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Morphogenesis of Torrent Beds in the Watersheds with a Different Geological Bedrock and Geomorphological Rock Value

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ABSTRACT
The paper deals with the morphogenesis of natural torrent beds in two watersheds with different geological backgrounds and a different geomorphological rock value: Hučava (geomorphological unit of Poľana with geological bedrock: neovulcanites – pyroxene and hornblende-pyroxene andesites, andesite porphyry, rhyolites, rhyodacites, rhyolite tuffs, diorite porphyry) and Mútňanka (geomorphological units of Podbeskydská brázda and Oravské Beskydy with geological bedrock: flysh – claystones, sandstones, shales-thin bedded flysh, microconglomerates). The bankfull geometric characteristics of a natural reference cross-sections of these torrents: the width of the channel inside the banks W_{bkf} (m), mean channel depth D_{bkf} (m), channel cross-section area A_{bkf} (m^2) and the hydraulic characteristic, namely bankfull discharge Q_{bkf} ($m^3.s^{-1}$) in relation to the watershed area A_w (km^2), were analyzed and compared. The analyses showed a strong correlation between the watershed area A_w (km^2) and the bankfull geometric characteristics of natural cross-sections: W_{bkf} (m), D_{bkf} (m), A_{bkf} (m^2) and the hydraulic characteristic Q_{bkf} ($m^3.s^{-1}$). In the analyzed relationships, the coefficient of determination (R^2) ranged from $R^2 = 0.905$ to $R^2 = 0.962$ in the Hučava torrent and between $R^2 = 0.912$ to $R^2 = 0.958$ for the torrent of Mútňanka. Using statistical testing, the significance of the differences between the absolute and as well as regression coeficients in the hydraulic geometry equations for these torrents and their watersheds of different geological bedrock were confirmed.

Keywords: rock resistance, regional hydraulic geometry, watercourse channel characteristics

INTRODUCTION

The morphogenesis of watercourse beds has been a longstanding interest of the scientists around the world dealing with many related problems within various scientific fields (geomorphology, fluvial morphology, river regulation, torrent control, landscape management etc.). The researchers focused on a wide range of related issues. The issue of watercourses regional hydraulic geometry is one of them. [Blackburn-Lynch et *al.*, 2017] mention the following basic regional hydraulic geometry equations:

$$W_{bkf} = aA_w^{\,b} \tag{1}$$

$$D_{bkf} = cA_w^{\,d} \tag{2}$$

$$A_{bkf} = eA_w^{\,f} \tag{3}$$

$$Q_{bkf} = gA_w^{\,h} \tag{4}$$

where: W_{bkf} – the width of the channel inside the banks (m),
D_{bkf} – mean channel depth (m),
A_{bkf} (m^2) – channel cross-section area,
Q_{bkf} ($m^3.s^{-1}$) – bankfull discharge,
A_w (km^2) – the watershed area.

The morphogenesis (long-term development) of watercourse beds varies, depending on different geological conditions of the watersheds. Authors [Wolock et al., 2004] divided the USA into 20 Hydrologic Landscape Regions (HLRs) on the basis of similar natural characteristics of watersheds. [Bieger et al., 2015, Blackburn-Lynch et al., 2017] confirmed a diverse nature of regional regression equation coefficients for equations

