

**Change of the Manning's coefficient in small stream influenced by vegetation**

Radoslav SCHÜGERL\*, Yvetta VELÍSKOVÁ

Aquatic vegetation in natural streams impedes the flow of water and may increase flood risks. This paper analyses impact of aquatic vegetation density on the dynamics of flow process by evaluation of the Manning's coefficient value obtained from field measurements. Measurements performed during two years (2020 and 2021) along the part of the Malina stream were used for determination of the Manning's roughness coefficient value for different extents of river bed overgrowth during the year. This stream, located at the Zahorská Lowland, is a stream with a low longitudinal slope (0.00037–0.00039) and aquatic vegetation occurrence. Value of the Manning's coefficient is varying during the growing season in the range from 0.025 to 0.157 for the year 2020 and from 0.038 to 0.266 for the year 2021.

KEY WORDS: Manning coefficient, aquatic vegetation, growing season, discharge and flow conditions

**Introduction**

The process of morphology development of streams is affected by many factors: flow, slope, bed material, its grain size, vegetation distribution, obstacles (constructions, woods), etc. Aquatic vegetation (type of plant, age, size), in particular, plays a significant role in this process and considerably influences discharge and flow conditions. Aquatic vegetation increases the flow resistance and effectively reduces the flow velocity (Thorne, 1990), sediment carrying capacity, and thus affecting the sediment transport - deposition process and final river bed morphology (Demich, 2008; Li et al., 2016; Oorschot et al., 2016). Many geomorphologists and engineers have recognized that aquatic vegetation impacts river channel hydrodynamic characteristics and morphology: vegetation roots alter morphological conditions and riparian stability, reduce riparian erosion, which in turn affects the channel lateral migration characteristics (Yang et al., 2018). The effects of different vegetation types and densities on these river parameters vary significantly. Channel with dense vegetation generally have lower river-widening rates than those without vegetation (Beeson and Doyle, 1995; Huang and Nanson, 1997), because aquatic vegetation can change the river pattern by changing its width and depth ratio (Van de Lageweg et al., 2010).

Although flow resistance can be reduced by a complete or partial removal of the in-stream vegetation, this is an expensive procedure and also can have ecological implications. A complete removal of the plants in a river can lead to erosion of the bed and banks and turbidity of

water. The roots of the vegetation bind the soil mass, the aquatic vegetation protects the channel from the erosive action of flowing water and hinders moving soil particles on the bed of the channel (Kováčová, 2022). This protective action varies with the species of vegetation and with uniformity of coverage. For any individual type of vegetation, it varies depending on the age and condition of the plants and on the season of the year. On the other hand, an unrestricted growth of vegetation can lead to a total loss of capacity to convey water (Boscolo, 2014).

The role of aquatic vegetation in morphodynamic behavior of rivers was largely investigated through field studies, which study the importance of vegetation for river process (stability/erosion), hydraulic efficiency of river channels or channel narrowing and sediment retention. For example, Dan and Wittenberg (2007) highlighted the importance of shrubs in reducing flow velocities, studied the effect of vegetation density on the river channel. Other results showed that when the vegetation coverage was high, the channel was narrow and deep; when the vegetation coverage was low, the channel was wide and shallow (Allmendinger et al., 2005; Huang and Nanson, 1997).

In this study, we try to evaluate the changes of the Manning's roughness coefficient value for flow conditions in the lowland stream with low longitudinal slope during growing seasons. Value of this coefficient was determined from sets of field measurements performed along the part of the Malina stream located at Záhorská lowland during the years 2020–2021.

