FLOW AND SEDIMENT SIZE VARIABILITY NAER GRAVEL BARS IN THE BESKIDY MOUNTAINS IN THE POLISH CARPATHIANS

ARTUR RADECKI-PAWLIK

Department of Water Engineering, Agricultural University of Cracow, Poland

ABSTRACT

The purpose of the paper is to identify differences in hydraulic conditions in the areas closest to already-developed gravel bars situated in a small, mountain stream in the area of the Polish part of the Carpathian Mountains. Basic hydraulic parameters of flowing water, including velocity, shear stress, Froude number, Reynolds number and flow resistance coefficient were examined within the region of two different gravel bars in a mountain stream. At the same time, sediment samples were drawn from the riverbed in the area in which the hydraulic measurements were taken. After analysing the data, several conclusions were presented concerning sedimentation of gravel and hydraulic parameters within the cross section of a mountainous stream. The study was undertaken on Skawica-Jałowiecki Stream in the Polish part of the Carpathian Mountains called the Beskidy Mountains.

Keywords: gravel bar, shear stress, shear velocity, bedload, hydraulics parameters, mountain stream

"The River lifts itself from its long bed. Poised wholly on its dream" by Hart Crane, from *The River*.

1. Introduction

River bars are typical of all rivers and are mimicked in other linear shear flows (Church, Jones 1982). So far, no formal criterion has been developed for the presence of bars in terms of flow and sediment characteristics. Bars, defined as accumulations of sediment grains, or sand and/or gravel deposits (Whittow 1984), cannot develop if the flow depth is approximately equal to the minimum grain size (Church and Jones 1982). In alluvial channels, three types of bars are commonly recognized: alternating bars, point bars and braid bars (Selby 1985). Alternating bars form in straight channel segments within curves of meandering thawleg. Point bars develop in areas of relatively low stream power at the inside of channel meander. Braid bars, mostly diamond-shaped, are often associated with coarse material. They are aligned to the flow and are called longitudinal bars (Selby 1985).

Although bar forms have been commonly described in sandy or gravelly meandering rivers, little attention has been given to the role of obstructions in controlling geomorphic forms in coarse-grained environments (Carling and Reader 1981; De Jong and Ergenzinger 1995; Galia and Hradecky 2012). As far as the geometry of mountain streams is concerned, bars start to develop in the middle and lower reaches where the channels reach high width-to-depth ratios (Chang 1980; Radecki-Pawlik 2011). Deposition of a river bar is directly related to bend curvature, reflecting particularly the role of sharp bands in arresting sediment under lower energy conditions. Other reasons for bar depositions are obstructions or hindrances caused by large boulders or bedrocks (a common spot for the formation of re-attachment bars), or wooden logs behind which sediment is trapped.

There are only a few studies on the role played by bars in a gravel stream environment, particularly in shaping a river channel and stopping bank erosion as well as improving river fauna conditions (Wyżga et al. 2009, 2013). It is sometimes suggested that bars height should be treated as roughness elements to calculate channel bed roughness associated usually with the dimensions of grains that form the river bed (Radecki-Pawlik 2002b). This finding is of great interest, particularly in relation to high floods, since when one is talking about roughness elements under flooding conditions the dimension of particular gravel found on the river bed might be not sufficient to describe the real roughness conditions in the river.

The purpose of the current paper is to identifydifferences in hydraulic conditions in the areas closest to already-developed gravel bars situated in a small, mountain stream in the area of the Polish part of the Carpathian Mountains. The paper also describes a difference in bedload particle size that was found in the area in which the hydraulics parameters were examined.