(1) to (4), describing different HLRs. Another author [Pšida, 2014] evaluated the relationships of bankfull regional hydraulic geometry in four geographic regions – geomorphologic units in the SR with different bedrocks. The author confirmed different development of the torrent beds under different geological conditions. The geological (rock) resistance or geomorphological rock value expresses the resistance of rocks to erosion and depends mainly on their hardness, cohesion and chemical reactivity. Notable papers and books on this issue were published by such authors as [Leopold et al., 1995, Montgomery and Buffington, 1997, Wohl, 1998, Tinkler and Wohl, 1998, Radecki-Pawlik, 2002, 2014, Vianello and D´Agostino, 2007, Charlton, 2008, Galia and Hradecký, 2014, Gleason, 2015, Roviński and Radecki-Pawlik, 2016]. Abroad, the term of geomorphological value is often used in the context of natural heritage and the natural value of the landscape [Dobos and Gali, 2010, Badman, 2010, Weiyan et al., 2013, Costa-Casais et al., 2015, Reynard and Brilha, 2018 etc.]. Moreover, the resistance of rocks or geological structures is called durability of rocks or rock durability [Lindqvist et al., 2003, Franke, 2018]. [Sládek, 2014] notes that the geomorphological rock value is a fundamental concept in geomorphology and this term has been widely adopted in the respective literature. This author proposes three degree of rocks resistance: (i) Highly resistant rocks (very hard rocks), (ii) Moderately resistant rocks and (iii) Less resistant rocks. For the territory of the SR, author [Valtýni, 1981] created five basic regions according to the resistance of the bedrock and the hydrologic efficiency. The neovolcanites (andesites, rhyolites, andesite porphyry, rhyolites, rhyodacites, rhyolite tuffs) rank among the highly resistant rocks. The author classified flysh (claystones, sandstones, shales-thin bedded flysh, microconglomerates) as occupying the position between moderately resistant and less resistant rocks. Important information on the issue was compiled in detail by [Sládek, 2014]. [Lacika, 1999] divided rocks into three groups by their origin: magmatic rocks, sedimentary rocks and metamorphic rocks and he also proposed three groups of classification by resistance. Andesites and rhyolites rank among highly resistant rocks; sandstones, claystones and conglomerates among moderately resistant rocks. Another author [Dzurovčin, 2000] prepared a table of rocks resistance table in a temperate continental climate according to [Klimaszewski, 1981]. According to the authors, the porphyry display great mechanical resistance; the sandstones – small to medium mechanical resistance and shales – even low mechanical resistance. [Michaeli, 2001] also ranked andesites among the highly resistant rocks from the three rock resistance groups; the sandstones, claystones and conglomerates ranked among the moderately resistant rocks. According to [Marko et al., 2007], the andesites and rhyolites rank as highly resistant rocks; sandstones and conglomerates as moderately resistant rocks. The geomorphological rock value affects the torrent bed development concurrently with the hydrological efficiency of geological bedrock. Hydrological rock efficiency means the ability of rocks to retain water in the watershed. High hydrological efficiency of the geological bedrock generally means lower surface runoff and vice versa.

MATERIALS AND METHODS

For the purpose of research, we selected two watersheds (Fig. 1) with a different geological bedrock (Table 1): Hučava in the geomorphological unit of Poľana with a geological bedrock: neovulcanites – pyroxene and hornblende-pyroxene andesites, andesite porphyry, rhyolites, rhyodacites, rhyolite tuffs, diorite porphyry and Mútňanka in the geomorphological units of Podbeskydská brázda and Oravské Beskydy, with a geological bedrock: flysh – claystones, sandstones, shales-thin bedded flysh, microconglomerates [Composite Authors, 2002].

Morphological characteristics of experimental watersheds and torrents are listed in Tables 2 and 3.

On straight stretches of both torrents, we selected the reference longitudinal sections (RLS) with reference cross-sections (RCS) and determined their geometric and hydraulic characteristics according to [Page, 1988, Rosgen and Silvey, 1996, Rosgen, 2009]. We estabilished RLS and RCS in the terrain under the torrents sediments source zones in natural sections without direct human intervention. We determined the geometric characteristics of the RCS by leveling. The measured and calculated geometric characteristics of reference cross-sections are as follows: width of the channel inside the banks W_{bkf} (m), mean channel depth D_{bkf} (m), reference cross-sectional area A_{bkf} (m^2) and the hydraulic characteristic: bankfull discharge Q_{bkf} ($m^3.s^{-1}$) for torrent Hučava with the medians of W_{bkf} = 8.10 (m), D_{bkf} = 1.00 (m),