## Theoretical background

Aquatic vegetation affects fluvial environment and flow, so it is one of the important objectives in river management and river hydraulics. In hydraulic analysis, non-submerged and submerged plant conditions is usually distinguished because the flow phenomenon becomes more complicated when the flow depth exceeds the plant height (Stone and Shen, 2002). Several authors, including Maione et al. (2000) and Sellin and van Beesten (2002) have reported considerable seasonal variation caused by the growth of vegetation. Any progress in understanding the behavior of flow over vegetation allow us to improve both the knowledge of flow-velocity profiles and flow resistance and the design of vegetated channels, eventually (Carollo et al., 2002). Understanding or determining of aquatic vegetation impact on flow in streams is not an easy task. Aquatic vegetation during growing season changes its properties – it can have various density, amount, flexibility, tallness, etc. – so the rate of impact on the hydraulic roughness also changes. This process is dynamic because of temporal changes in roughness due to natural vegetative growth, management practices, and dynamic response of vegetation to the flow (Franklin et al., 2008). Many studies have tried to solve this problem by different ways (Stephan and Gutknecht, 2002; Okhravi and Gohari, 2020; Čubanová et al., 2022).

In this study, our approach is based on commonly and widely applied empirical derived Manning's formula.

The Chézy's equation (also empirically derived) was initially identified as a method for finding flow velocity in form (Kolář et al., 1983):

$$v = C \sqrt{R \cdot i_e} \quad (1)$$

where

$v$  – is a mean flow velocity [ $\text{m s}^{-1}$ ],

$C$  – is the Chézy's coefficient,

$R$  – is a hydraulic radius [ $\text{m}$ ],

$i_e$  – is a slope of energy line [–].

Consequently, if Manning's empirical formula is introduced into the Chezy's equation, then we get formula for flow velocity in form:

$$v = \frac{1}{n} R^{2/3} i_e^{1/2} \quad (2)$$

where

$n$  – is the Manning's roughness coefficient.

Both equations look simple, but in practical applications in the conditions of natural streams, the determination of flow resistance is not quite simple. Most difficulties connect with determination of channel roughness, which should mirror existed conditions along investigated or designed reach of a stream. There are various approaches how the roughness can be expressed, for example description with constant roughness coefficient through the Chézy formula, the Darcy-Weisbach equation, the Manning's equation or roughness coefficient

dependent on flow characteristics, for example the Strickler and Keulegan approach (Carrier d'Odeigne and Soares Frazao, 2016).

Factors affecting flow resistance in open channels include granular composition of the channel bottom, flow depth, cross-sectional shape, vegetation, sinuosity, bed forms, sediment transport, etc. Vegetation can be a major source of temporal variation in flow resistance. Dense vegetation can also alter the effective area of a cross section that conveys the discharge (Järvelä, 2004). Most of the factors impact affecting the value of the roughness coefficient can be quantified in laboratory conditions, but its complex value can be, and more correctly, obtained from field measurements. Evaluation of the impact of aquatic vegetation on flow conditions in a lowland stream is complicated. Influence of vegetation on the coefficient  $n$  can be described, for example as a function of the flow depth, density, velocity distribution and type of vegetation (Tuozzolo et al., 2019). Nevertheless, it is possible to determine the value of the roughness coefficient  $n$  for a stream reach by using the Manning's formula (Eq. 2) along the part of a stream with steady uniform flow conditions, on which can be considered that the slope of energy line equals the water level slope  $i$  as follows:

$$n_m = \frac{A_m R_m^{2/3} i_m^{1/2}}{Q_m} \quad (3)$$

where

$A_m$  – is a measured discharge area [ $\text{m}^2$ ],

$Q$  – is a discharge [ $\text{m}^3 \text{s}^{-1}$ ],

index  $m$  – means a measured value.

This equation (Eq. 3) is used also in this study.

Since the vegetation is strongly dependent on the season, the roughness coefficient can be significantly different for summer or winter conditions. Thus, the effects of vegetation on the roughness or on the flow field in this method are not taken into account arbitrarily, but are calculated from the actual velocity profile and represent the equivalent roughness of the bed.