2. Study area

The upper part of Skawica-Jałowiecki Stream in the Polish part of the Carpathian Mountains (Figure 1) is flashy and experiences frequent bedload movement. It is situated in the Carpathian flysch, and its streambed consists mostly of sandstone and claystone bedload

http://dx.doi.org/10.14712/23361980.2014.21
Radecki-Pawlik, F. (2014): Flow and sediment size variability near gravel bars in the Beskidy Mountains in the Polish Carpathians
AUC Geographica, 49, No. 2, pp. 121–126

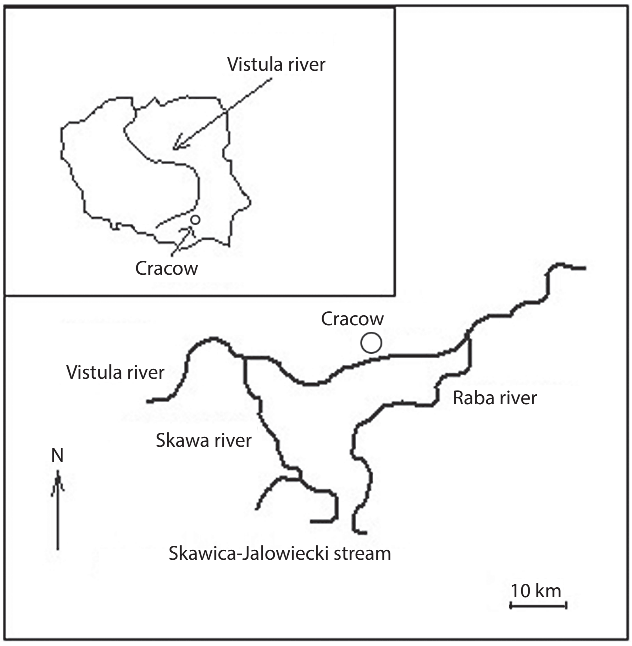

Fig. 1 Catchment study region.

pebbles and cobbles that form a framework, the interstices of which are filled by a matrix of finer sediment.

Tab. 1 Physical characteristics of Skawica-Jałowiecki Stream catchment.

Variables	Skawica-Jałowiecki Stream
Precipitation [mm]	1189
Catchment study area [km^2]	19.300
Maximum stream altitude [m a.s.l.]	1130
Minimum research point altitude [m a.s.l.]	594
Channel gradient (average within study area) [–]	0.085
Minimum annual discharge [m^3 s^{-1}]	0.020
Mean annual discharge [m^3 s^{-1}]	0.460
Bankfull [m^3 s^{-1}]	18.400
Two years flood $Q_{50\%}$ [m^3 s^{-1}]	11.300
Four years flood $Q_{25\%}$ [m^3 s^{-1}]	21.200
Five years flood $Q_{20\%}$ [m^3 s^{-1}]	23.950
Ten years flood $Q_{10\%}$ [m^3 s^{-1}]	38.400
One hundred years flood $Q_{1\%}$ [m^3 s^{-1}]	80.400

Suspended sediment loads are small and contribute insignificantly to channel morphology. Within the 1109.5 m long study reach, Skawica-Jałowiecki cuts through an alluvial bed, mostly Quaternary Holocene river gravel, sand and mudstone (Książkiewicz 1963). The upstream portion of the study reach just borders upon a Tertiary Palaeogene reach where mica-sandstone, sandstone, mudstone and phyllite predominate.

Many gravel river bed-forms, such as point and middle bars, can be seen within the investigated Skawica-Jalowiecki reach. Most gravel bed-forms have developed behind and in front of obstacles, and those situated at riverbanks (meander-bars) are quite stable. The detailed geology and geomorphology of the region has been described in Radecki-Pawlik (2002a). Some basic physical characteristics of the catchment study area are presented in Table 1.

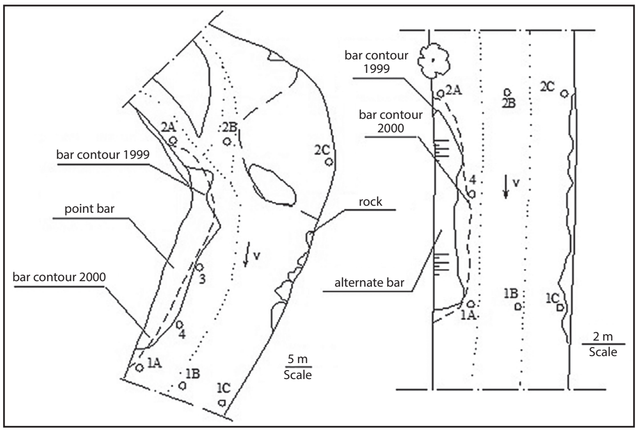

Fig. 2 Investigated gravel bars and measuring points.

