ARPHA Proceedings

*Proceedings CAUSummit 2024, 0184-0189*
*doi: 10.3897/ap.7.e0184*

World Summit: Civil Engineering-Architecture-Urban Planning Congress

# Evaluation of the Effect of Aquatic Vegetation on the Accuracy of ADCP Discharge Measurements in Lowland Streams

Valentín Sočuvka[1, a)], Saeid Okhravi[1], Yvetta Velísková[1], Radoslav Schügerl[1], Renáta Dulovičová[1]

[1] *Institute of Hydrology, Slovak Academy of Sciences, Dúbravská cesta 9, 84104, Bratislava, Slovak Republic*

[a)] Corresponding author: socuvka@uh.savba.sk

**Abstract.** Discharge dynamics in natural streams can be influenced by aquatic vegetation, therefore its precise evaluation is crucial for effective river management especially in lowland environments. This paper investigates the accuracy of discharge measurements in lowland natural streams with aquatic vegetation using an Acoustic Doppler Current Profiler (ADCP). The research highlights the challenges and issues of using ADCP in areas with aquatic vegetation, which cause measurement inaccuracies and deviations in the measuring sections. Field measurements carried out on the Gabčíkovo – Topoľníky canal stream during the growing seasons of 2018 and 2023 recorded differences in accuracy and calculated discharges and flow velocity attributes due to denser vegetation.

**Keywords:** ADCP, aquatic vegetation, lowland streams, discharge area, field measurement


Published by CAUSummit and peer-reviewed under the responsibility of "World Summit: Civil Engineering-Architecture-Urban Planning Congress - CAUSummit-2024".

## INTRODUCTION

Correctly determining discharge and streamwise velocity provides crucial information for the field of engineering hydrology, which generally deals with the assessment of watercourses, flood management, design of water structures (such as dams, reservoirs, drainage systems), their maintenance, as well as the protection of water resources and the environment from the negative impacts of water phenomena. Today, various tools and methods exist for field measurement of flow velocity in both laboratory conditions and natural water bodies. The selection of the appropriate method depends on several factors, including water depth, range of water flow velocity, water quality, presence of obstacles in the streams (fallen trees, aquatic plants, etc.), and ultimately on the availability and capabilities of human resources. Each measurement method is associated with a certain measurement deviation. Common practice in hydraulic experiments is to determine the uncertainty interval, within which it is assumed that the actual measured value lies [1]. Currently, methods utilizing the Doppler principle are mainly used for measuring water flow velocity. They work on the principle of emitting ultrasonic pulses into moving water, which naturally contains suspended particles from which these acoustic pulses are subsequently reflected. This method allows for the measurement of cross section geometry as well as flow velocity within the measurement profile. Subsequently, using the continuity equation, it is possible to calculate the discharge. Although ADCP measurements offer significantly better accuracy and time efficiency compared to traditional methods, they still contain certain limitations and sources of uncertainty. Sources of uncertainties in ADCP measurements and related strategies to reduce these uncertainties were discussed in the article [2]. In addition, aspects of choosing a suitable location for the measurement profile are also discussed in the literature [3]. Natural component of many lowland river ecosystems is aquatic vegetation, which can be characterized as a significant source of uncertainty. Aquatic vegetation in natural channels significantly affects the dynamics of the river system, increasing the local resistance as well as the marginal flow resistance in the riverbed and, as a result, reducing the average flow velocity [4]. This study deals with the influence of submerged plants in the stream bed as well as plants above the water surface located mainly near the shoreline. The influence of these plants on the flow velocity was evaluated as well as their effect on changes in stream flow and sedimentation over the years.

## MATERIAL AND METHODS

Field measurements were carried out on the Gabčíkovo – Topoľníky canal, which is one of the main canals in the canal network in the area of Žitný ostrov (Rey Island).This area is part of the Danubian Lowland. It is located in the territory of Slovakia, between the Danube river and the Little Danube river (Fig. 1). The area of Žitný ostrov consists of a flat plain with only small differences in altitude. Due to its favorable climate, soil and morphological conditions, it is one of the most productive agricultural areas in Slovakia. However, the presence of aquatic vegetation in the canal network is a significant problem. The primary factor influencing the presence of aquatic vegetation is the small gradient of the terrain, which results in a slow water flow, as well as the application of fertilizers in the surrounding area. This leads to the settling of carried particles in the stream, subsequently increasing the thickness of sediments at the bottom and enhancing conditions for the growth of aquatic vegetation. These aspects affect the hydrodynamic conditions in the bed as well as the conditions and possibilities of determining the correct value of the basic hydraulic parameters.

