INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND EKOLOGY OF RURAL AREAS

Nr 3/2007, POLSKA AKADEMIA NAUK, Oddział w Krakowie, s. 197–207
Komisja Technicznej Infrastruktury Wsi

Jacek Florek, Leszek Książek, Damian Śmiałek, Artur Radecki-Pawlik

CHARACTERISTIC OF GRANULOMETRIC COMPOSITION ALONG CHOSEN SAND-GRAVEL DUNES WITHIN THE RABA RIVER OUTLET

Summary

The paper presents measurement and calculation results of volume samples taken from the bedforms of the sand-gravel bed river in Polish Carpathians. As a sample method the "in situ" sample freezing method was applied. River channel geometry and changes in the morphology of the river bed were investigated using laser geodimeter. The procedures have been carried out on the Raba River downstream of its confluence with the Vistula River. The main research was conducted in spring and autumn 2006. To give a picture of the long term processes which have the influence on the changes of the river bed along the investigated reach for comparison some of the results from year 2005 are also presented. The basic information about research catchment, its location, gravel sampling methodology and characteristics of sand-gravel dunes are included. Development of riverbed forms as a mixture of sand and gravel according to their granulometric composition was detailed. The samples were analyzed considering the layered structure of the dunes and the results of statistical calculations are provided. Tables of granulometric parameters in metric and logarithmic scales are presented among other information such as: mean diameter, sorting index, sorting degree, coefficient of grains uniformity and non-uniformity, standard deviation, skewness, flatness. With this information the genealogy of dune and their mobility along the river bed could be predicted.

Key words: sand-gravel dunes, river bed granulometry, river outlet, the Raba River

INTRODUCTION

One of the most common features among the bed-forms which one can easily recognize on the sand river bed are dunes. They are defined as accumulations of sediments, which particles usually sand-sized (2 mm or less in diameter) [Thomas and Goudie 2000]. Dunes can be formed by wind in eolian environments but also in water, generated by turbulent flow structures in fluvial environments. The present literature quite a bit is saying about river sand dunes [Allen 1968, 1984, 1985; Flemming 1988; Ashley 1990; Carling *et al.* 2000] whereas gravel sub-aqueous bed forms (those with a median grain size greater than 2 mm), which occur on river beds which are composed of sand and gravel mixtures are reported very rarely within the literature. Reviewing the literature, equilibrium and non-equilibrium gravel dunes range in length from less than 0.6 m to greater than 100 m. Their heights range from less then 0.1 m to 16 m [Carling 1999]. Height (H) and length (L) data for the gravel dunes reported by some researchers [Carling 1999] are consistent with the H:L function reported by Ashley [1990] for equilibrium dunes developed in sand. Using Ashley's (1990) dune form criteria of height (>0.1 m) and length (>0.6 m) as a general guide it can be shown that gravel dunes have been correctly identified in the number of studies [e.g. Dinehart 1992 and Carling *et al.* 2005]. The aim of the present paper is to show how riverbed forms develope in the mixture of sand and gravel and most of all what is their internal granulometric composition using the detailed example of one of them. The study site was in the upland part of the Raba River below the Dobczyce Water Reservoir and close to the confluence with the Vistula River. The study is important firstly because of the need for a better understanding of the process of formation such features like sand-gravel bed forms in fluvial environments (especially that field works of such subject are vary rare reported in the literature) and secondly for understanding of bed form forming process for geologists to interpret how sedimentary rocks were composed, where ancient sedimentary assemblages are believed to be of alluvial origin.

MATHERIALS AND METHODS

Research catchment

The Raba River (Fig. 1) is mostly (86%) situated in the Polish part of the Eastern Carpathian Mountains (the Wyspowy Beskid and the Zywiecki Beskid) which are Carpathian flysh. The basic catchment parameters of the river is presented in table 1 (Radecki-Pawlik *et al.* 2006, Słowik-Opoka 2006). Its streambed, along the alluvial part, consists mostly of sandstone and mudstone bed-load pebbles and cobbles (from Magurian nappe). The typical structure of the lower Raba River alluvial plain, from the beginning of the 20th century consists of normally loose pebble gravels, open work pebble gravels, dilated framework pebble gravels, trough cross-stratified and parallel laminated medium to very coarse grained sands, massive find sands and muds [Wyżga 1993]. The coarser grains which collect as armour on the river bed, also form a framework, the interstices of which are filled by a matrix of finer sediment.