3. Methods

For the purpose of the study, the 1109.5 meter-long research reach was selected within Zawoja municipality. Identification and field measurements of bed-forms were carried out during autumn 1999 and early spring 2000. The study was based on a hydraulic survey of water velocity close to the stream bed to calculate shear stress, drag coefficient and other hydraulic characteristics. Two well-developed stream bed features were recognized in the form of Point Bar A, situated downstream of a stream band at the upper part of the reach, and Alternation Bar B, an upstream-of-obstruction bar attached to the right bank of the creek (the obstruction in this case being a megacluster). Research cross-sections were established within the regions of the two bars, and measuring points were fixed within them. Wading velocity measurements were performed at all of these points (Figure 2).

Photo 1 Investigated gravel point bar in Skawica-Jałowiecki stream.

Photo 2 Investigated alternate point bar in Skawica-Jałowiecki stream.

Water velocity measurements were based on Jarrett's (1990) findings regarding the taking of velocity profiles in mountain stream cross-sections. It means that flow velocity was measured at 0.6 of depth measured from the surface (depth-averaged velocity) and 1 cm above bed surface (near-bed velocity) using Ott Nautilus C 2000 electro-magnetic current-meter. Gordon et al. (1992) and Bergeron, Abraham's (1992) methods were then applied to the field data, and shear velocity V_* values were calculated from the velocity profiles obtained near-to-river-bed. Finally, shear stress τ values were calculated from:

$$\tau = V_*^2 \rho \ [\mathrm{N\ m^{-2}}],$$

where ρ is water density [kg m^{-3}] and V_* is shear velocity [m s^{-1}].

Shear stress value (V_*) was obtained just directly from the equation $v = f(D)$ (Gordon et al. 1992):

$$V_* = a / 5.75,$$

where a is slope coefficient v = $f(D)$, according to the general line equation:

$$v = aD + b,$$

where D is water depth above the stream bed [m], b is free coefficient.

To calculate the flow resistance coefficient (f), the conclusions drawn by VenTe Chow (1967), Wijbenga (1990) and Przedwojski et al. (1995) were applied. Flow resistance coefficient was obtained from:

$$f = 8gJR/V_{mean}^2 = 8(V_*/V_{mean})^2,$$

where R is hydraulic radius [m], J is slope [–], V_{mean} is mean velocity [m/s].

The detailed methods used to obtain values for all of the above-mentioned parameters using classic hydraulics equations are shown in Radecki-Pawlik (2002a).

Samples of bed-load sediment deposits were also collected in the area in which the hydraulics data were

Tab. 2 Results of hydraulic measurements and calculations – point bar "a".

Point number	Water discharge (Q) [$m^3 s^{-1}$]	Froude number (Fr)	Shear velocity (V_*) [cm s^{-1}]	Reynolds number (Re)	Shear stress (τ) [N m^{-2}]	Flow resistance coefficient (f)
1a	0.34	0.20	1.95	7,571	0.38	0.1225
1b	0.34	0.30	8.59	488,851	7.39	0.4367
1c	0.34	0.20	4.11	16,886	1.69	0.3021
2a	0.34	0.30	8.39	106,663	7.06	0.9053
2b	0.34	1.50	11.98	106,555	14.36	0.0543
2c	0.34	0.08	1.50	15,196	0.25	0.1466
3	0.34	0.44	4.48	38,862	2.01	0.0787
4	0.34	0.10	5.23	16,282	2.74	0.8835
1a	1.04	0.60	79.61	94,623	22.30	0.2823
1b	1.04	0.70	15.50	182,856	24.00	0.1414
1c	1.04	0.40	8.87	43,015	7.80	0.2885
2a	1.04	1.06	17.60	221,360	31.10	0.1015
2b	1.04	0.50	11.09	57,007	12.30	0.3239
2c	1.04	0.01	0.19	1,637	0.01	0.3136
3	1.04	0.80	31.77	211,493	100.93	0.0444
4	1.04	0.80	11.41	75,261	13.04	0.1555

Tab. 3 Results of hydraulic measurements and calculations: up-stream-of-obstruction bar "b".