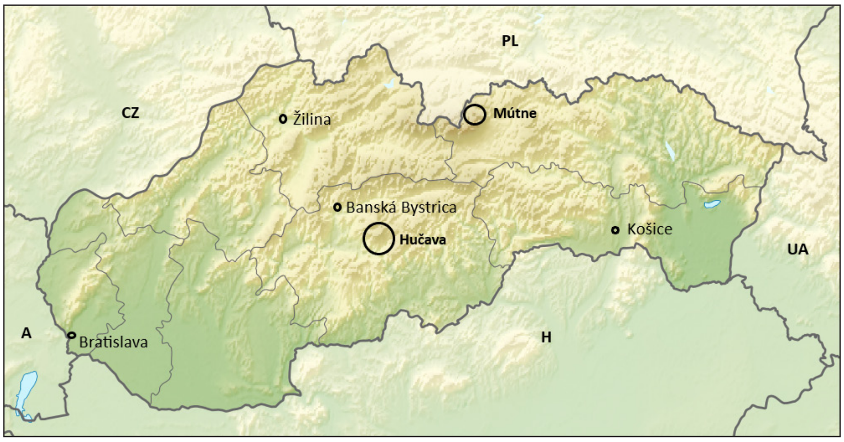

Figure 1. Map of Slovakia with the research areas

Table 1. Geological bedrock in watersheds of analyzed torrents

Watershed	Geological bedrock
Hučava	Pyroxene and hornblende-pyroxene andesites, andesite porphyry, rhyolites, rhyodacites, rhyolite tuffs, diorite porphyry
Mútňanka	Claystones, sandstones, shales-thin bedded flysh, microconglomerates

Table 2. Basic characteristics of watersheds (part 1)

Torrent	A_w (km²)	H_{minw} (m a.s.l.)	H_{maxw} (m a.s.l.)	ΔH_w (m)	$H_{øw}$ (m a.s.l.)	L_{tr} (km)	L (km)	L_t (km)	L_v (km)
Hučava	41.16	523	1457	934	929	33.626	14.198	47.824	14.516
Mútňanka	29.93	789	1556	767	1008	38.894	8.370	47.264	8.855

Explanatory notes to Table 2: A_w – watershed area (km^2); H_{minw} – minimal altitude in the watershed (m a.s.l.); H_{maxw} – maximal altitude in the watershed (m a.s.l.); ΔH_w – absolute height difference of the watershed; $H_{øw}$ – mean altitude of the watershed (m a.s.l.); L_{tr} – total length of tributaries (km); L – length of main stream (km); L_t – total length of watercourses in the watershed (km); L_v – length of torrent valley (km).

Table 3. Basic characteristics of watersheds (part 2)

Torrent	H_{mint} (m a.s.l.)	H_{maxt} (m a.s.l.)	ΔH_t (m)	A_f (km²)	L_d (km)	$S_{øt}$ (%)	$S_{øw}$ (%)	B_w (km)	$w_w:\ell_w$ (-)
Hučava	523	1328	805	34.831	43.340	5.67	32.48	2.835	1 : 5.12
Mútňanka	789	1251	462	26.456	31.080	5.52	23.80	3.380	1 : 2.62

Explanatory notes to Table 3: H_{mint} – maximal altitude of the torrent (m a.s.l.); H_{maxt} – maximal altitude of the torrent – source (m a.s.l.); ΔH_t – absolute torrent height difference (m); A_f – forested watershed area (km^2); L_d – legth of the divide (km); $S_{øt}$ – mean gradient of the torrent (%); $S_{øw}$ – mean slopes gradient of the watershed (%); B_w – mean width (km); $w_w:\ell_w$ – width/lenght ratio of the watershed (-).

A_{bkf}= 6.40 (m^2) and Q_{bkf} = 16.12 (m^3.s^{-1}) are listed in Table 4 and for torrent Mútne with medians of W_{bkf} = 6.20 (m), D_{bkf} = 0.65 (m), A_{bkf}= 2.98 (m^2) and Q_{bkf} = 5.29 (m^3.s^{-1}) are listed in Table 5. The longitudinal slope S (%) of RLS was calculated from the RLS altitude differences estabilished by their leveling with the median for the torrent Hučava of S = 1.65 (%) and Mútňanka S = 1.84 (%). More than fifty kilogram of sediment samples were collected on each RCS in order to conduct of sieve granulometric analyses used to determine the grain diameter D_{50} (m) with the medians of Hučava D_{50} = 0.125 (m) and Mútňanka D_{50} = 0.169 (m). We also determined the hydraulic radius R_{bkf} (m) with the medians of Hučava R_{bkf} = 0.716 (m) and Mútňanka