Table 1. Physical characteristics of investigated river

Variables	The Raba River
Precipitation [mm]	760
Catchment Area [km^2]	1573
Channel Length [km]	137
Mean annual flow [m^3 s^{-1}]	20.86
Minimal annual flow [m^3 s^{-1}]	2.71
Average slope [-]	0.0044
Average slope of the research region [-]	0.0006
Two years flood $Q_{50\%}$ [m^3 s^{-1}]	498
Ten years flood $Q_{10\%}$ [m^3 s^{-1}]	1007
One hundred years flood $Q_{1\%}$ [m^3 s^{-1}]	1724
One thousand years flood $Q_{0.1\%}$ [m^3 s^{-1}]	2074

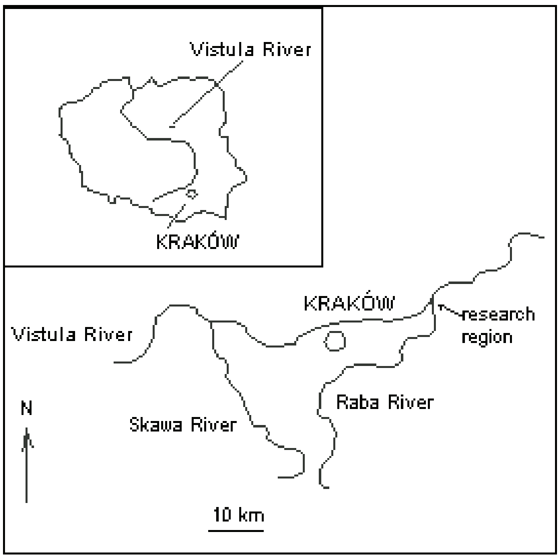

Figure 1. The research region location

The Raba River, during the spring and early summer floods, experiences frequent bed load movement, which is reflected in many mobile gravel bars which form along the margins and centre of the river channel. The research region of the Raba River (reach 700 m long, averages 50 m wide - close to the Uscie Solne municipality), where the Raba joins the Vistula River, is situated at the border of the uplands (14% of the catchment is situated in Carpathian intramontane and submontane depressions).

The river loses here its mountainous character and is alluvial. The river bed sediment here is the mixture of sand and gravel. The river bed usually is characterised by an armour layer where the range of sediment is from 0.4 mm do 50 mm, with sand and gravel moving above it. In low to medium flows the water is very clear making the sediment transport processes visible to the eye. On the armoring layer sand and sand-gravel bedforms appear under certain range of hydraulics conditions. These bedforms are built up with sediment of the range of D_{50} placed them within the sand-gravel bedforms.

Gravel sampling methodology

Volume sample

One of the method we used to sample river bed matherial was volume-sampling. Volume sampling is the method which is usually applied to the sieve analysis. A predetermined volume of material is removed with a shovel from the riverbed. The volume should be large enough to become independent of the individual particles that comprise the sample. The pavement is typically on grain size thick and so the sample is usually dependent on the individual grain size [Church *et. al.*1987]. After a sample has been removed from the riverbed, the particles are placed into sizes classes based on particle sieve diameters and by calculating the ratio of the volume of particles in each size to the total volume in the sample and the weight was substituted for volume. A gravelometer is used to measure particles between 10-mm and 80-mm. The gravelometer use a templates with round openings corresponding to different sieve sizes. The sieve diameter represents the opening in the gravelometer template that the particle with smaller intermediate axis will pass through. The maximum grain size d_{max} is obtained in direct measurement.