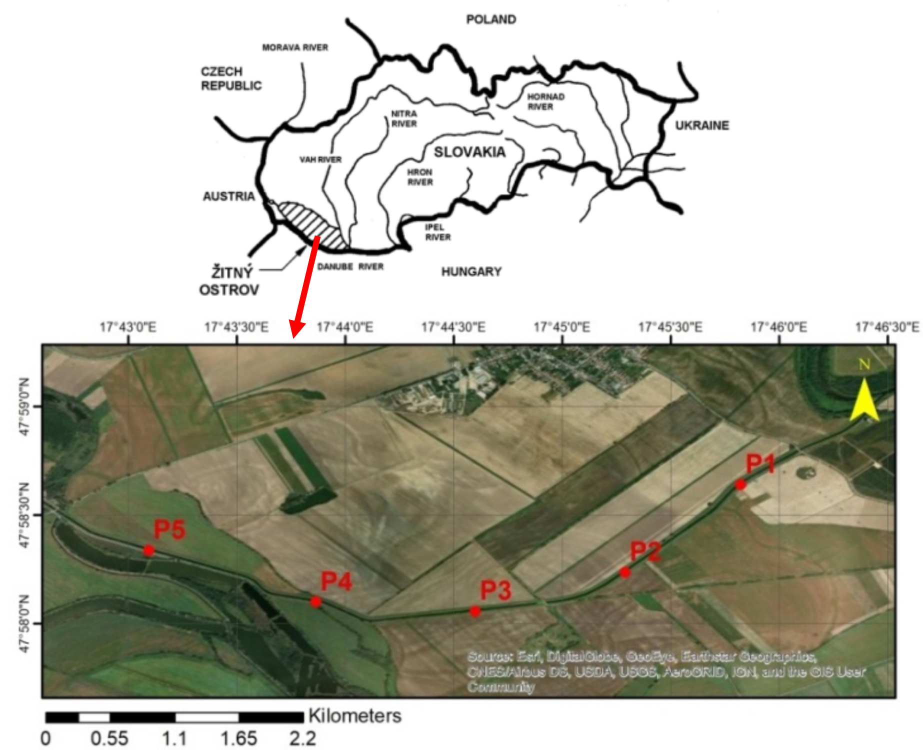


**FIGURE 1.** Gabčíkovo – Topoľníky canal, Žitný ostrov, Danube Lowland

Field surveys were conducted in the May 2018 (start of vegetation season) & July 2023 (high vegetation season) to assess the canal's bathymetry, sediment thickness and calculate flow velocity and discharge. The measurements were conducted manually and with the ADCP SonTek RiverSurveyor M9. Manual measurements involved using a boat and a dual rod system: one rod fixed in a plastic disc to gauge water depth, while the other, movable rod for measured sediment thickness (Fig. 2a). Data were collected at 1 meter intervals across the canal's width.

(a) (b)

**FIGURE 2.** Field surveys on Gabčíkovo – Topoľníky canal using manual method (a) and ADCP method (b).

The ADCP device utilized for this study was the SonTek RiverSurveyor M9, a multi-frequency ADCP consisting of 4 beams operating at 1 MHz, 4 beams operating at 3 MHz, and vertical beam operating at 0.5 MHz. (Fig. 2b). Based on the current site conditions, a built-in algorithm, SmartPulseHD, automatically determines the appropriate acoustic pulse scheme at which the transducers emit and collect signals [5].