R_{bkf} = 0.446 (m) during the office-run processing. Watersheds areas with up to the RCS as enclosing profiles were from the maps with GIS methods determined with median of A_w = 31.99 km^2 (Hučava) and 6.10 km^2 (Mútne). In orde to calculate the bankfull discharge Q_{bf} (m^3.s^{-1}), we used the equation according to [Parker, 2004]:

$$Q_{bf} = 3.732 W_{bkf} D_{bkf} \sqrt{g R_{bkf} S} \left(\frac{R_{bkf}}{D_{50}}\right)^{0.2645} \quad (m^3 s^{-1}) \tag{5}$$

We used the following regression equation for the analysis:

$$y = a_0 . x^{a1} \tag{6}$$

RESULTS AND DISCUSSION

The geometric and hydraulic characteristics of RCS of both torrents are shown in Tables 4 and 5. The analyses showed a strong correlation between the watershed area A_w (km^2) and the bankfull geometric characteristics of natural cross-sections: the width of the bed inside the banks W_{bkf} (m), mean depth of the bed D_{bkf} (m), the channel cross-section area A_{bkf} (m^2) and the hydraulic characteristic – bankfull discharge Q_{bkf} (m^3.s^{-1}). The regression equations of the relationships are shown in Table 6. In the analyzed relationships, the coefficient of determination (R^2) ranged from R^2 = 0.905 to R^2 = 0.962 in the Hučava torrent and between R^2 = 0.912 and R^2 = 0.958 for the torrent of Mútňanka (Tab.7). Subsequently, the differences between the absolute and relative coefficients in regression equations for torrents Hučava and Mútňanka were statistically tested and their statistical significance was confirmed (Table 8). The statistical significance of the differences was not confirmed only by evaluating of relative coefficients a_1 in the relation Q_{bkf} = f(A_w) for both watersheds. Figures (2) to (5) show the graphical representation of each relationship, making it clear that the development of the geometric characteristics of the bed and also the bankfull discharge in relation to the watershed area A_w (km^2) is significantly different. The torrent bed of Mútňanka, developed in the flysh geological bedrock with a lower geomorphological rock value (rock resistance), has – in

Table 4. Geometric and hydraulic characteristics of RCS – Hučava

No. RCS	A_w	H_w	W_{bkf}	D_{bkf}	A_{bkf}	R_{bkf}	S	D_{50}	Q_{bkf}
1	41.16	523	10.3	1.15	9.4	0.847	1.03	0.090	23.45
2	39.05	554	9.9	1.15	9.1	0.843	1.10	0.112	21.94
3	38.15	568	9.7	1.1	8.8	0.846	0.92	0.115	18.68
4	37.58	575	9	1	8	0.784	1.30	0.110	17.83
5	37.31	582	8.8	1.05	7.7	0.762	1.39	0.120	18.10
6	36.65	602	8.7	1	7.3	0.753	1.57	0.117	18.11
7	36.09	620	8.7	1.05	7.3	0.73	1.30	0.117	16.84
8	35.30	625	8.7	1.1	7.1	0.755	1.39	0.135	18.11
9	34.58	640	8.5	1	7	0.737	1.51	0.128	16.64
10	32.90	656	8.6	1	6.9	0.767	1.40	0.132	16.58
11	32.21	662	8.2	1	6.7	0.744	1.55	0.125	16.45
12	31.76	670	8	0.95	6.1	0.701	1.85	0.129	15.79
13	30.53	681	7.9	1	6	0.682	1.72	0.125	15.69
14	29.10	695	8	0.95	6.1	0.685	1.90	0.128	15.79
15	27.03	711	7.8	0.9	5.6	0.675	2.04	0.124	15.04
16	26.80	728	7.6	0.9	5.3	0.631	2.09	0.115	14.43
17	24.55	740	7.1	0.95	5	0.617	2.17	0.121	14.03
18	23.77	755	6.8	0.9	4.5	0.584	2.17	0.130	12.01
19	20.47	765	6.6	0.85	4.4	0.603	2.40	0.133	17.76
20	19.43	775	6	0.8	3.6	0.571	3.12	0.140	10.86
21	12.63	785	5.2	0.75	3.3	0.579	2.82	0.144	8.38
22	9.71	810	3.9	0.65	2.1	0.457	3.05	1.134	4.82

