

**EFFECT OF AQUATIC VEGETATION ON MANNING'S ROUGHNESS
COEFFICIENT VALUE – CASE STUDY AT THE ŠÚRSKY CHANNEL**

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Vegetation growing in the water along watercourses has been the subject of several studies since it was recognized that it could have a significant impact on the water flow. Increased bed roughness caused by aquatic vegetation is a very often phenomenon in case of flow in natural open channel during the growing season. Vegetation impedes the water flow and may increase flood risks. Thus, determining the effect of aquatic vegetation on flow conditions in streams is very important for estimation of hydrodynamics in natural streams. Occurrence of aquatic vegetation is more often in case of lowland streams. The purpose of this paper is to investigate and determine how aquatic vegetation influences flow resistance, water depth and discharge in the Šúrsky channel at the Podunajská lowland area. Measurements performed during three various times of year 2019 at this stream were used for an evaluation of vegetation impact on flow conditions in this stream. The Manning's coefficient was used as one way of quantifying this impact. The results show variation of this parameter during the winter and summer season.

KEY WORDS: aquatic vegetation, water-level, discharge, Manning's roughness coefficient

Introduction

Vegetation affects flow processes and by this way it affects hydraulics of streams and river management. Advances in understanding the behaviour of flow over vegetation allow us to improve both the knowledge of flow-velocity profiles and flow resistance (James et al., 2004; Cheng, 2011; Nehal et al., 2013; Nikora et al., 2008).

In natural streams conditions, the complexity is increased due to many factors: heterogeneity of plant species, difficulty in parameterization of plant characteristics, plant distribution within sections, three-dimensional effects due to side walls, seasonal variations etc. In natural environments, studies of the effect of vegetation have mainly focused on the influence on resistance (Green, 2005; 2006), which can be related to the blockage factor defined as the ratio of total frontal area of a vegetation to total area in the cross section profile.

Artificial water conveyance systems may be considered as intermediate media between laboratory flumes and natural streams as they generally have a regular shape (similar to laboratory flumes), but also present some of the complexity of natural stream, with the presence of natural and non-uniform vegetation. This vegetation may be composed of macrophytes, but smaller-size colonies present in open-channels, such as algal biofilms, may also affect velocity profiles.

For correct design or computation of discharge and water

level in an open channel, it is necessary to evaluate the channel resistance to flow, which is typically represented by a roughness parameter, such as Manning's n (Velísková et al., 2017). Its determination is not easy for natural streams, because the characteristics of channels and the factors that affect channel capacity can vary greatly; furthermore, the combinations of these factors are numerous. Therefore, the selection of roughness for natural and constructed channels is often based on field judgment and personal skill, which are acquired mainly through experience. Determination of the roughness coefficient n , according to a seasonal variation, is an important tool in hydraulic modelling (De Doncker et al. 2009; Korichi and Hazzab 2012).

The aim of this contribution is to demonstrate, on the basis of results from experimental field measurements along the Šúrsky channel (Slovakia), how overgrowing of the stream by aquatic vegetation affects the flow conditions and capacity of the stream.

Theoretical background

Resistance accounts for the (boundary) turbulence caused by surface properties, geometrical boundaries, obstructions and other factors causing energy losses. Therefore, a resistance coefficient reflects the dynamic behaviour in terms of momentum or energy losses in resisting the flow of the water.

Roughness reflects the influence of the surface on

the momentum and energy dissipation in resisting the flow of the water. Therefore, with a roughness factor the actual or effective unevenness of the boundary surface is meant.

We know several ways how to describe the resistance of vegetation - ranging from simple roughness descriptions to descriptions that take into account various vegetation characteristics. In addition we know new approaches for describing the resistance of vegetation, mainly for flexible submerged vegetation (Kutija and Hong, 1996; Stone and Shen, 2002; Wilson, 2007).

In general, hydraulic models for open channel flow are based on the Saint-Venant equations. These equations (continuity equation and momentum equation) are the one dimensional simplification of the Navier Stokes equations, which describe fluid flow in three dimensions. In simple general form, the discharge in a stream cross section is given as discharge cross-sectional area multiplied by mean flow velocity.

Relationships for determination of mean flow velocity in natural open channels can be found in literature as:

$$\text{Chézy's equation:} \quad v = C \sqrt{R i_o} \quad (1)$$

$$\text{Darcy-Weisbach's equation:} \quad v = \sqrt{\frac{8g}{f}} \sqrt{R i_o} \quad (2)$$

$$\text{Manning's equation:} \quad v = \frac{1}{n} R^{2/3} i_o^{1/2} \quad (3)$$

or other ones, where

v – mean flow velocity [m s^{-1}],

R – hydraulic radius [m],

i_o – water level slope,

C – Chézy's coefficient [$\text{m}^{1/2} \text{s}^{-1}$], $C = (1/n) \cdot R^y$,

n – Manning's roughness coefficient [$\text{xm}^{-1/3} \text{s}$],

f – Darcy-Weisbach's friction factor,

g – gravity acceleration [m s^{-2}].