Point number	Water discharge (Q) [m³ s⁻¹]	Froude number (Fr)	Shear velocity (V*) [cm s⁻¹]	Reynolds number (Re)	Shear stress (τ) [N m⁻²]	Flow resistance coefficient (f)
1a	0.34	0.43	2.50	48,358	0.62	0.0205
1b	0.34	0.50	8.37	42,930	7.02	0.2255
1c	0.34	0.40	3.29	30,429	1.09	0.0505
2a	0.34	0.05	1.44	9,402	0.21	0.3765
2b	0.34	0.30	7.39	67,310	5.47	0.6687
2c	0.34	0.20	5.21	18,539	2.72	0.4038
4	0.34	0.04	0.56	2,341	0.04	0.2439
1a	1.04	0.53	6.49	53,784	4.21	0.0989
1b	1.04	0.60	17.27	214,292	29.80	0.1898
1c	1.04	0.60	19.29	136,091	37.20	0.3584
2a	1.04	0.08	2.69	9,056	0.87	0.9142
2b	1.04	0.90	13.38	195,812	17.90	0.0789
2c	1.04	0.54	5.63	159,169	3.10	0.0291
4	1.04	0.50	10.93	62,525	11.90	0.2891

Tab. 4 Characteristic grain size dimensions within the region of investigated point bars.

					alternate bar "b"					
	d_5	d_{10}	d_{16}	d_{25}	d_{50}	d_{60}	d_{75}	d_{84}	d_{90}	d_{95}
1A	77.6	95.4	115.7	146.2	230.8	264.6	315.4	345.9	366.2	383.1
1B	14.8	25.0	39.6	55.3	72.3	74.5	77.8	79.8	109.5	138.7
1C	6.1	10.8	15.3	20.6	36.2	42.9	52.1	56.4	59.2	76.1
2A	15.0	28.5	34.9	42.9	73.2	96.6	131.6	152.6	166.7	178.3
2B	21.1	32.6	43.8	54.4	72.8	78.6	133.3	171.7	197.3	218.7
2C	7.8	13.5	19.8	29.2	45.4	52.0	76.2	111.8	135.5	155.2
4	22.1	33.0	46.9	70.8	75.4	77.3	80.6	120.0	146.2	168.1
					point bar "a"					
1A	18.500	34.100	54.40	70.40	77.50	82.20	111.40	128.90	140.6	150.30
1B	41.200	70.200	71.10	72.50	76.40	77.90	90.10	151.20	192.00	226.00
1C	20.300	32.000	43.20	56.50	74.40	77.60	107.80	141.00	163.10	181.60
2A	15.800	25.500	36.40	52.60	74.70	77.50	105.70	143.30	168.30	189.10
2B	14.300	17.900	21.70	27.40	45.20	51.30	56.80	61.00	98.10	129.10
2C	0.002	0.003	0.01	0.02	0.13	0.21	0.34	0.41	0.47	0.51
3	11.100	18.900	28.90	49.30	94.30	117.40	152.10	173.00	186.60	198.40
4	24.600	37.900	50.40	60.90	76.30	80.00	136.20	170.00	192.50	211.20

Tab. 5 Percentage of different grain shapes of bed load.

Grain shape	Percentage
Spherical	4.43
Bladed	41.00
Disc-shaped and rod-like	54.57
	100 %

gathered. The technique of sampling described by Wolman (1954) was applied. Later, grain size curves were plotted and characteristic grain dimensions were read. Additionally, for grain shape analysis, 339 single grains were chosen randomly from the riverbed and carefully measured along axis b. Grain shapes were described according to Zingg (Gradziński et al. 1986; Gordon et al. 1992).