Explanatory notes to Tables 4 and 5: A_w [km^2]: watershed area; φH_w [amsl]: mean altitude of the watershed; W_{bkf} [m]: width of the RCS inside the banks; D_{bkf} [m]: mean depth of the RCS; A_{bkf} [m^2]: RCS area; S [m/m]: energy gradient; R_{bkf} [m]: hydraulic radius of RCS; D_{50} [m]: grain diameter; Q_{bkf} [m^3/s]: bankfull discharge.

Table 5. Geometric and hydraulic characteristics of RCS – Mútňanka

No. RCS	A_w	H_w	W_{bkf}	D_{bkf}	A_{bkf}	R_{bkf}	S	D_{50}	Q_{bkf}
1	29.93	789	15.20	1.20	12.00	0.771	0.73	0.180	23.51
2	26.13	802	14.30	1.10	12.51	0.830	0.60	0.150	20.37
3	24.72	807	12.10	1.00	9.04	0.722	0.77	0.155	15.85
4	16.43	814	8.50	0.90	6.25	0.669	1.05	0.140	11.34
5	15.32	818	9.90	0.85	5.89	0.579	1.25	0.155	11.86
6	14.92	826	9.50	0.80	5.82	0.588	1.27	0.130	11.45
7	8.92	834	8.20	0.80	4.60	0.539	2.02	0.160	11.05
8	8.82	841	8.40	0.75	4.56	0.489	1.77	0.162	9.17
9	6.82	845	8.20	0.70	4.02	0.472	1.48	0.152	7.58
10	6.70	854	6.20	0.65	3.03	0.454	1.29	0.125	5.09
11	6.20	863	6.10	0.60	2.74	0.423	2.22	0.176	5.23
12	5.99	871	6.30	0.65	2.93	0.430	2.05	0.220	5.34
13	5.79	877	6.20	0.65	2.85	0.435	1.54	0.185	4.81
14	5.23	889	5.70	0.70	3.11	0.506	1.90	0.202	5.81
15	4.17	904	5.90	0.65	2.61	0.424	1.91	0.191	4.96
16	4,01	913	5.40	0.60	2.53	0.437	2.11	0.210	4.40
17	3.40	926	4.60	0.55	1.76	0.365	2,26	0.222	3.06
18	3.23	937	4.30	0.50	1.53	0.333	2.07	0.183	2.44
19	2.09	965	4.00	0.50	1.45	0.335	2.09	0.153	2.40
20	1.18	992	3.70	0.45	1.04	0.268	2.73	0.162	1.83
21	1.09	1012	4.00	0.50	1.67	0.355	1.21	0.220	2.34
22	0.70	1037	2.80	0.50	0.84	0.279	3.44	0.240	1.67

Explanatory notes to Tables 4 and 5: A_w [km^2]: watershed area; φH_w [amsl]: mean altitude of the watershed; W_{bkf} [m]: width of the RCS inside the banks; D_{bkf} [m]: mean depth of the RCS; A_{bkf} [m^2]: RCS area; S [m/m]: energy gradient; R_{bkf} [m]: hydraulic radius of RCS; D_{50} [m]: grain diameter; Q_{bkf} [m^3/s]: bankfull discharge.