Manning's equation is the limit form of the Chézy's formula and it is the most widely used equation among these. Although it expresses the resistance at the reach scale and reflects only the influence of the boundary shear on flow depth and averaged velocity, Manning's coefficient n is often used as a summarizing parameter accounting for all the various influences in a river reach. Theoretical calculation of the Manning coefficient n is difficult. It is commonly estimated through experience from simple verbal or photograph descriptions of channels and their table values. In case of natural channel bed with various roughness parts (sand, gravel, grass, brushwood, etc.) in a cross-section profile, there is used following the relation:

$$\bar{n} = \frac{\sum_{i=1}^k (n_i P_i)}{P} \quad (4)$$

where

P – wetted perimeter [m].

It might also be determined by empirical formula, which splitted channel resistance into several parts, including

the bed material, presence of vegetation in the river, meandering, etc.:

$$n = (n_0 + n_1 + n_2 + n_3 + n_4) \cdot m \quad (5)$$

where

n_0 – basic value, for a straight, uniform channel,

n_1 – irregularities of the bottom,

n_2 – variations in the geometry of the channel,

n_3 – obstacles,

n_4 – vegetation,

m – correction factor for meandering.

The determination of spatial parameters of a stream, such as the discharge area, stream bed slope, wetted perimeter and hydraulic radius, is quite easy, but the stream bed roughness assessment could be a problem. During a year, the various degrees of in-channel sprouting could be found and usually the different kinds of water plants grow up in stream cross-section profiles. The extension of aquatic vegetation depends mainly on flow velocities, longitudinal slope, but also on the water temperature and nutrient content. The height of the vegetation with respect to the water level is important in describing vegetation resistance, because it influences the flow velocity profile (Velísková et al., 2017).

There are many vegetation characteristics that affect the hydraulic resistance in overgrown channels. The first important vegetation characteristic that affects the flow resistance is the geometry of the vegetation itself, concerning the taxonomy of the species as the branching index, the density of the shoots, the maximum level of growth that each species can reach in a cross section and the seasonal presence of the plant. In addition to this, there is a hydraulic parameter which considers the characteristic dimension of the vegetation in relation to flow conditions.

So, it is clear that determination of correct value of the Manning's roughness coefficient in natural open channel is not easy. Determination of n value is very complex task, but by calculation from the discharge and the water levels along the river reach with steady uniform flow condition and with applying of the Saint-Venant equations, it is possible to calibrate the roughness of the channel (expressed by the roughness coefficient or friction factor) by comparing with field measured data:

$$n = \frac{A \cdot R^{2/3} i_o^{0.5}}{Q} \quad (6)$$

where

A – discharge area [m^2],

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

Material and methods

Field measurements, related to the investigation of aquatic vegetation impact on flow in a lowland stream, were performed along the Šúrsky channel at the Podunajská lowland. The Šúrsky channel flows through the territory of the Pezinok and the Senec town district. It is a left tributary of the Malý Dunaj river and it is 16.95 km long.

Four observing cross-section profiles were selected along the Šúrsky channel, their locations are shown in Fig. 1. Measurements were carried out in two sections: the first section with distance 3620 meters (from bridge profile to Račiansky stream profile / upstream) and the second section with distance 2150 meters (from Račiansky stream profile / downstream to speedway profile). Cross-section profiles parameters – channel width, distribution of water depth along the width of a cross-section profile (by levelling device), discharges and velocity distribution along the width of cross-section profile (by ADV – Acoustic Doppler Velocimeter device Flow Tracker) were measured. Measurements were performed in the channel segments with steady uniform flow conditions. Field measurements were done in February and during summer time (June and August), thereby we try to detect if any changes occur in these different periods of the growing season.

Results and discussion

As it was mentioned, there exists a number of ways how to evaluate the influence of aquatic vegetation on flow in lowland streams. Quantification of the impact of aquatic vegetation through the calibration of roughness coefficient on base of field measurement data is one of the practically suitable methods. This roughness coefficient represents an actual parameter influencing discharge capacity of streams. Ranges of measured data from each measurement campaign are summarized in Table 1 (for section 1 from the bridge profile to the Račiansky stream profile/upstream) and Table 2 (for section 2 from the Račiansky stream profile/downstream to the speedway profile). Tables contain data on the mean flow velocity (v), discharge area (A), wetted perimeter (P), hydraulic radius (R), water level change (Δh), water level slope (i_o) and determined Manning's roughness coefficient (n).