## Material and methods

Field measurements, related to the investigation of aquatic vegetation impact on Manning's coefficient in a lowland stream, were performed along the Malina stream at the Záhorská lowland. The Malina stream is a small stream flows through the territory of the Malacky district. It is a left tributary of the Morava River, its length is 47.75 km. Catchment area is 516.6  $\text{km}^2$  and its discharge is from 0.828  $\text{m}^3 \text{s}^{-1}$  in the first monitoring cross-section profile at the Jakubov village to 2.234  $\text{m}^3 \text{s}^{-1}$  in the estuary. Two observation cross-sectional profiles were selected along the Malina stream (river kilometer 7–8), their location is shown in Fig. 1.

Measurements were performed in the channel segments with steady uniform flow conditions. In general, field measurements were done from April to September to detect what changes occur in different periods of the growing season. The measurement were carried out

in a part of the stream with a length of 1140 meters (from profile A to profile B), along which the width varied from 5 to 8 meters. Average depth in the study stream reach ranged from 0.4 m to 1.2 m (depending on flow and biomass of aquatic vegetation). Cross-section profiles parameters (channel width, water depth distribution along the cross-section profile width), water levels (by levelling device), discharges and velocity profile (by ADV – Acoustic Doppler Velocimeter – device Flow Tracker) were measured (Fig. 2). Each cross-section profile was measured at least three times and

the average value from these measurements was used in the calculation. The ADV Flow Tracker device determines the discharge value immediately after the finishing of the measurement (SonTek, 2009). If this value differed by about 5%, the measurement was excluded from further processing and repeated once more. This ADV device uses three methods for calculations of discharge in the open channels in accordance with the applicable standard (mid-section, mean-section and Japanese method). In our case, we used the mid-section method.