## DATA POSTPROCESSING AND RESULTS

ADCP data were post processed using SonTek RiverSurveyorLive PC software. Parameters such as transducer depth, screening distance, magnetic declination, and GPS quality were verified. Cell screening was applied to eliminate bins with signal to noise ratios below 1 dB. The River Surveyor M9 provides two options for depth reference: Vertical Beam (VB), utilizing the echo sounder at 0.5 MHz or Bottom Track (BT), which determines water column depth by averaging the depth data from the four angled beams. These options are both available for analysis or for recalculating discharge during post-processing (River Surveyor S5/M9 System Manual, 2022). Firstly, both the VB and BT data were exported in ASCII format and compared with data from manual survey (Fig.3).

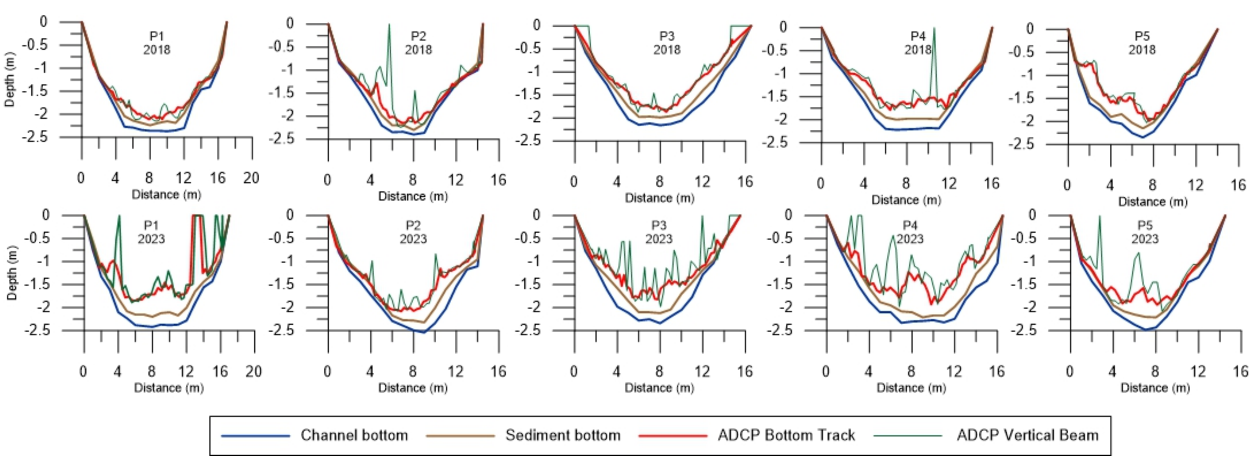


**FIGURE 3.** Comparison of cross-sectional profiles measured using various methods in May 2018 and July 2023.

The presence of aquatic vegetation in the canal may result in invalid depth detection or the inability to lock onto depth, especially for the vertical beam option. In the case of the Gabčíkovo – Topoľníky canal, the occurrence of aquatic vegetation exacerbates such problems. For this reason, we aim to evaluate the degree of inaccuracy by comparing the results of manual measurements with those obtained using the River Surveyor, utilizing both methods (VB, BT) provided by this device. Discharge area value was calculated as the sum of the partial areas between the measured verticals:

$$A_D = \sum_{i=1}^{n} A_{D_i} \tag{1}$$

where
$A_D$ – a discharge area of a cross-section profile [m$^2$],
n – number of partial areas,
$A_{Di}$ – a partial discharge area between the measured verticals [m$^2$]:

$$A_{D_i} = x_i\,(V_L + V_R)/2 \tag{2}$$

where
$V_L$ – a value of the left vertical [m],
$V_R$ – a value of the right vertical [m],
$x_i$ – a distance between measured verticals [m].

