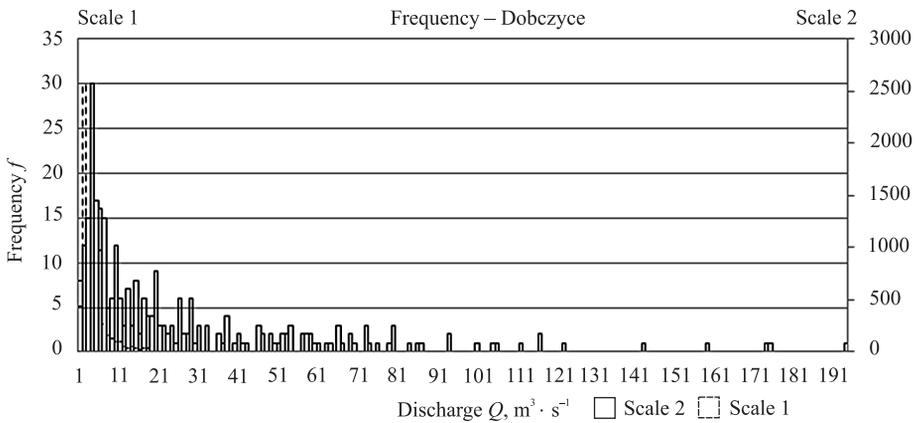


Fig. 14. Frequency of discharge in Dobczyce gauge station

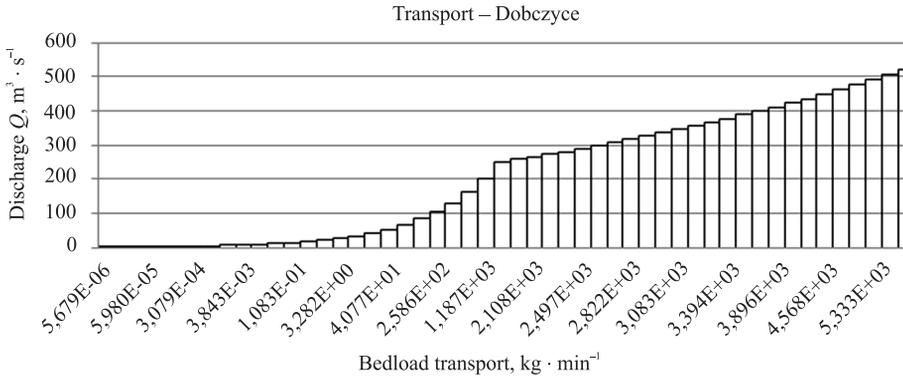


Fig. 15. Bedload transport in Dobczyce gauge station

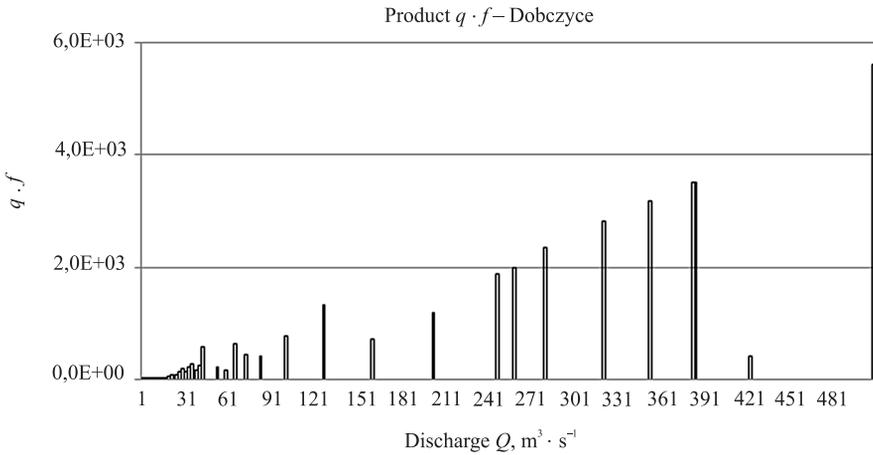


Fig. 16. Product $q \cdot f$ in Dobczyce gauge station

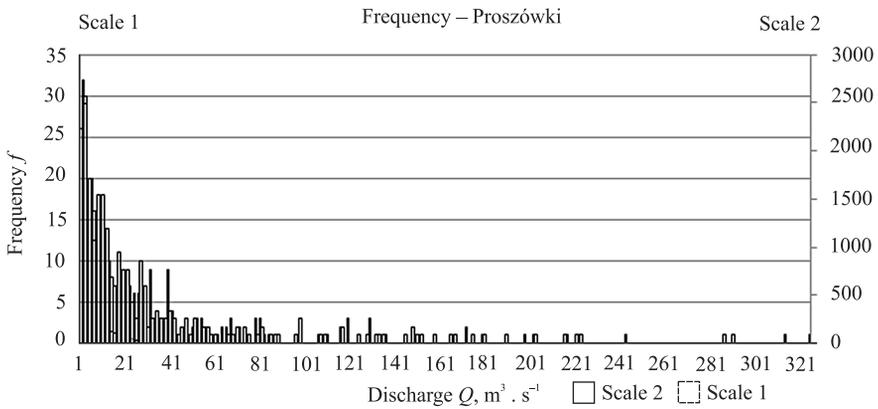


Fig. 17. Frequency of discharge in Proszówki gauge station

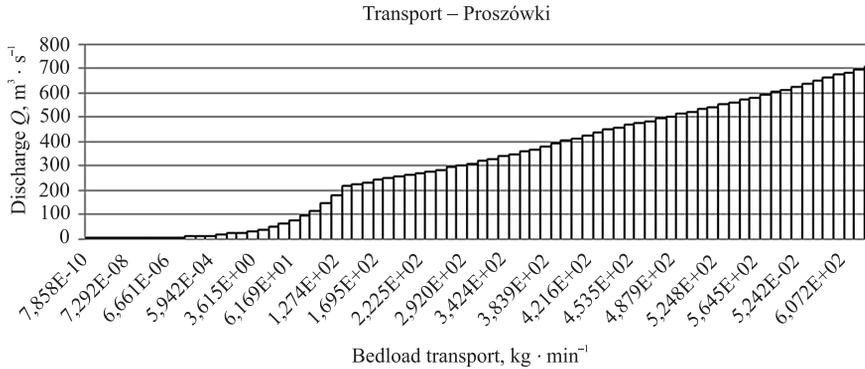


Fig. 18. Bedload transport in Proszówki gauge station

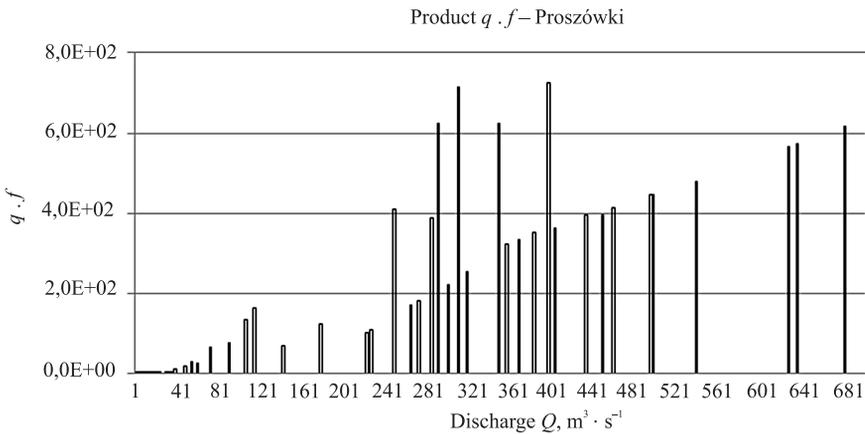


Fig. 19. Product $q \cdot f$ in Proszówki gauge station

As final results we obtained 6 dominant discharge values for 6 gauging stations of the Raba River – the four upstream the dam in Dobczyce (in the villages of: Rabka-Zdrój, Mszana Dolna, Kasinka Mała, Stróża) and two downstream of the dam (in Dobczyce and Proszówki villages).

Table 1. Dominant discharge values obtained for 6 gauging stations for the Raba River.

	Rabka	Mszana	Kasinka	Stróża	Dobczyce	Proszówki
Dominant discharge $m^3 \cdot s^{-1}$	31	55	131	173	383	397

The obtained results for dominant discharge we compared with t-year’s floods we found for the analyzed gauging stations using Punzet formula [Radecki-Pawlik 1995].