4. Results

For reasons of clarity, all results obtained are presented in tables. Tables 2 and 3 show all hydraulics parameters measured and calculated above the research points within the regions of the investigated bars (Figure 3). Wading measurements were taken under two discharges. The first was Q = 0.34 $m^3 s^{-1}$, which is close to the mean annual flow (Q = 0.46 $m^3 s^{-1}$) (Table 1). The second discharge was a spring flood, when Q reached 1.04 $m^3 s^{-1}$. In the case of the second discharge, bedload movement under these conditions was observed. Sediment samples were taken from all the places in which the velocity measurements were done, right after the water dropped. The sediment data are presented in the form of characteristic grain dimensions (Tables 4), and as shape dominant grains (Table 5).

5. Discussion and Conclusions

The sediment deposited within the region of the investigated bars varied in diameter along the structure as well as across the cross-sections of the stream. In general, d_{50} was between 36.2–230.8 mm (a representative grain size), d_{16} between 15.3–125.7 mm, and d_{84} between 56.4–345.0 mm. The biggest differences in sediment diameters were observed along Alternate Bar B. Along Point Bar A, coarser sediment was deposited very close to the bar structure (Point 3) where the highest value of shear stress ($\tau = 100.93$ N m^{-2}) was noted, as well as the highest value for shear velocity (all calculated for Q = 1.04 m^3 s^{-1} flood discharge). Above Point 2B, the biggest shear stress value ($\tau = 14.36$ N m^{-2}) was found under mean annual flow conditions (Q = 0.34 m^3 s^{-1}). In this case, Fr was > 1, whereas at 2B under Q = 1.04 m^3 s^{-1} Fr was < 1 and shear stress and shear velocity were significantly smaller than under mean annual flow conditions. In the latter case, the water appeared to behave as it does above a typical riffle in a riffle-and-pool sequence when reversal velocity phenomena are observed. Point 2C is extraordinary in that it lies in the shadow of rock piled up on the streambed. A huge amount of fine sediment is deposited here, and Fr remains < 1, even under flood conditions.

Along Alternate Bar B, coarser sediment was deposited at Points 1A and 4, again close to the bar structure. The highest values of shear stress under flooding conditions were above Points 1B and 1C. The biggest shear stress value under annual discharge was again observed at Point 2B. The finest sediment was deposited along the left bank of the stream – opposite to the developed alternate bar structure. Point 2A was in the shadow of the bar, and shear stress and shear velocity were smallest here. The thawleg line, in the contest of hydraulics parameters, appeared to work like a vertical riffle within the reach. Along that line, Fr, shear stress and shear velocity were the highest under both run discharges.

When analyzing the sediment we observed that his sediment size variation is characterised by a complex pattern rather than a simple decreasingtrend and by a relatively low overall rate of fining, similar like in Surian 2002. But since the distance along which we did investigations was relatively short we could not find any connectivity's (again in Surian 2002; Liebaultand Piegay 2001). We observed that the trends in grain sizes observed along the barsmight differ with scale – and also significantpredictor of grain size is site location because localchannel width appears to strongly influence the parametersof grain size (compare Rengers and Wohl 2007). We also associated the changes of sediment sizes with discharges (Emmett and Wolman 2001) through values of shear stresses we calculated. And finally we observed that since the coarser sediment in a cross-section is deposited along the outer line of developed bars, we might presume that it is due to flow through the gravel (here groundwater) along the bars (compare Bunke and Gonser 1997; Carling et al. 2007). Thus, the following conclusions were drawn from the analysis of hydraulic and sediment results within the regions of the investigated bars:

1. Coarser sediment in a cross-section is deposited along the outer line of developed bars. Thus, bars are in a constant process of build-up. The distal part of the bars appears to be particularly stable.
2. Fine sediment is deposited at the opposite bank to where the bars are formed. Shear stress, FR and shear velocity values are the smallest here.
3. Fine sediment is deposited at spots within the stream reaches called "shadows", even under flood conditions. Such shadows may be found behind rocks and/or proximal part of bars.
4. In the case of Alternate Bar B, the highest values of shear stress, shear velocity and Froude number are found along the thawleg linelying approximately in the middle of the stream cross-sections within a bar region.
5. For Point Bar A, the highest Froude number is observed in the proximal part of the bar, at the entrance between the bar and the opposite bank, along the thawleg. Under annual flow conditions, it is possible to find places within a region of point bar that function similarly to riffle-and-pool sequences, where reversal velocity phenomena are observed.
6. With respect to the shapes of grains deposited in mountain, alluvial streams, the highest percentage are disc-shaped and rod-like. The next highest percentage are bladed. Spherical grains are a very small percentage less than 5%.