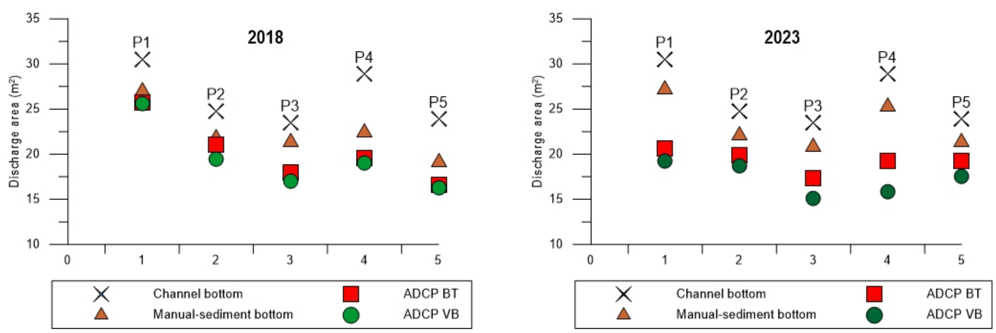


**FIGURE 4.** Discharge area values calculated by various methods in May 2018 and July 2023.

The discharge area values computed for 2018 and 2023 are graphically represented in Figure 4. Discharge area values derived from ADCP measurements are lower compared to manual measurements because of either blanking near the transducer face, side-lobe interference near the canal bed as well as due the presence of aquatic vegetation. While this aquatic vegetation has minimal effect on manual measurements, its impact on ADCP data is considerable. The differences between the manual and ADCP methods were particularly noticeable in 2023, primarily because of the differing measurement dates and levels of aquatic vegetation coverage. In 2018, at the beginning of the growing season, the differences between vertical beam and bottom track were insignificant. However, in 2023, nearly every profile was affected by aquatic vegetation. The most significant differences in calculated discharge were observed on profiles P3 and P4 in 2023 as shown in Fig 3.

Based on the analysis of the calculated discharge areas and comparison with manual measurements, it was concluded that utilizing the "bottom track" function to determine the average depth is more suitable for further data processing. Processed files were then exported using SonTek RiverSurveyorLive PC software in Matlab format for further analysis using the Velocity Mapping Toolbox (VMT v4.09). This tool provided by the USGS combines individual ADCP traverses into spatiotemporal averages. The toolbox can average and smooth bathymetric and flow structure data of multiple cross-sections transects into a single representative cross-section. Transects in the VMT were processed with a horizontal and vertical grid node spacing of 0.50m and 0.05m, respectively, to average out turbulence fluctuations and more readily discern patterns of fluid motion [6]. The setup of the VMT remained consistent for each dataset, ensuring that any variations in the flow structure observed could not be attributed to different configurations.

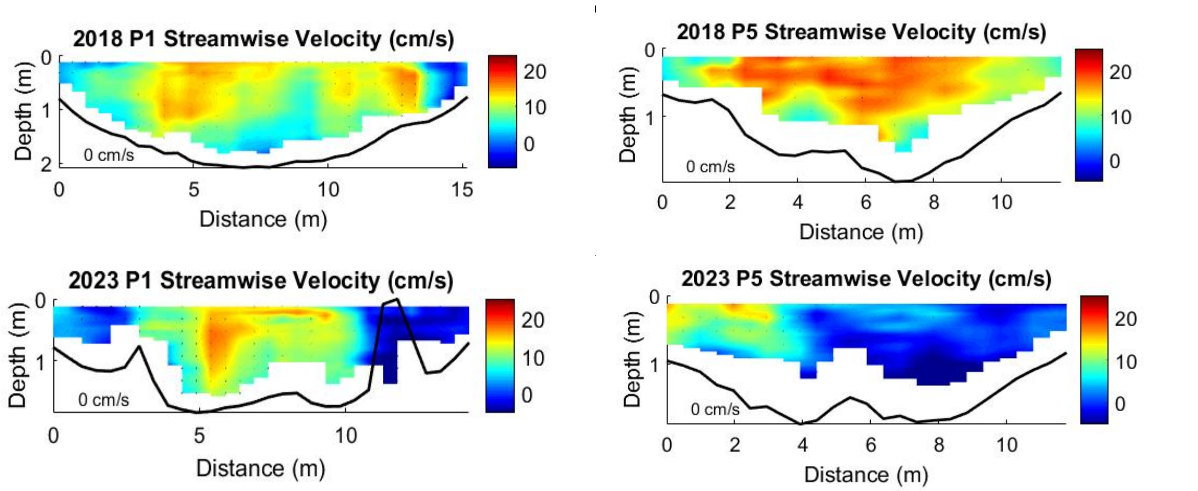


**FIGURE 5.** Cross-sectional plot of flow structures for the same profiles in May 2018 and July 2023. The color map represents the primary flow (looking downstream) in cm/s.