Table 6. Regression equations for analyzed relations

Correlation relation	Regression equation
$W_{bkf\,(H)} = f(A_{wH})$	$W_{bkf(H)} = 1.0343*(A_{wH})^{0.6023}$
$D_{bkf(H)} = f(A_{wH})$	$D_{bkf(H)} = 0.2755*(A_{wH})^{0.3721}$
$A_{bkf\,(H)} = f(A_{wH})$	$A_{bkf(H)} = 0.3288*(A_{wH})^{1.0712}$
$Q_{bkf\,(H)} = f(A_{wH})$	$Q_{bkf(H)} = 0.7797*(A_{wH})^{0.8818}$
$W_{bkf(M)} = f(A_{wM})$	$W_{bkf(M)} = 2.7660*(A_{wM})^{0.4778}$
$D_{bkf(M)} = f(A_{wM})$	$D_{bkf(M)} = 0.4078*(A_{wM})^{0.2869}$
$A_{bkf(M)} = f(A_{wM})$	$A_{bkf(M)} = 0.6645*(A_{wM})^{0.8482}$
$Q_{bkf(M)} = f(A_{wM})$	$Q_{bkf(M)} = 1.3287*(A_{wM})^{0.8202}$

Explanatory notes to Tab. 6: $W_{bkf\,(H)}$, $D_{bkf\,(H)}$, $A_{bkf\,(M)}$, $Q_{bkf\,(M)}$; bankfull characteristics (Hučava); $W_{bkf\,(M)}$, $D_{bkf\,(M)}$, $A_{bkf\,(H)}$, $Q_{bkf\,(M)}$; bankfull characteristics (Mútňanka); A_{wH} – watershed area Hučava; A_{wM} – watershed area Mútňanka.

relation to the increasing watershed area – significantly steeper development compared to the Hučava torrent bed with a higher geomorphological rock value (rock resistance) of the watershed.

[Wolock et al., 2004] divided the USA into 20 HLRs on the basis of similar natural characteristics, of which the geological bedrock plays a very important role. Other authors [Vianello and D´Agostino, 2007] evaluated the variations in bankfull cross-sections along a steep stream in dolomites (Northern Italy). The relations between watershed area A_w (from 0.040 to 7.084 km^2) and bankfull width of the channel inside the banks W_{bkf} (from 0.35 to 5.10 m) were evaluated with $R^2 = 0.620$. The relations between watershed area A_w and channel mean depth D_{bkf} (from 0.11 to 0.81 m) were evaluated with $R^2 = 0.49$. [Pšida, 2014] evaluated the relationships of the bankfull regional hydraulic geometry in four geographic regions – geomorphologic units in the SR with different bedrocks, whose bankfull characteristics medians displayed the following values: A_w = 18.81 (km^2), W_{bkf} = 8.10 (m), D_{bkf} = 0.83 (m), A_{bkf} = 4.53 (m^2), Q_{bkf} = 8.02 (m^3.s^{-1}) and the coefficients of determination in relations to the watershed area ranged between $R^2 = 0.723$ and $R^2 = 0.977$. The author confirmed the variations in the development of the natural geometric and hydraulic characteristics of torrent beds and their long-term morphogenesis in watersheds with different bedrocks. [Galia and Hradecký, 2014] evaluated 120 bankfull cross-sections of

Table 7. Statistical testing of the correlation relations

Correlation relation	R	R^2	S_R	t	> = <	$t_{0,01\ (22)}$	RMSE
$W_{bkf\ (H)} = f(A_{wH})$	0.981	0.962	0.044	22.3	>	2.819	0.30
$D_{bkf(H)} = f(A_{wH})$	0.951	0.905	0.069	13.8	>	2.819	0.04
$A_{bkf\ (H)} = f(A_{wH})$	0.976	0.953	0.048	20.3	>	2.819	0.42
$Q_{bkf\ (H)} = f(A_{wH})$	0.965	0.932	0.058	16.6	>	2.819	1.11
$W_{bkf(M)} = f(A_{wM})$	0.971	0.943	0.053	18.3	>	2.819	0.82
$D_{bkf(M)} = f(A_{wM})$	0.955	0.912	0.066	14.5	>	2.819	0.06
$A_{bkf(M)} = f(A_{wM})$	0.978	0.958	0.046	21.3	>	2.819	0.69
$Q_{bkf(M)} = f(A_{wM})$	0.977	0.954	0.048	20.4	>	2.819	1.32

Explanatory notes to Tab. 7: R: index of correlation; R^2: index of determination; $S_R: \sqrt{\frac{1-R^2}{n-2}}$; t: $\frac{R}{S_R}$; RMSE: root mean square error.