Method of in situ sample freezing

To study in details the bed form composition we used the sample freezing method. Here a bedload sample from the river bed is frozen by means of a probe, supplied with liquid nitrogen and driven into the bed (Fig. 2). It's main part, viz. a copper tube (1), Ø = 5 cm is driven into the river bed at a depth of 30-50 cm. The tube is ended with a cross with a hoist holder (2) and an inlet bowl. Liquid nitrogen is poured through a funnel (3) into the probe. The freezing time depends mainly upon the water temperature, debris consolidation degree and the debris grain size. Fast cooling down of the tube freezes the surrounding bed material [Michalik 2000].

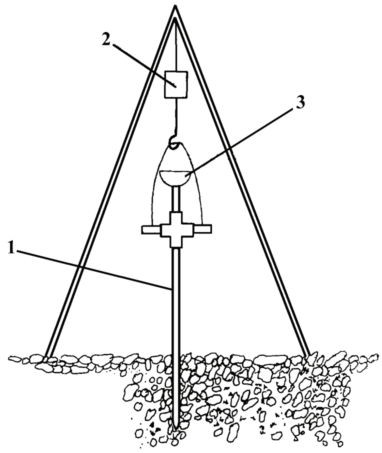

Figure 2. Freeze sampler 1 – copper tube, Ø = 5 cm, 2 – hoist holder, 3 – funnel

A frozen sample is taken out with a hand hoist and placed on a special box. The box is provided with baffles, for example at 5 cm intervals, so that the material under de-freezing may fall in the apposite layer. For each layer one can determine the grain-size distribution.

The application of the bedload sample freezing method enables the recognition of the structure in the river bed, i.e. to determine either the armouring layer and the bed/substratum.

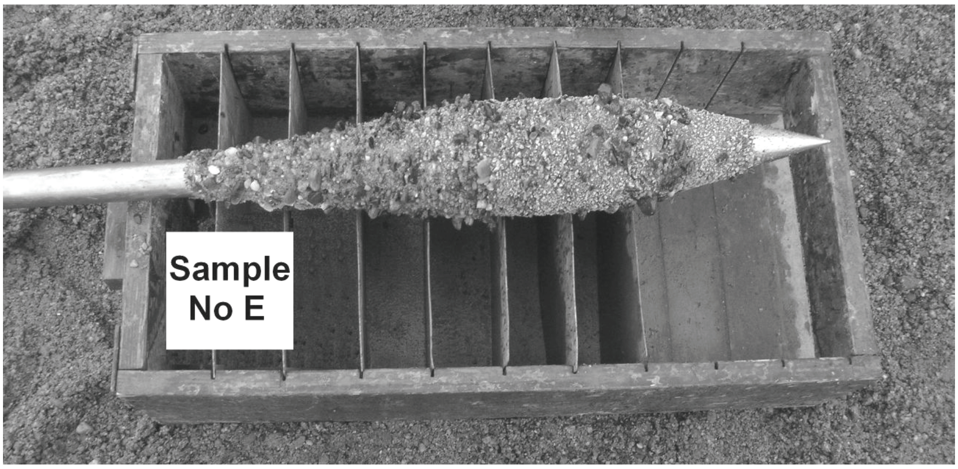

Figure 3. Frozen sample of the bed material, the Raba River, km 0+560, July 2005 (by E. Słowik-Opoka)

Granulometric analysis

To analyze the granulometric parameters of the measured bed form material we used the following relationships and formulea:

Mean diameter $S_s = \frac{d_{16} + d_{50} + d_{84}}{3}$; Sorting index according to Trask $S_o = \sqrt{\frac{d_{75}}{d_{25}}}$;

Sorting degree according to Hazen $u = \frac{d_{60}}{d_{10}}$; Coefficient of grains non-uniformity according to Knoroz $\varepsilon = \frac{d_{95}}{d_5}$; Coefficient of grains uniformity according to Kollis $C_d = \frac{d_{90} d_{10}}{d_{50}^2}$