As depicted in Figure 5, the accurate detection of depth in the measured cross-section profile using the ADCP significantly decreased in 2023 due to the influence of aquatic vegetation. Simultaneously, the current streamwise velocity was notably reduced due to the increasing aquatic vegetation, and there was a change in the distribution the highest streamwise velocity.

Further analysis of the bathymetric data and the distribution of streamwise velocity were carried out to investigate changes in sediment storage across the reach over time. The most relevant measured and calculated hydraulic parameters for the corresponding years are summarized in Tables 1 and 2. The relevant parameters are: flow depth $h$, river width $w$, wetted area $A$ and perimeter $P$, water slope $S_f$, flow velocity $u$, shear velocity $u_*$, discharge $Q$, area of fine sediment $A_s$, Forude number Fr, and Manning coefficients $n$.

**TABLE 1.** Hydraulic parameters for five selected cross-sections: May 2018 measurements

| Name | $h$ (m) | $w$ (m) | $A$ (m$^2$) | $P$ (m) | $R$ (m) | $S_f$ | $u$ (m/s) | $u_*$ (m/s) | $Q$ (m$^3$/s) | $A_s$ (m$^2$) | Fr | $n_m$ | $n_r$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | 1.49 | 16 | 22.41 | 18.73 | 1.20 | 0.000038 | 0.120 | 0.021 | 1.88 | 2.73 | 0.035 | 0.08 | 0.07 |
| P2 | 1.41 | 16.5 | 21.36 | 19.1 | 1.12 | 0.000014 | 0.115 | 0.012 | 1.90 | 2.54 | 0.035 | 0.04 | 0.04 |
| P3 | 1.57 | 14.5 | 21.77 | 17.85 | 1.22 | 0.000016 | 0.103 | 0.014 | 1.93 | 1.75 | 0.03 | 0.05 | 0.04 |
| P4 | 1.76 | 17 | 27.03 | 20.13 | 1.34 | 0.000053 | 0.090 | 0.026 | 2.00 | 2.47 | 0.025 | 0.12 | 0.10 |
| P5 | 1.57 | 14.0 | 19.17 | 16.94 | 1.13 | 0.000044 | 0.123 | 0.022 | 1.82 | 2.1 | 0.037 | 0.076 | 0.06 |

**TABLE 2.** Hydraulic parameters for five selected cross-sections: June 2023 measurements

| Name | $h$ (m) | $w$ (m) | $A$ (m$^2$) | $P$ (m) | $R$ (m) | $S_f$ | $u$ (m/s) | $u_*$ (m/s) | $Q$ (m$^3$/s) | $A_s$ (m$^2$) | Fr | $n_m$ | $n_r$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | 1.59 | 16.5 | 25.25 | 19.40 | 1.30 | 0.000092 | 0.062 | 0.034 | 1.39 | 3.62 | 0.017 | 0.21 | 0.17 |
| P2 | 1.48 | 15.5 | 20.86 | 18.35 | 1.14 | 0.000057 | 0.061 | 0.025 | 1.31 | 2.62 | 0.018 | 0.13 | 0.11 |
| P3 | 1.60 | 14.5 | 22.15 | 17.89 | 1.24 | 0.000066 | 0.064 | 0.028 | 1.69 | 2.62 | 0.018 | 0.12 | 0.10 |
| P4 | 1.70 | 17.0 | 27.23 | 20.14 | 1.35 | 0.000043 | 0.044 | 0.023 | 1.47 | 3.27 | 0.012 | 0.15 | 0.12 |
| P5 | 1.63 | 14.50 | 21.40 | 17.60 | 1.22 | 0.000195 | 0.049 | 0.048 | 1.88 | 2.47 | 0.014 | 0.18 | 0.15 |

The results showed that a decrease in total discharge and section-averaged velocity in 2023. Moreover, the calculated discharge values in 2023 fluctuate significantly compared to those in 2018. It is primarily attributed to denser vegetation in 2023 compared to 2018, where cross sectional geometric shapes maintained almost unchanged along the canal reach (Fr and R remained nearly constant for each corresponding section). This resulted in a reduction in the Manning values $n_m$ and the one $n_r$ developed under the former research work of the coauthors and which are describe and discussed in [7].