Table 8. Testing of statistical significance of differences between absolute and relative coefficients in correlation relations

Correlation relation	a_0	a_1	s_{a0}	s_{a1}	t_a (t_r)	> = <	$t_{0,05\ (40)}$
$W_{bkf(H)} = f(A_{wH})$	1.0343	*0.6023*	0.1122	*0.0313*	7.307	>	2.021
$W_{bkf(M)} = f(A_{wM})$	2.7660	*0.4778*	0.2088	*0.0283*	*2.952*	>	2.021
$D_{bkf(H)} = f(A_{wH})$	0.2755	*0.3721*	0.0281	*0.0297*	3.815	>	2.021
$D_{bkf(M)} = f(A_{wM})$	0.4078	*0.2869*	0.0203	*0.0203*	*2.368*	>	2.021
$A_{bkf(H)} = f(A_{wH})$	0.1462	*1.1031*	0.0359	*0.0699*	5.149	>	2.021
$A_{bkf(M)} = f(A_{wM})$	0.6645	*0.8482*	0.0940	*0.0478*	*8.798*	>	2.021
$Q_{bkf(H)} = f(A_{wH})$	0.7797	*0.8818*	0.1829	*0.0672*	2.080	>	2.021
$Q_{bkf(M)} = f(A_{wM})$	1.3287	*0.1893*	0.8202	*0.0484*	*0.745*	<	2.021

Explanatory notes to Tab. 8: $t_a = \frac{|a_{01} - a_{02}|}{\sqrt{s_{a01}^2 + s_{a02}^2}}$; $t_r = \frac{|a_{11} - a_{12}|}{\sqrt{s_{a11}^2 + s_{a12}^2}}$;

t_a – test characteristic for the absolute coefficient ;

t_r – test characteristic for the relative coefficient.

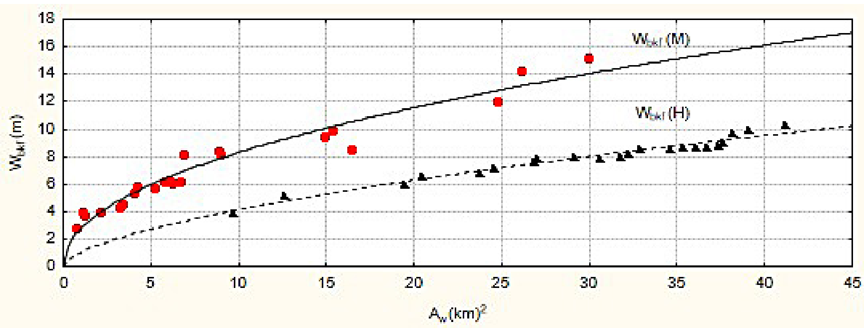

Figure 2. Relations between A_w (km^2) and W_{bkf} (m)

14 mountain streams in flysch bedrock of Outer Western Carpatians in the relations between watershed area (A_w from 0.45 km^2 to 2.59 km^2), width of the channel inside the banks (W_{bkf} from 2.17 m to 3.96 m) and mean channel depth (D_{bkf} from 0.23 to 0.30 m). The observed reaches showed a fairly good correlation ($R^2 = 0.53$) between increasing A_w (km^2) and W_{bkf}(m). By contrast, bankfull mean depth D_{bkf} (m) indicated its independence on increasing watershed area A_w (km^2) with $R^2 = 0.03$. [Blackburn – Lynch et al., 2017] reported the results of regional equations from 2856 sites for