Mean diameter $GSS = \frac{\varphi_{16} + \varphi_{50} + \varphi_{84}}{3}$; Standard deviation $GSO = \frac{\varphi_{84} - \varphi_{16}}{4} + \frac{\varphi_{95} - \varphi_5}{6,6}$

Skewness $GSK = \frac{\varphi_{16} + \varphi_{84} - 2\varphi_{50}}{2(\varphi_{84} - \varphi_{16})} + \frac{\varphi_5 + \varphi_{95} - 2\varphi_{50}}{2(\varphi_{95} - \varphi_5)}$; Flatness $GSP = \frac{\varphi_{95} - \varphi_5}{2,44(\varphi_{75} - \varphi_{25})}$

Channel geometry

To characterize river channel geometry the measurements of Raba section were taken. The research location was safely accessible from the Raba River banks on foot under low discharge and from a rubber boat under mean discharge conditions. The location was being visited daily during the several sampling periods. The work within the research reach concentrated on surveying with laser geodimeter. The distance between cross-sections was from 5 m to 20 m. The whole number of cross-section was 59. The whole measurements were done to localize precisely the all identyfied dunes (especially this one of interest) and also changes in the geometry of the river bed.

RESULTS AND DISCUSSION

The longitudaul profile of the measured Raba River reach are shown below in the Figure 4. The distance of the research reach was 732 m with the slope 0,32 ‰. It is important to know it to set up all measurements within the measured profiles and to know the changes of the river bed along the measured research reach.

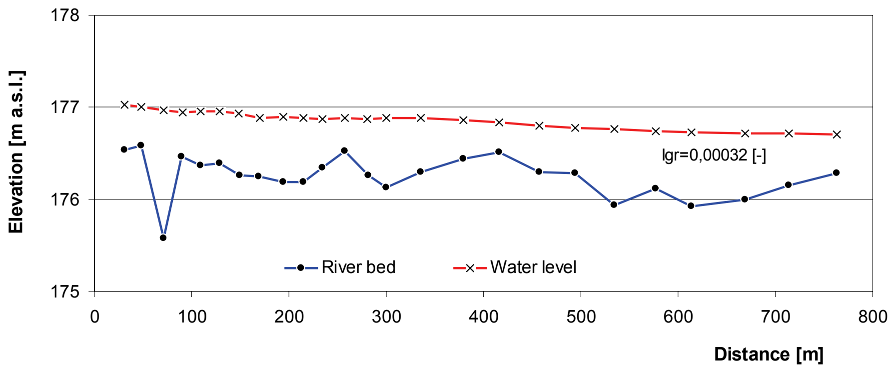

Figure 4. Longitudinal profile of the section of the Raba River

The measured river bed form with different grain size diameter in the layers (d_{50}=4÷11mm) has the surface layer with the lowest diameter, the next four layers 5÷25cm were not enough consolidated to become a part of the probe. Surface layer according to sampling method which use the isolation protection from above moving water almost always takes a part in a probe. Observing the vertical profiles of standard deviation one can see there is no direct regularity in corresponding values for the same depth in the nearby profile value (fig. 5) nor there are any other similarities among the measured probes. What repeats in each probe are high differences between neighboring layers in figure 5 up to 60% for the middle part of the dune. The direct contact of layers with different standard deviation values is a device for intensive and continuous process of bed material transport. The time for achieving uniform depository among the layers is too short compare to the speed of new layers creation. As a result of this quick processes armored layers of standard deviation lower than 1.5 and layers of mixed bed material with observed values higher than 3.5 are in the contact. Going up from down parts of the bed form the changes in standard deviations are presented.

All of the probes have an deep laying 20-30 cm or even 50 cm armoured layer. Missing values are representing layers of consolidation too weak to freeze with used method so in this layers the lowest values are to be expected. The explanation for the situation like this is the intensive water filtration in missing layers giving high exchange of heat preventing the probes freeze. So the empty spots in the measurement results despite the fact that the accurate values are unknown gives the information about the localization of the dune armouring layer.