## CONCLUSION

This study explored the impact of aquatic vegetation on the accuracy of ADCP discharge measurements in lowland streams. Two ADCP depth reference methods (VB, BT) were examined for evaluating water depth. The presence of aquatic vegetation significantly influences the accuracy of measurements compared to manual measurement, particularly in densely vegetated areas. The ADCP method remains the most effective approach for discharge measurements, particularly under specific conditions such as great depths or flood flows. However, attention to limitations and correct positioning of measurement locations is essential to minimize measurement inaccuracies. To achieve higher accuracy, it would be advised to repeat measurements at shorter intervals (especially during growing season) as well as in shorter distance between cross section. This approach would not only enable obtaining more reliable data, but also support hydrodynamic modeling of the flow regime in the given location. Based on the USGS recommendation, the minimum exposure time using an ADCP device should not be less than 720 seconds, with a measurement deviation of less than 5 percent. In ADCP applications the exposure time is defined as the total time of measurement. In most cases this exposure time is taken to be the total time that an ADCP measures perpendicular to the flow direction while moving across a canal [8]. Another option to gain a better understanding of changes in streamwise velocity resulting from the presence of aquatic vegetation in the stream could involve integrating ADCP data with the use of Unmanned Aerial Vehicles (UAVs) to capture actual orthophoto images or utilizing LiDAR detection of the area of interest. This approach would entail assessing the area and level of aquatic vegetation growth near the shoreline as well as in the stream.

## ACKNOWLEDGMENTS

This work was supported by the contracts No. VEGA 2/0140/24, VEGA 2/0028/23 and by the contract No. APVV-22-0610.

## REFERENCES

1. M. Muste, D.A. Lyn, D. Admiraal, R. Ettema, V. Nikora, M.H. García. "Experimental hydraulics: Methods, instrumentation, data processing and management: Volume I: Fundamentals and methods". CRC Press. 496 pp. ISBN 978-1-138-03816-5, (2017).
2. J. A. Boldt, K. A. Oberg. "Validation of streamflow measurements made with M9 and RiverRay acoustic Doppler current profilers". Journal of Hydraulic Engineering, 142(2), 04015054. (2015).
3. R. J. Bialik, M. Karpinski, A. Rajwa. "Discharge measurements in lowland rivers: field comparison between an electromagnetic open channel flow meter (EOCFM) and an acoustic doppler current profiler (ADCP)". GeoPlanet: Earth and Planetary Sciences: Achievements, History and Challenges in Geophysics: 60th Anniversary of the Institute of Geophysics, Polish Academy of Sciences. pp 213–222. doi:10.1007/978-3-319-07599-0_12, (2014)
4. K. Flynn, M. Asce, S. Chapra, F. Asce. "Evaluating Hydraulic Habitat Suitability of Filamentous Algae Using an Unmanned Aerial Vehicle and Acoustic Doppler Current Profiler". Journal of Environmental Engineering. 146. 04019126. 10.1061/(ASCE)EE.1943-7870.0001616, (2020).
5. Sontek - RiverSurveyor S5/M9 System Manual Firmware Version 4.02 (2022).
6. D. R Parsons, P.R. Jackson, J.A. Czuba, F. L. Engel, B. L. Rhoads, K. A. Oberg, J. L. Best, D. S. Mueller, K. K. Johnson, J. D. Riley. "Velocity Mapping Toolbox (VMT): A processing and visualization suite for moving-vessel ADCP measurements." Earth Surf. Process Landforms 38 (11): 1244–1260. (2013).
7. S. Okhravi, R. Schügerl, Y. Velísková. "Flow resistance in lowland rivers impacted by distributed aquatic vegetation". Water Resour Management., 36(7), 2257-2273, (2022).

M. R. Klema, A. G. Pirzado, S. K. Venayagamoorthy, T. K. Gates. "Analysis of acoustic Doppler current profiler mean velocity measurements in shallow flows". Flow Measurement and Instrumentation, Volume 74, 101755, ISSN 0955-5986, (2020)