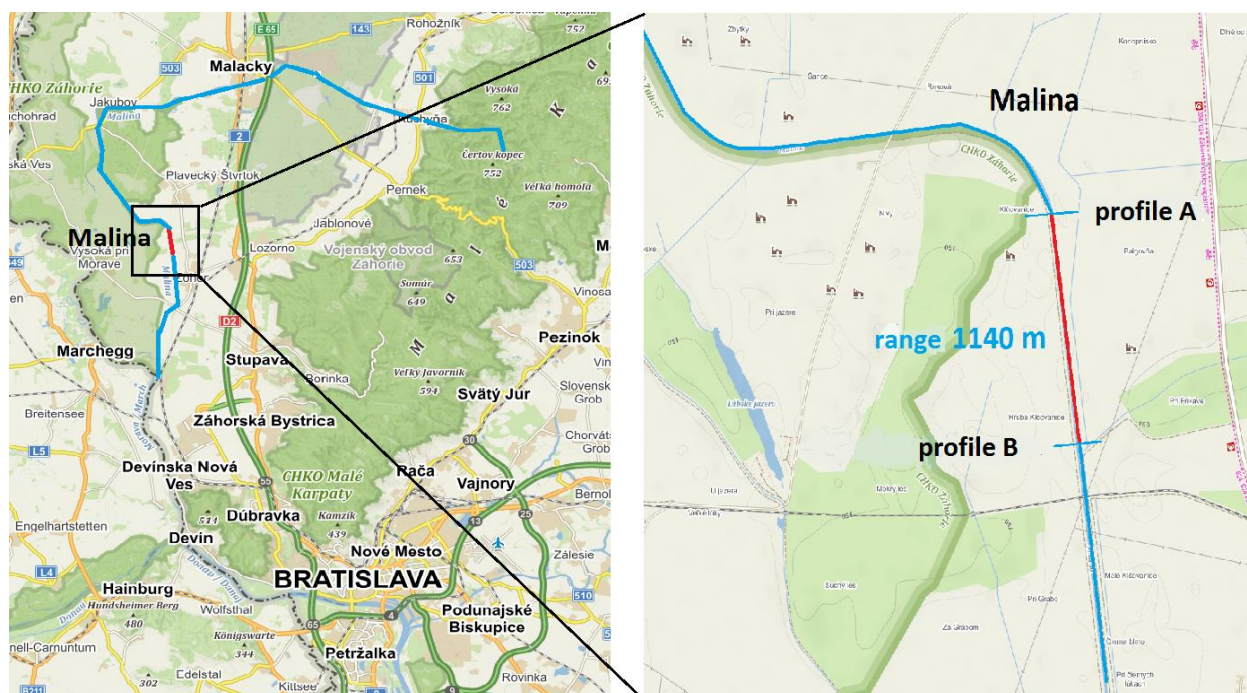


Fig. 1. Map and location of the Malina stream and observation cross-sectional profiles - profile A and profile B.



Fig. 2. Acoustic Doppler Velocimeter – Flow Tracker device for measurement of velocity profile and discharge (left) and photo of the overgrowth of the Malina stream during summer season (right).

## Results and discussion

As it was mentioned, aquatic vegetation has significant impact on change of Manning's coefficient. Measurements on the Malina stream were carried out during two growing seasons (years 2020 and 2021). Table 1 shows the measured data from individual months (from April to September) for defined reach. Table contains discharge ( $Q$ ), cross section profile area ( $A$ ), average flow velocity ( $v$ ), average flow depth ( $h$ ), water level slope ( $i$ ) and Manning's coefficient ( $n$ ).

The roughness coefficient value  $n$  in the overgrown streambed is changing during the growing season depending on aquatic vegetation growth. In consequence of raised roughness, the velocity profile is changing and thereafter the discharge capacities are also changed. The rate of the vegetations impact on flow regime during the vegetation season differed. The reason is that each month had different climatic conditions, which stimulated aquatic vegetation growth to a different extent.

Higher roughness coefficient values (from 0.038 to 0.266) were recorded in each month in 2021 than in 2020 (from 0.025 to 0.157). For example, the value of the Manning's roughness coefficient by Chow (1959) for channels not maintained (dense uncut weeds, high equals the flow depth) is from 0.050 to 0.120 or for channels with dense brush is from 0.080 to 0.140. The difference between minimum and maximum in roughness coefficient values was 0.132 (for 2020) and 0.228 (for 2021). Values of Manning's coefficient continuously increase during the growing season, with the highest values recorded in August and September. The lowest value of the flow velocity was recorded in the spring, in April or May. After these months, the aquatic vegetation

starts to grow and influences the value of roughness coefficient evidently. The relationship between the discharge values and the Manning's coefficient values is shown in the Fig. 3. The highest values of the discharge were in the months without dense vegetation (until June; in June 2021, the highest discharge value was recorded due to excessive precipitation). On the other hand, discharges around  $0.4 \text{ m}^3 \text{ s}^{-1}$  were measured in wide range of the Manning's coefficient values. It is interesting, that in 2020 value of Manning's coefficient increased with value of the discharge. In contrast, year 2021 shows opposite results – the increasing value of the coefficient shows lower value of the discharge. Relation between values of flow velocity and Manning's coefficient, in the Fig. 4, more evidently shows indirect dependence of flow velocity and the Manning's coefficient values. Comparable result published also O'Hare et al. (2010). The highest values of the flow velocity were measured in April (without dense vegetation) in both measured profiles, the lowest values in August (when vegetation is fully-grown).

Regarding the measured water depth, results indicate increasing value of the Manning's coefficient with increasing water depth (Fig. 5) during the growing season. The greatest depth was reached in August in both measured years and in both profiles, when the flow velocity had its minimal value the observed data. On the other side, the smallest depth was measured in April, respectively in May, with the highest values of the flow velocity. Our measurement results confirmed the fact that with aquatic vegetation growing/occurrence the water depth in the channel increases together with the decrease of the flow velocity during the growing season.