The roughness coefficient value in the sprouted stream bed 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. For example, in the season of observation, the differences of n values along the channel varied in the most extensive range (0.051–0.203) for the first section, for the second section the differences of n values along the channel varied in the most extensive range (0.055–0.300).

Aquatic vegetation recording by means of camera during the year 2019 (February vs. June vs. August) are shown in Fig. 4, 5 and 6 (the bridge profile and the Račiansky stream profile/downstream). The mean flow velocity values decrease with increasing roughness coefficient and there are lower during the summer season than during winter for the same discharge sub-range.

By Chow (1959), the values of the Manning's roughness coefficient for overgrown - not maintained channel with dense aquatic vegetation higher than flow depth is from 0.050 to 0.120 or with shrubby vegetation is from 0.080 to 0.140. In our case the calculated values of n are higher, mainly during the summer season.

Changes of discharge and water-level during the experimental time in 2019 for section 1 (from the bridge profile to the Račiansky stream profile / upstream) and section 2 (from the Račiansky stream profile / downstream to the speedway profile) are shown in Fig. 2 and Fig. 3 and Table 3. The results show, that when there is recorded the biggest discharge value, the water-level value is the smallest one (for all measured cross-section profile). On the other side, when the discharge value is the smallest one, water-level value is not the biggest.

Fig. 4, Fig. 5 and Fig. 6 illustrate aquatic vegetation growing situation in the Šúrsky channel during the experiments time in 2019 (for the bridge profile and the Račiansky stream profile / upstream).

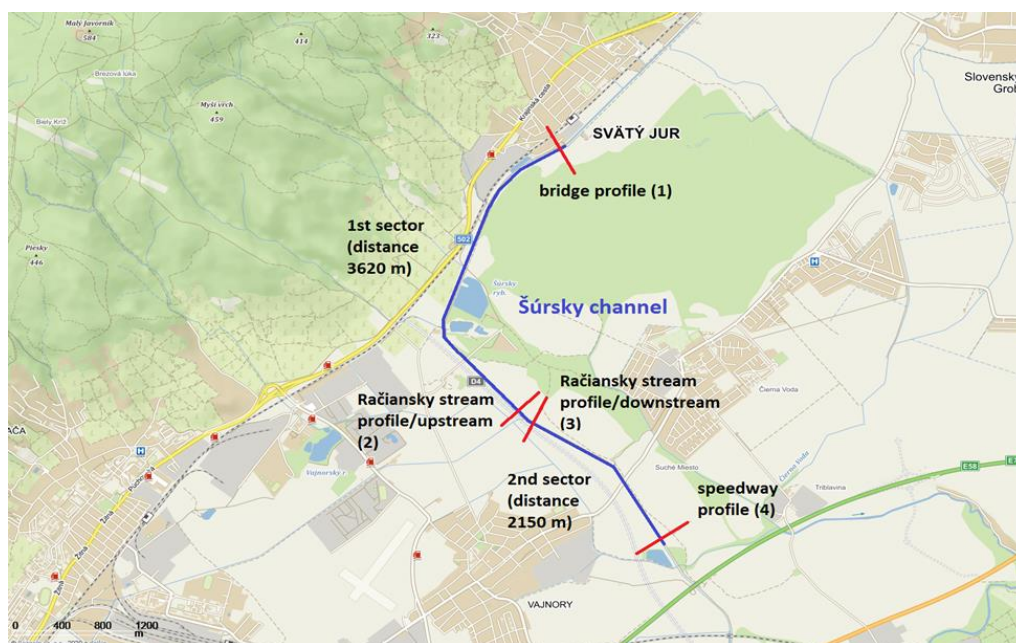


Fig. 1. Location of observing cross-section profiles along the Šúrsky channel.

Table 1. Summary of measured and calculated data of the first experiment section (from the bridge profile to the Račiansky stream profile/upstream)

Date of measur.	bridge profile				Račiansky stream profile (upstream)				Δh [m]	i_0	n
	$v[m\ s^{-1}]$	$A[m^2]$	P [m]	R [m]	$v[m\ s^{-1}]$	$A[m^2]$	P [m]	R [m]			
02/2019	0.317	0.608	4.75	0.129	0.212	1.805	5.15	0.350	1.749	0.000483	0.051
06/2019	0.198	0.432	4.50	0.096	0.050	1.955	5.60	0.349	1.520	0.000419	0.203
08/2019	0.105	0.58	4.40	0.131	0.064	2.335	5.75	0.355	1.594	0.000441	0.179

Table 2. Summary of measured and calculated data of the second experiment section [from the Račiansky stream profile/downstream to the speedway profile]