In the first section, located in Rabka calculated dominant discharge was $Q_{dd} = 31 m^3 \cdot s^{-1}$. Comparing this flow value to the values of t-years floods obtained by Punzet formula, calcu-

lated Q_{dd} is the flow which is very close to $Q_{50\%}$ for the Raba River ($Q = 37 \text{ m}^3 \cdot \text{s}^{-1}$). The cross-section located in Mszana Dolna represents more natural part of the river, with no reinforced river banks. For Mszana Dolna $Q_{50\%}$ according to Punzet method is $54 \text{ m}^3 \cdot \text{s}^{-1}$, thus again calculated Q_{dd} is very close to $Q_{50\%}$.

For the cross section located in Kasinka t-year floods are as follows: $Q_{30\%} = 137 \text{ m}^3 \cdot \text{s}^{-1}$, $Q_{40\%} = 111 \text{ m}^3 \cdot \text{s}^{-1}$ and $Q_{50\%} = 98 \text{ m}^3 \cdot \text{s}^{-1}$. And for Stróża $Q_{30\%} = 202 \text{ m}^3 \cdot \text{s}^{-1}$, $Q_{40\%} = 166 \text{ m}^3 \cdot \text{s}^{-1}$ and $Q_{50\%} = 147 \text{ m}^3 \cdot \text{s}^{-1}$. Both of these cross sections are in a similar morphological conditions. They are very close to the national road S7 (Krakow–Zakopane) where the Raba River has been substantially changed by river engineering works. In these sections calculated dominant discharge was for Kasinka $Q_{dd} = 131 \text{ m}^3 \cdot \text{s}^{-1}$ (which is close to $Q_{30\%}$) and in Stróża $Q_{dd} = 173 \text{ m}^3 \cdot \text{s}^{-1}$ (which is close to $Q_{40\%}$). This shows that both gauging stations are in the incised river channel because of previous human river hydraulic works interventions.

The biggest difference in the results compared to the assumptions of Wolman and Miller can be observed in the cross section in Dobczyce. In this village is located a water reservoir which for the last years determines the flow regimes in the river. In this cross section $Q_{dd} = 383 \text{ m}^3 \cdot \text{s}^{-1}$, and this flow is between $Q_{10\%}$ and $Q_{20\%}$ ($392\text{--}286 \text{ m}^3 \cdot \text{s}^{-1}$ respectively). It shows that cross section here is altered here a lot.

In the last cross section in the Proszówki Q_{dd} according to Wolman and Miller method is $Q_{dd} = 397 \text{ m}^3 \cdot \text{s}^{-1}$. This flow represents here the flow of the probability of occurrence of $Q_{25\%}$ for Punzet method which is $390 \text{ m}^3 \cdot \text{s}^{-1}$. Since the sediment changes here into fine it looks as the river recovers slowly from the Dobczyce dam influence.

From the above observations one can redraw a few final conclusions:

1. River engineering works affect the dominant discharge value.
2. River alteration by building dams and water reservoirs alter the discharges but also changes dominant discharge on the much larger scale than river engineering works.

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PRZEPLYW KORYTOTWÓRCZY – ZARYS TEORII I PRZYKŁAD OBLICZENIOWY ZE ZLEWNI RZEKI RABY

Streszczenie. Projektowanie konstrukcji wodnych przez inżynierów hydrotechników opiera się prawie zawsze w Polsce na obliczeniach przepływów prawdopodobnych. Wiedza o wartości przepływu dominującego może pomóc projektantom, którzy są zainteresowani zmianami morfologii koryt rzecznych, szczególnie w zakresie transportu rumowiska. To właśnie ruch rumowiska rzecznej zmienia geometrię rzeki w poszczególnych przekrojach. W niniejszej pracy wykorzystując obserwacje Wolmana i Millera i przeanalizowano wartość przepływu dominującego w sześciu wodowskazowych przekrojach rzeki Raby, a następnie porównano je z wartościami przepływów prawdopodobnych obliczonych wzorami Punzeta. Dla Raby wartości przepływu dominującego wahają się od $31 \text{ m}^3 \cdot \text{s}^{-1}$ (dla sekcji w Rabce-Zdroju) $395 \text{ m}^3 \cdot \text{s}^{-1}$ (w Proszówkach). Na wartość tych przepływów mają zarówno prace hydrotechniczne jak i obecność zbiornika wodnego.

Słowa kluczowe: przepływ korytotwórczy, rzeka góraska, metoda Wolmana, transport rumowiska wleczonego

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