**Table 1.** Summary of measured and calculated data for studied reach (from cross section profile A to cross section profile B)

date of measurement	Profile A				Profile B					
	$h$ [m]	$A$ [m <sup>2</sup> ]	$v$ [m s <sup>-1</sup> ]	$Q$ [m <sup>3</sup> s <sup>-1</sup> ]	$h$ [m]	$A$ [m <sup>2</sup> ]	$v$ [m s <sup>-1</sup> ]	$Q$ [m <sup>3</sup> s <sup>-1</sup> ]	$i$	$n$
04/2020	0.25	2.10	0.23	0.33	0.42	1.27	0.28	0.35	0.000328	0.025
05/2020	0.24	1.40	0.12	0.31	0.46	1.47	0.27	0.33	0.000395	0.027
06/2020	0.56	2.90	0.13	0.38	0.59	3.57	0.14	0.37	0.000248	0.067
07/2020	0.73	4.02	0.09	0.39	0.55	3.88	0.17	0.40	0.000409	0.086
08/2020	0.90	4.09	0.09	0.36	0.84	4.24	0.07	0.34	0.000451	0.157
09/2020	0.84	4.39	0.09	0.42	0.78	4.44	0.09	0.40	0.000411	0.150
<b>average</b>	<b>0.58</b>	<b>3.15</b>	<b>0.13</b>	<b>0.36</b>	<b>0.60</b>	<b>3.14</b>	<b>0.17</b>	<b>0.37</b>	<b>0.000374</b>	<b>0.085</b>
04/2021	0.36	2.92	0.28	0.82	0.41	2.55	0.30	0.86	0.000357	0.038
05/2021	0.38	2.52	0.27	0.71	0.39	2.37	0.29	0.74	0.000416	0.039
06/2021	0.71	4.25	0.24	1.05	0.61	5.56	0.26	1.08	0.000375	0.054
07/2021	0.79	4.08	0.09	0.50	0.57	3.95	0.09	0.49	0.000378	0.139
08/2021	0.88	4.03	0.05	0.35	0.74	4.32	0.04	0.34	0.000407	0.265
09/2021	0.85	4.85	0.05	0.20	0.55	4.09	0.04	0.19	0.000392	0.266
<b>average</b>	<b>0.66</b>	<b>3.77</b>	<b>0.16</b>	<b>0.60</b>	<b>0.54</b>	<b>3.80</b>	<b>0.17</b>	<b>0.62</b>	<b>0.000387</b>	<b>0.133</b>

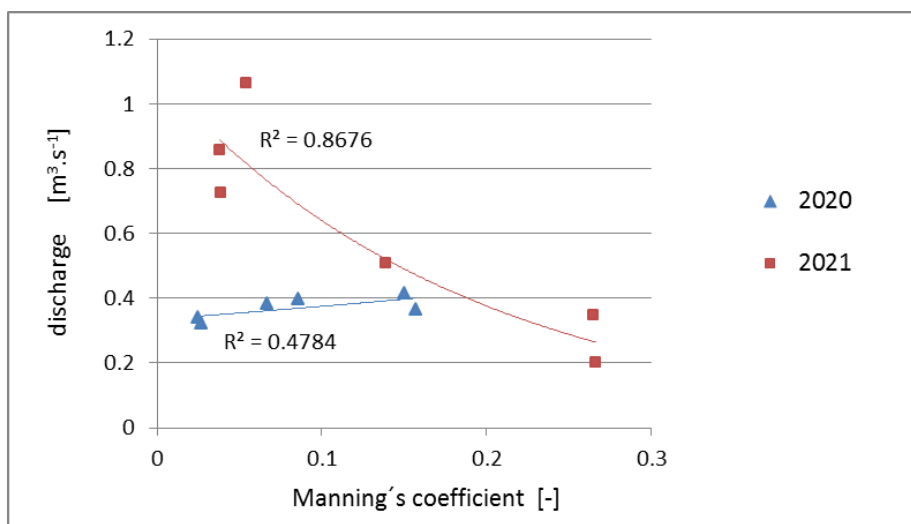


Fig. 3. Dependence between values of discharge and Manning's coefficient.