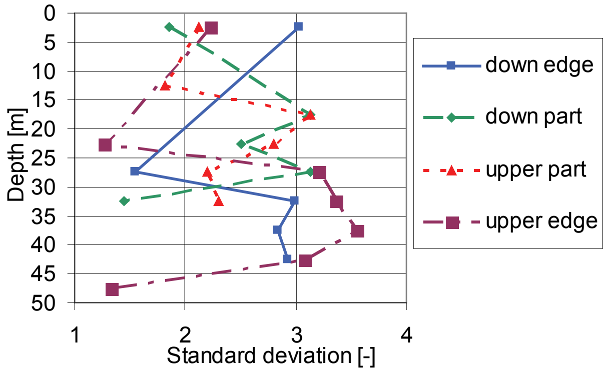

Figure 5. Standard deviation distributions, Raba 2006, dune

The histogram of the grain size presented on figure 6 shows distribution skewness along the bed form. In every each point and layer of the bed form the dominating shear stresses as a result of forces acting on the bed material sorting the grain. For the whole grain size of the probes the critical shear stresses are mostly smaller than created by the acting forces and so the dominance of highest fraction in probes which proves the continuous movement of the bed form. Listing of all recorded granulometric parameters and calculated values based on equations written above for the dune 1 in year 2006 presents the table 3 in metric scale.

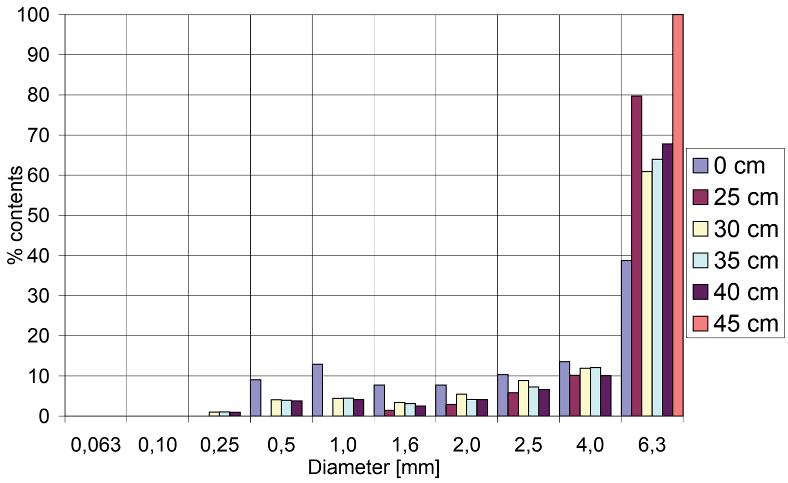

Figure 6. Grain size histogram, Raba 2006, dune, down edge

Table 2 gives the complete information of measured and calculated values partially analyzed in previously presented figures.