REFERENCES

BERGERON, N. E., ABRAHAMS, A. D. (1992): Estimating shear velocity and roughness length from velocity profiles. Wat. Resour. Res., 28 (8), 2155–2158. http://dx.doi.org/10.1029/92WR00897

BRUNKE, M., GONSER T. (1997): The ecological significance of exchange process between rivers and groundwater. Freshwater biology, 37, 1–33. http://dx.doi.org/10.1046/j.1365-2427.1997.00143.x

CARLING, P. A., READER, N. A. (1981): Structure, composition and bulk properties of upland stream gravels. Earth Surface Proc. and Landforms, 7, 349–365. http://dx.doi.org/10.1002/esp.3290070407

CARLING, P., WHITCOMBE, L., BENSON, I., HANKIN, B., RADECKI-PAWLIK, A. (2006): A new method to determine interstitial flow patterns in flume studies of sub-aqueous gravel bedforms such as fish nests. River Research and Applications, 22, 691–701. http://dx.doi.org/10.1002/rra.930

CHANG, H. H. (1980): Geometry of gravel stream, Journal of Hydraulics Div., ASCE, 106, 1443–1456.

CHOW, VEN TE (1959): Open-Channel hydraulics. McGraw-Hill, New York, p. 108–114.
CHURCH, M. A., JONES, D. (1982): Channel Bars. In: Hey, R. D. (ed.): Gravel-bed Rivers. London, p. 291–325.
DE JONG, C., ERGENZINGER, P. (1995): The interaction between mountain valley forms and river bed arrangement. In: Hickin, E. J. (ed.): River Geomorphology. John Wiley and Sons, New York, p. 54–91.
EMMETT, W. W., WOLMAN, M. G. (2001): Effective discharge and gravel-bed rivers. Earth Surf. Process. Landforms 26, 1369–1380. http://dx.doi.org/10.1002/esp.303
GALIA, T., HRADECKÝ, J. (2012): Bedload transport and flow resistance in steep channels – introduction to the issues in the context of mountain basins of the Central European region. Acta Universitatis Carolinae Geographica, 47, 23–33.
GORDON, D., MCMAHON, T. A., GINLAYSON, B. L. (1992): Stream Hydrology. An Introduction for Ecologists. Wiley and Sons, London.
GRADZIŃSKI, R., KOSTECKI, A., RADOMSKI, A., UNRUG, R. (1986): An outline of sedimentology (in Polish). Zarys sedymentologii. Wyd. II, Warszawa.
JARRETT, R. D. (1991). Wading measurements of vertical velocity profiles. Geomorphology, 4, 243–247. http://dx.doi.org/10.1016/0169-555X(91)90007-W
LIEBAULT, F., PIEGAY, H. (2001): Assessment of channel changes due to long-term bedload supply decrease, Roubion River, France. Geomorphology 36, 167–186. http://dx.doi.org/10.1016/S0169-555X(00)00044-1
KSIĄŻKIEWICZ, M. (1963): An outline of the Babia Góra geology (in Polish). Zarys geologii Babiej Góry. Zakład Geologii UJ Kraków, Materiały BPN.
PRZEDWOJSKI, B., BŁAŻEJEWSKI, R., PILARCZYK, K. W. (1995): River training techniques. Balkema, Rotterdam, Brookfield.
RADECKI-PAWLIK, A. (2002a): Some aspects of the formation of mountain stream bars and lowland river dunes (in Polish). Wybrane zagadnienia kształtowania się form korytowych potoku górskiego i form dennych rzeki nizinnej. Zesz. Nauk. AR w Krakowie, seria Rozprawy, no. 281.
RADECKI-PAWLIK, A. (2002b): Field investigations of a roughness coefficient within a riffle and pool sequences of mountainous stream (in Polish). Określenie wartości współczynnika szorstkości koryta potoku górskiego na podstawie pomiarów terenowych. Zesz. Nauk. AR Kraków, 23, 251–261.
RADECKI-PAWLIK, A. (2011): Hydromorphology of rivers and streams – Hydromorfologia rzek i potoków górskich – działy wybrane. A book (in Polish). UniwersytetRolniczy w Krakowie.
RENGERS, F., WOHL, E. (2007): Trends of grain sizes on gravel bars in the Rio Chagres, Panama. Geomorphology 83, 282–293. http://dx.doi.org/10.1016/j.geomorph.2006.02.019
SELBY, M. J. (1985): Earth's changing surface. Clarendon Press, Oxford.
SURIAN, N. (2002): Downstream variation in grain size along an Alpine river: analysis of controls and processes. Geomorphology 43, 137–149. http://dx.doi.org/10.1016/S0169-555X(01)00127-1
WHITTOW, J. (1984): Dictionary of physical geography. Penguin, London.
WIJBENGA, J. H. (1990): Flow resistance and bed-form dimensions for varying flow conditions. Delft Hydraulics. Part 1–4 (main text and appendix). Toegepast Onderzoek Waterstaat A58.
WOLMAN, M. (1954): A method of sampling coarse river-bed material, American Geophysics Union, 35 (6), 951–955. http://dx.doi.org/10.1029/TR035i006p00951
WYŻGA, B., AMIROWICZ, A., RADECKI-PAWLIK A., ZAWIEJSKA J. (2009): Hydromorphological conditions, potential fish habitats and the fish community in a mountain river subjected to variable human impacts, the Czarny Dunajec, Polish Carpathians. River Research and Applications, 25 (5), 499–659.
WYŻGA, B., OGLĘCKI, P., HAJDUKIEWICZ, H., ZAWIEJSKA, J., RADECKI-PAWLIK, A., SKALSKI, T., MIKUŚ, P. (2013): Interpretation of the invertebrate-based BMWP-PL index in a gravel-bed river: insight from the Polish Carpathians. Hydrobiologia. Springer. July 2013, 712 (1), 71–88. http://dx.doi.org/10.1007/s10750-012-1280-0