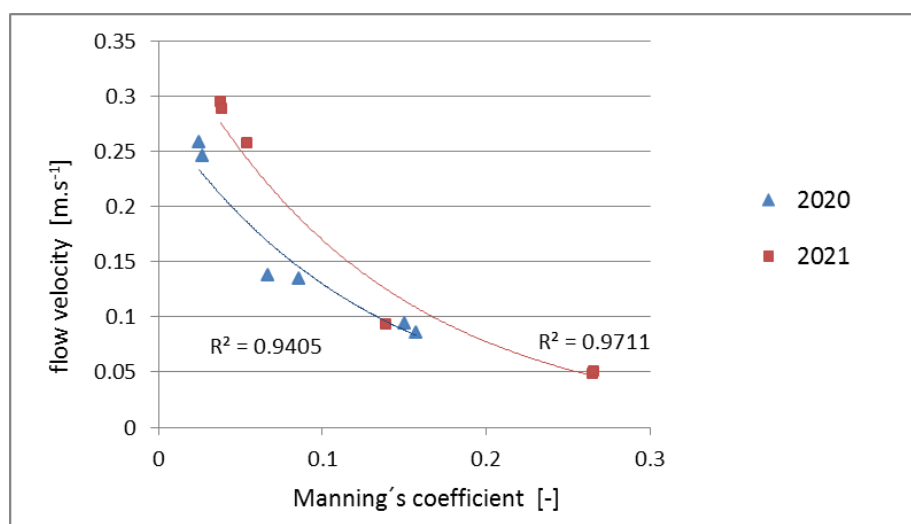


Fig. 4. Dependence between values of flow velocity and Manning's coefficient.

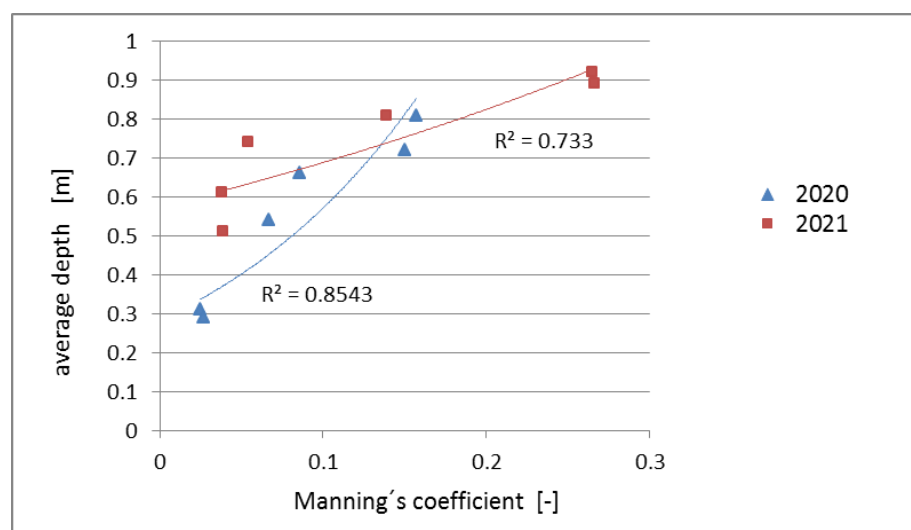


Fig. 5. Dependence between values of average depth and Manning's coefficient.



## Conclusion

Vegetation in natural streams influences the flow and related characteristics and phenomena, such as discharge capacity, velocity profile, roughness, but also erosion and sedimentation, pollutant transport and water biota. The aim of this paper was to investigate and determine the impact rate of aquatic vegetation on change of the Manning's coefficient, based on field measurements along the Malina stream.