Date of measur.	Račiansky stream profile (downstream)				speedway profile				Δh [m]	i_0	n
	$v[m\ s^{-1}]$	$A[m^2]$	P [m]	R [m]	$v[m\ s^{-1}]$	$A[m^2]$	P [m]	R [m]			
02/2019	0.208	1.563	5.15	0.304	0.136	2.715	9.20	0.295	0.633	0.000294	0.055
06/2019	0.037	2.578	5.90	0.436	0.029	3.127	9.85	0.317	0.707	0.000328	0.300
08/2019	0.054	1.618	6.55	0.247	0.046	3.042	10.10	0.301	0.770	0.000351	0.223

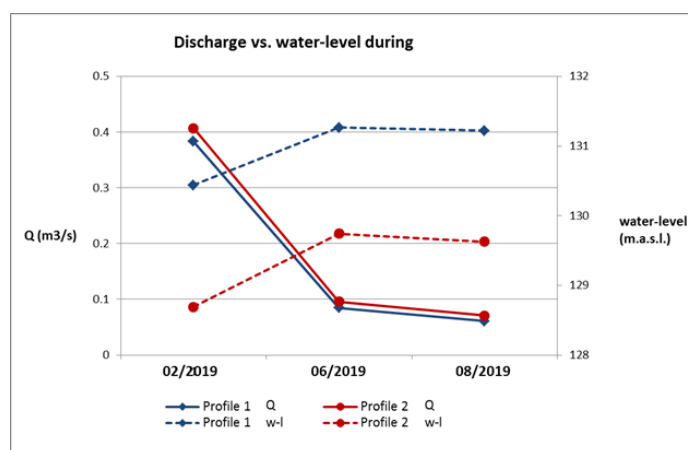
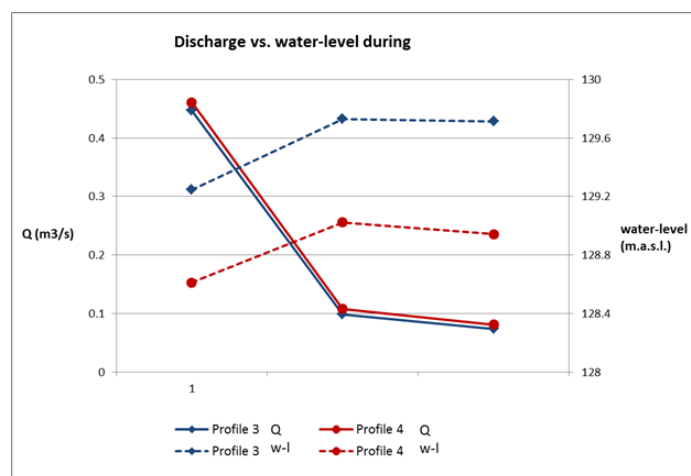
*Fig. 2.* Changes of discharge and water-level in the Šúrsky channel during the experiment time – section 1.*Fig. 3.* Changes of discharge and water-level in the Šúrsky channel during the experiment time – section 2.

Table 3. Summary of measured data on the discharge and water-level in four cross-section profiles (profile 1 – the bridge profile, profile 2 – the Račiansky stream profile / upstream, profile 3 – the Račiansky stream profile / downstream, profile 4 – the speedway profile)

Date of measur.	profile 1		profile 2		profile 3		profile 4	
	Q [m ³ s ⁻¹]	w-l [m a.s.l.]	Q [m ³ s ⁻¹]	w-l [m a.s.l.]	Q [m ³ s ⁻¹]	w-l [m a.s.l.]	Q [m ³ s ⁻¹]	w-l [m a.s.l.]
02/2019	0.383	130.439	0.407	128.690	0.477	129.246	0.461	128.613
06/2019	0.085	131.265	0.096	129.745	0.099	129.730	0.108	129.023
08/2019	0.061	131.222	0.071	129.628	0.072	129.713	0.081	128.943



Fig. 4. Aquatic vegetation in the Šúrsky channel during February 2019 – profile (1) and profile (3).



Fig. 5. Aquatic vegetation in the Šúrsky channel during February 2019 – profile (1) and profile (3).



Fig. 6. Aquatic vegetation in the Šúrsky channel during August 2019 – profile (1) and profile (3).

Conclusions

Vegetation in natural streams influences the flow field 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 flow conditions, based on field measurements along the Šúrsky channel during the year 2019. The roughness coefficient n was used as a way of quantifying this impact.

An analysis of the obtained data revealed that the roughness coefficient value changes mainly during the growing season. Results of measurements showed and confirmed that consequence of vegetation growth in the channel is the change of velocity profile and water level in comparison with discharge amount. The analyses of measured data showed and confirmed the complexity of the impact of in-channel vegetation on stream flow and despite obtaining important database of roughness coefficient value for the Šúrsky channel the necessity to continue investigation of this problem.

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