Table 2. Granulometric parameters of dune, year 2006, metric scale

Level [cm]	d_5 [mm]	d_{10} [mm]	d_{16} [mm]	d_{25} [mm]	d_{50} [mm]	d_{60} [mm]	d_{75} [mm]	d_{84} [mm]	d_{90} [mm]	d_{95} [mm]	d_m [mm]	Mean diameter	Sorting index according to Trask	Sorting degree according to Hazen	Coefficient of grains non-uniformity according to Knoroz	Coefficient of grains uniformity according to Kollis
											A					
0	0,39	0,54	0,77	1,24	2,75	3,86	4,81	5,35	5,71	6,01	3,69	2,96	1,97	7,15	15,41	0,41
25	2,06	2,49	3,37	4,14	4,86	5,15	5,58	5,84	6,01	6,16	5,65	4,69	1,16	2,07	2,99	0,63
30	0,49	1,08	1,83	2,38	4,41	4,79	5,36	5,70	5,92	6,11	4,76	3,98	1,50	4,44	12,47	0,33
35	0,50	1,10	1,93	2,63	4,50	4,86	5,40	5,72	5,94	6,12	4,89	4,05	1,43	4,42	12,24	0,32
40	0,53	1,28	2,05	2,93	4,60	4,94	5,45	5,76	5,96	6,13	5,03	4,14	1,36	3,86	11,57	0,36
45	4,12	4,23	4,37	4,58	5,15	5,38	5,73	5,93	6,07	6,19	6,30	5,15	1,12	1,27	1,50	0,97
											B					
0	2,62	3,62	4,11	4,34	4,99	5,26	5,65	5,88	6,04	6,17	5,94	4,99	1,14	1,45	2,35	0,88
15	0,59	1,01	1,76	2,69	4,57	4,91	5,43	5,75	5,95	6,13	4,94	4,03	1,42	4,86	10,39	0,29
20	0,75	1,69	2,35	3,64	4,72	5,03	5,51	5,79	5,98	6,14	5,25	4,29	1,23	2,98	8,19	0,45
25	0,33	0,47	0,80	1,64	3,25	4,07	4,91	5,41	5,74	6,02	3,90	3,15	1,73	8,66	18,24	0,26
30	1,42	3,10	4,05	4,29	4,96	5,23	5,63	5,87	6,03	6,17	5,80	4,96	1,15	1,69	4,35	0,76
											C					
0	0,89	1,87	2,40	3,51	4,69	5,01	5,49	5,78	5,98	6,14	5,25	4,29	1,25	2,68	6,90	0,51
10	1,63	1,92	2,26	3,10	4,61	4,95	5,46	5,76	5,96	6,13	5,17	4,21	1,33	2,58	3,76	0,54
15	0,46	0,86	1,62	2,27	4,29	4,69	5,30	5,66	5,90	6,10	4,62	3,86	1,53	5,45	13,26	0,28
20	0,52	1,12	1,94	2,56	4,46	4,83	5,38	5,71	5,93	6,12	4,86	4,04	1,45	4,31	11,77	0,33
25	0,70	1,78	2,44	3,69	4,72	5,04	5,51	5,79	5,98	6,14	5,27	4,32	1,22	2,83	8,77	0,48
30	0,41	0,73	1,70	2,69	4,43	4,81	5,37	5,70	5,93	6,11	4,80	3,94	1,41	6,59	14,90	0,22
											D					
0	2,90	4,02	4,18	4,40	5,04	5,29	5,67	5,90	6,05	6,17	6,02	5,04	1,14	1,32	2,13	0,96
20	2,69	2,88	3,10	3,44	4,38	4,77	5,34	5,69	5,92	6,11	5,38	4,39	1,25	1,66	2,27	0,89
25	0,38	0,63	1,29	2,33	4,51	4,87	5,41	5,73	5,94	6,12	4,77	3,84	1,52	7,73	16,11	0,18
30	0,41	0,66	1,16	2,13	4,37	4,75	5,33	5,68	5,91	6,11	4,60	3,74	1,58	7,20	14,90	0,20
35	0,41	0,69	1,21	2,02	4,27	4,68	5,29	5,65	5,90	6,10	4,49	3,71	1,62	6,78	14,88	0,22
40	0,37	0,62	1,09	1,88	4,06	4,51	5,18	5,58	5,85	6,08	4,29	3,58	1,66	7,27	16,43	0,22
45	2,95	3,40	3,94	4,23	4,92	5,20	5,61	5,86	6,02	6,16	5,92	4,91	1,15	1,53	2,09	0,85

CONCLUSIONS

From the above analysis and observations there we redrawn the following conclusions:

– According to granulometric parameters calculations one can say that on the observed Raba River section the dominating is a coarse-grain samples fraction. Also the dunes localized here are of grain-sand material (d_{50}>2mm).

– Sorting degree in observed grain-sand dunes is not fully uniform. As an example dune "1" localized in the middle of the river bed is of a bad sorting. The material going with the stream down to the highest point of dune is of a weak sorting and this value becomes better at the lowest part of bed form.

– The analyzed grain-sand dunes are of a uni-modal grain-size distribution. This proves the form was created by only one high discharge.