The analysis of the obtained data shows increase values of the roughness coefficient during the vegetation period to a significant degree. More influence is manifested not exactly in the summer, but more in the end of this season or in the beginning of autumn. Value of flow velocity significantly decreases with increasing roughness coefficient value in growing season (when  $n$  increases 6–7 times, the velocity decreases 3–7 times, depending on other conditions that need to be analyzed in the future). In contrast, but logically, the water depth value and the discharge area increase with the roughness coefficient value, but not in such steep way. In general, the discharge value is also related to the value of Manning's roughness coefficient, but this dependence is not unambiguous.

Our measurements were carried out from April to September, but results show the necessity to extend this period, because evident weakening of vegetation influence was not observed. Anyway, analyses of measured data showed and confirmed the complexity of the impact of lowland river vegetation on flow condition, and the necessity to continue investigation of this problem.

## Acknowledgement

*This paper was prepared with the support of the project No. VEGA 2/0028/23.*

## References

- Allmendinger, N. E., Pizzuto, J. E., Potter, N., Johnson, T., Hession, W. C. (2005): The influence of riparian vegetation on stream width, Eastern Pennsylvania, USA. *Geol. Soc. Am. Bull.* 2005, 117, 229–243.
- Beeson, C. E., Doyle, P. F. (1995): Comparison of bank erosion at vegetated and non-vegetated channel bends. *Water Resour. Bull.* 1995, 31, 983–990.
- Boscolo, V. (2014): Effect of in-stream vegetation on hydraulic resistance in regulated rivers. Master thesis, Padova, Aberdeen, 2014, 117 p.
- Carlier d'Odeigne, O., Soares Frazao, S. (2016): Determination of bed roughness parameters from field survey: application to the Cavaillon River, Haiti. In: *International Conference on Fluvial Hydraulics*, 2016, 2262–2268. <http://hdl.handle.net/2078.1/183207>
- Carollo F. G., Ferro V., Termini D. (2002): Flow velocity measurements in vegetated channels. In: *Journal of Hydraulic Engineering*, vol. 128, no. 7, 2002, 664–673. ISSN 0733-9429
- Chow, V. T. (1959): *Open channel hydraulics*. McGraw-Hill, 1959.
- Čubánová, L., Šoltész, A., Mydla, J. (2022): Analysis of droughts due to the operation of water structures: Gidra river case study. *Pollack Periodica*. vol. 17, no.1, 2022, 111–116. ISSN: 1788-1994
- Dan, M., Wittenberg, L. (2007): Scaling the effects of riparian vegetation on cross-sectional characteristics of ephemeral mountain streams - A case study of Nahal Oren, Mt. Carmel, Israel. *CATENA* 2007, 69, 103–110.
- Demich, R. L. (2008): The effect of submerged aquatic vegetation on flow in irrigation canals. Dissertation thesis, Texas A&M University, 2008, 165 p.
- Franklin, P., Dunbar, M., Whitehead, P. (2008): Flow controls on lowland river macrophytes: A review. In: *Science of the Total Environment*, 2008, vol. 400, no. 1–3, 369–378. <https://doi.org/10.1016/j.scitotenv.2008.06.018>
- Huang, H. Q., Nanson, G. C. (1997): Vegetation and channel variation; a case study of four small streams in Southeastern Australia. *Geomorphology* 1997, 18, 237–249.
- Järvelä, J. (2004): Flow resistance in environmental channels: Focus on vegetation. Helsinki University of Technology, Espoo, 2004, 54 p. ISBN 951-22-7073-0.
- Kolář, V., Patočka, C., Bém, J. (1983): *Hydraulics*, Alfa, Prague, 474 p. (in Czech)
- Kováčová, V. (2022): Impacts of excessive nutrients load in aquatic ecosystems. In: *Acta Hydrologica Slovaca*, vol. 23, no. 1, 2022, 99–108. DOI: 10.31577/ahs-2022-0023.01.0011
- Li, Z. W., Yu, G. A., Brierley, G., Wang, Z. Y. (2016): Vegetative impacts upon bedload transport capacity and channel stability for differing alluvial planforms in the Yellow River source zone. *Hydrol. Earth Syst. Sci.* 2016, 20, 3013–3025.
- Maione, U., Monti, R., Romiti, R. (2000): Hydraulic drag in vegetated channels – A campaign investigation. In: Maione, U., Lehto, M. and Monti, R. (eds.). *Proceedings of an international conference New Trends in Water and Environmental Engineering for Safety and Life*. Balkema, Rotterdam.
- O'Hare, T. M., McGahey, C., Bisset, N., Cailes, C., Henville, P., Scarlett, P. (2010): Variability in roughness measurements for vegetated rivers near base flow, in England and Scotland. In: *Journal of Hydrology*, 2010, vol. 385, no. 1–4, 361–370. <https://doi.org/10.1016/j.jhydrol.2010.02.036>
- Okhravi, S., Gohari, S. (2020). Form friction factor of armored river beds. *Canadian Journal of Civil Engineering*, 47(11): 1238–1248.
- Oorschot, M. V., Kleinhans, M., Geerling, G., Middelkoop, H. (2016): Distinct patterns of interaction between vegetation and morphodynamics. *Earth Surf. Process. Landf.* 2016, 41, 791–808.
- Sellin, R. H. J., van Beesten, D. (2002): Berm vegetation and its effects on flow resistance in a two-stage river channel: an analysis of field data. In: Bousmar, D. and Zech, Y. (eds.). *River Flow 2002*. 319–327.
- SonTek, (2009): *FlowTracker Handheld ADV Technical Manual*, Firmware Version 3.7, Software Version 2.30 – SonTek/YSI, San Diego, p. 126, 2009.
- Stephan, U., Gutknecht, D. (2002): Hydraulic resistance of submerged flexible vegetation. In: *Journal of Hydrology*, vol. 269, no. 1–2, 27–43. [https://doi.org/10.1016/S0022-1694\(02\)00192-0](https://doi.org/10.1016/S0022-1694(02)00192-0)
- Stone, M. B., Shen, H. T. (2002): Hydraulic resistance of flow in channels with cylindrical roughness. In: *Journal of Hydraulic Engineering*, vol. 128, no. 5, 2002, 500–506.