RÉSUMÉ

Flow and sediment size variability in different gravel bars region – the Beskidy Mountains in Polish Carpathians

The purpose of the paper is to identify differences in hydraulic conditions in the areas closest to already-developed gravel bars situated in a small, mountain stream in the area of the Polish part of the Carpathian Mountains. Basic hydraulic parameters of flowing water, including velocity, shear stress, Froude number, Reynolds number and flow resistance coefficient were examined within the region of two different gravel bars in a mountain stream. At the same time, sediment samples were drawn from the riverbed in the area in which the hydraulics measurements were taken. After analyzing the data, several conclusions were presented concerning sedimentation of gravel and hydraulics parameters within the cross section of a mountainous stream. The study was undertaken on Skawica-Jałowiecki Stream in the Polish part of the Carpathian Mountains called Beskidy Mountains. The following main conclusions were drawn from the analysis of hydraulic and sediment results within the regions of the investigated bars: coarser sediment in a cross-section is deposited along the outer line of developed bars; fine sediment is deposited at the opposite bank to where the bars are formed thus shear stresses, FR and shear velocity values are the smallest here; fine sediment is deposited at spots within the stream reaches called "shadows", even under flood conditions – such shadows may be found behind rocks and/or proximal part of bars; with respect to the shapes of grains deposited in mountain, alluvial streams, the highest percentage are disc-shaped and rod-like – the next highest percentage are bladed, whereas spherical grains are a very small percentage less than 5%.

Artur Radecki-Pawlik
Agricultural University of Krakow, Department of Water Engineering
Al. Mickiewicza 21
31–120 Kraków
Poland
E-mail: rmradeck@cyf-kr.edu.pl