– To calculate sorting of a material the Trask (metric scale) and the Folk (logarithmic scale) equations were used giving similar results.

– Based on the changes of bed material diameters (d_{16}, d_{50}, d_{84}, d_m) the observation was made the maximal diameter d_{max} in every each of probes taken appears at in the deepest layer. That suggests an armouring layer at this deep.

REFERENCES

Allen J.R.L. 1968. *Current Ripples.* Amsterdam, North Holland, 433 p.

Allen J.R.L. 1984. *Sedimentary Structures: Their Character and Physical Basis.* Amsterdam, Elsevier, 539 p.

Allen J.R.L. 1985. *Loose-boundary hydraulics and fluid mechanics: selected advances since 1961.* In Brenchley. P.J., and Williams. B.P.J. eds. *Sedimentology: Recent Developments and Applied Aspects*: Geological Society of London. Special Publication 18, p. 7-28.

Ashley G.M. 1990. *Classification of large-scale subaqueous bedforms: a new look al an old problem: Journal of Sedimentary Petrology*, v. 60, p. 160-172.

Carling P.A. 1999. *Subaqueus gravel dunes.* Journal of sediment research, v. 69, n. 3, p. 534-545.

Carling P.A., Gölz E., Orr H.G., Radecki-Pawlik A. 2000. *The morphodynamics of fluvial sand dunes in the River Rhine near Mainz*, Germany. I. Sedimentology and morphology. *Sedimentology*, 47, s. 227-252.

Carling, P.A., Radecki-Pawlik, A., Williams, J.J., Rumble, B., Meshkova, L., Bell, P. *Breakspear R. 2005. The morphodynamics and internal structure of intertidal fine-gravel dunes:* Hill Flats, Severn Estuary, UK. *Sedimentary Geology*, Elsvier, p.21 (in print).

Church, M. A. , D. G. McLean, and J. F. Wolcott. *River Bed Gravels: Sampling and Analysis." Sediment Transport in Gravel-Bed Rivers.* Ed. C. R. Thorne, J. C. Bathurst, and R. D. Hey. John Wiley and Sons, 1987. 43-88.

Dinehart R.L. 1989. *Dune migration in a sleep, coarse-bedded stream: Water Resources Research,* v. 25, p. 911-923.

Flemming B.W. 1988. *Zur klassifikation subaquatischer stomungsiransversaler Transport-korper. Bochumer Geologische und Geotechnische Arbeiten*, v. 29, p. 44-47.

Michalik A., 2000, *Bedload transport in mountain rivers – measurements and results,* 10th Inter. Conf. on Transport and Sedimentation of Solid Particles, Zesz. Nauk. AR we Wrocławiu, Nr 382, 41-58, Radecki-Pawlik A., Carling P., Słowik-Opoka E., Książek L., Breakspeare R., 2006. *Field investigations of sand-gravel bed forms within the Raba river, Poland.* River Flow Monograph edited by Rui. M.L. Ferreira, Elsa C.T.L. Alves, Jao G.A.B. Leal abd Antonio H. Cardoso, Engineering, Water and Earth Science, AABALKEMA Taylor&Francis group, Rotterdam, vol. 1, p. 979-985.

Słowik-Opoka E. 2006. *Warunki hydrauliczne kształtujace dno rzeki o podłożu żwirowo piaszczystym.* Rozpr. Dokt. Katedra Inżynierii Wodnej, AR w Krakowie.

Wyzga B. 1992. *Evolution of the fluvial system of the middle and lower Raba in the last 200 years, in Polish.* PAN IGiPZ. Ph.D. thesis. Warszawa, p. 92.

Jacek Florek, Ph.D., Leszek Książek, Ph.D., Damian Śmiałek, Ph.D
Ph.D., Dr.Sc. Artur Radecki-Pawlik
Agricultural University of Cracow, Mickiewicza
Department of Water Engineering

Rewiever: *Prof. Stanisław Węglarczyk, Ph.D., Dr.Sc.*