- Thorne, C. R., (1990): Effects of vegetation on riverbank erosion and stability. In: *Vegetation and Erosion*; Thornes, J. B., Ed.; John Wiley: Chichester, UK, 1990; 125–143.
- Tuozzolo, S., Langhorst, T., de Moraes Frasson, R. P., Pavelsky, T., Durand, M., Schobelock, J. J. (2019): The impact of reach averaging Manning's equation for an in-situ dataset of water surface elevation, width and slope. In: *Journal of Hydrology*, vol. 578, 2019. <https://doi.org/10.1016/j.jhydrol.2019.06.038>
- Van de Lageweg, W. I., Van Dijk, W. M., Hoendervoogt, R., Kleinhans, M. G. (2010): Effects of riparian vegetation on experimental channel dynamics. In: *Proceedings of the International Conference on Fluvial Hydraulics River Flow*, Braunschweig, Germany, 8–10 September 2010; p. 2.
- Yang, S., Bai, Y., Xu, H. (2018): Experimental analysis of river evolution with riparian vegetation. In: *Water*, 2018, vol. 10, no. 11. <https://doi.org/10.3390/w10111500>.

Mgr. Radoslav Schügerl, PhD. (\*corresponding author, e-mail: [schugerl@uh.savba.sk](mailto:schugerl@uh.savba.sk))  
Ing. Yveta Velísková, PhD.  
Institute of Hydrology SAS  
Dúbravská cesta 9  
841 04 Bratislava  
Slovak Republic