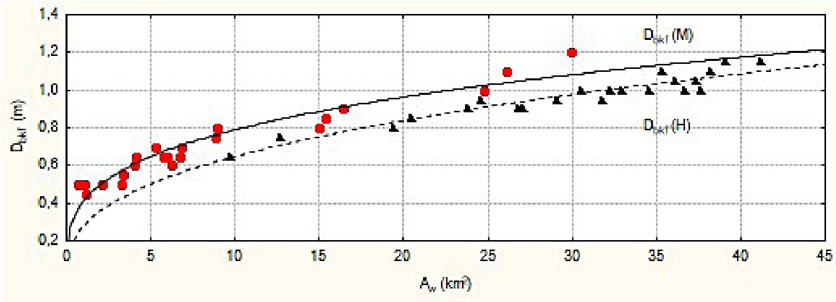

Figure 3. Relations between A_w (km^2) and D_{bkf} (m)

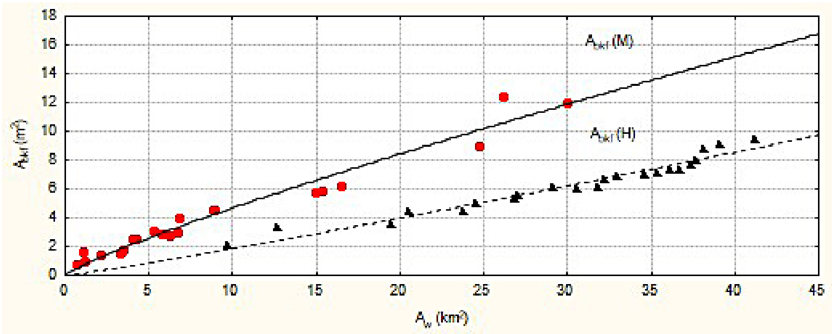

Figure 4. Relations between A_w (km^2) and A_{bkf} (m^2)

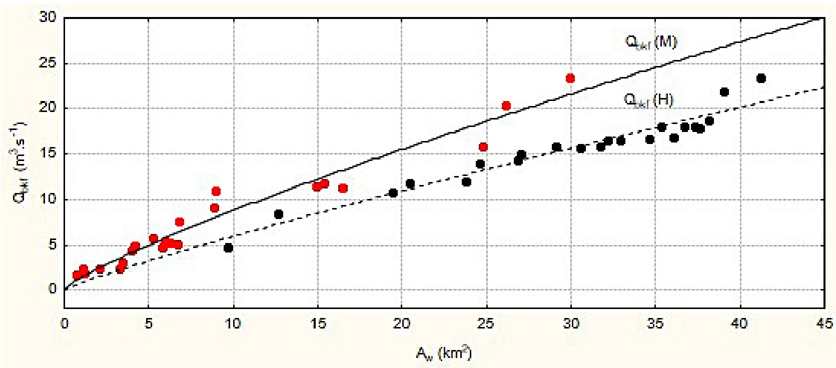

Figure 5. Relations between A_w (km^2) and Q_{bkf} (m^3/s)

20 various HLRs in the contiguous USA with the medians of characteristics A_w = 71.2 (km^2), W_{bkf} = 10.5 (m), D_{bkf} = 0.7 (m), A_{bkf} = 7.0 (m^2) and Q_{bkf} = 19.5 (m^3.s^{-1}). The coefficients of determination in relations to the watershed area varied from $R^2 = 0.410$ to $R^2 = 0.710$. The authors confirmed (i) the importance of research of the regional hydraulic geometry, (ii) the development of relationships between watershed area A_w (km^2) and W_{bkf} (m), D_{bkf} (m), A_{bkf} (m^2), Q_{bkf} (m^3.s^{-1}) and (iii) the differences between the regional equations and curves of hydraulic geometry for various HLRs of the USA with various geologic bedrock. Different results are attributable to specific natural features of each geologic region [Powel et al., 2004].

CONCLUSIONS

Our research confirms that the regional hydraulic geometry equations provide reliable results only for specific geologic regions and can be used in practice only in the regions of data origination. The derived specific regional curves and equations enable a valuable input into the process of ecological designing and torrent control dimensioning, into flood and erosion control and torrent revitalization, especially in large-scale protected areas, with the simultaneous gradual HLRs creation in the SR or as an example of a procedure to deal with these tasks in other countries.

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