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Impact of selected sampling method on resulting value of discharge area in a lowland stream with aquatic vegetation

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Hydrodynamic as well as balance analysis of flow or discharge conditions in surface streams cannot be done without knowledge of the basic hydraulic parameters of the flow. These are, for example, the bathymetry of the water body, the distribution of velocities in the transverse and longitudinal directions, roughness, etc. To determine the value of discharge in a given cross section profile, it is necessary to know the discharge area and the velocity profile. There are several devices and methods for measuring these quantities. Recently, devices based on the application of the Doppler principle are increasingly being used to determine velocity profiles and discharges in field conditions. In ideal conditions, the use of such devices is very effective, but in the case of the presence of aquatic vegetation below the water surface, a problem may arise. The paper analyses the accuracy of determining the discharge area in a lowland stream with a small longitudinal slope with the presence of aquatic vegetation using the Acoustic Doppler Current Profiler (ADCP) device (River Surveyor, SonTek/a Xylem brand). The results of the analysis show that for such cases, this method shows limitations, the extent of which depends on the used sub-method (Bottom Track or Vertical Beam), as well as on the amount of aquatic vegetation below the water surface.

KEY WORDS: discharge area, field measurement, ADCP, bathymetry, lowland stream, aquatic vegetation

Introduction

Measurements or determination of stream discharges have an irreplaceable role in solving a wide range of tasks in water management and engineering hydrology. This kind of data are essential for water management authorities who need to know how much water they can manage and how, for ecologists who try to maintain rivers in a good ecological state, for civil engineers who design various engineering structures (e.g., bridges, dams, flood protection), as well as for hydrologists who analyse the records to better understand runoff generation processes (Almikaeel et al., 2022; Halmová et al., 2022; Almikaeel et al., 2023; Sabová and Kohnová, 2023). Today, there are various instruments and methods for field measurements of discharge value in natural water bodies. Anyway, the right choice of used methods or instruments depends on a number of factors, such as the water depth and velocity range, the water quality, the presence of obstacles in a flowing water (fallen trees, structures, aquatic vegetation, etc.), and last but not least on the availability and possibilities of human resources. Flow in an open channel is a rather complex process, therefore it is not possible to mark one of the methods or instruments as better than the others. Additionally, each of them is associated with measurement errors. It has become standard practice when conducting hydraulic flow experiments to quantify an interval of uncertainty within which the true value of a measurement is believed to reside (Pugh et al., 2021; Muste et al., 2017).
The role of a hydrologist is to be aware all these factors and select the best method for the particular conditions.
Development of information technologies and electronics has brought new and sophisticated methods for measurements in natural stream conditions. Such methods are becoming more and more popular among hydrologists and water managers for their easy use, quick and reliable measurements, and the visualisation and quality control tools available. Currently, the most common method for measuring discharges in streams is a method utilizing the Doppler principle (WMO, 2010). By this method can be measured both the geometry and flow velocities within the measurement profile and by this way it is possible to calculate discharges from a continuity equation. A device using this principle is called as an Acoustic Doppler Current Profiler (ADCP). The ADCP is a flow measurement device that utilizes the Doppler principle by emitting ultrasonic pulses sent into a body of moving water containing suspended particulate matter that reflects the pulses (Mueller et al., 2013). This method is far more time-efficient than the typical section-by-section velocity-area method of

streamflow quantification. Although an ADCP offers time efficiency, enhanced precision, and ease-of-use improvement over traditional flow measurement methods, it is far from being a perfect instrument (Gonzáles-Castro and Muste, 2007; Pugh et al., 2021). The sources of uncertainty an ADCP measurement, and associated mitigation strategies, have been documented and discussed (Boldt and Oberg, 2015; Le Coz et al., 2016). Anyway, there are still a lot of questions and uncertainties regards to this device application in natural conditions. For example, the ADCP suffers from an inability to directly measure the entirety of the cross-sectional area of the flow; thus, the instrument must extrapolate on the nature of the flow outside its gauging capacity. Additionally, complementary discussion in the current literature is provided concerning aspects of site selection (Bialik et al., 2014; Muste et al., 2017). Concerning this, the aquatic vegetation occurrence could be the source of many uncertainties. Aquatic vegetation affects hydrodynamics through vegetation flow resistance (Aberle and Järvelä, 2015; Bal et al., 2011), which increases water depth, decreases mean velocities or creates preferential flow paths. On the other hand, aquatic vegetation are often inseparable components of lowland streams/channel systems. For this reason, this study deals with evaluation how sampling method of the ADCP selected for measurement in natural lowland stream with aquatic vegetation affects value of the discharge area, which is very important parameter for discharge value determination.

Material and methods

Description of locality

Field measurements were carried out at the Gabcikovo-Topolniky channel. It is one of the main channel of channel network at the Žitný ostrov (Rye Island) area. This area is a part of the Danube Lowland at the Slovakia territory, it is an area between the Danube River and the Small Danube (Fig. 1). Because of its favourable climate, soil and morphological conditions, it is one of the most productive agricultural areas of Slovakia. The average width of the Žitný ostrov area is 20 km; its area is approximately 2000 km^2, which represents about 4% of the Slovak territory, but about 10% of the most productive arable land. The Žitný ostrov area forms a flat plain with only small differences in altitude. The surface of this area decreases in the south-east direction. Its average slope is about 2,5.10^{-4}, and there was one of the reasons for building channel network at this area (as a drainage system). The Gabčíkovo-Topoľníky channel is one of the biggest channels of the channel network at the Žitný Ostrov area. Its length is about 30 km, channel width ranges from 8 to 17 m. The presence of aquatic vegetation in this stream is a significant problem. Due to global warming, mean air temperature in Slovakia is increasing, summers are warmer and winters milder. For this reason is no exception occurrence of aquatic vegetation during whole year. Another factor, influencing occurrence of aquatic

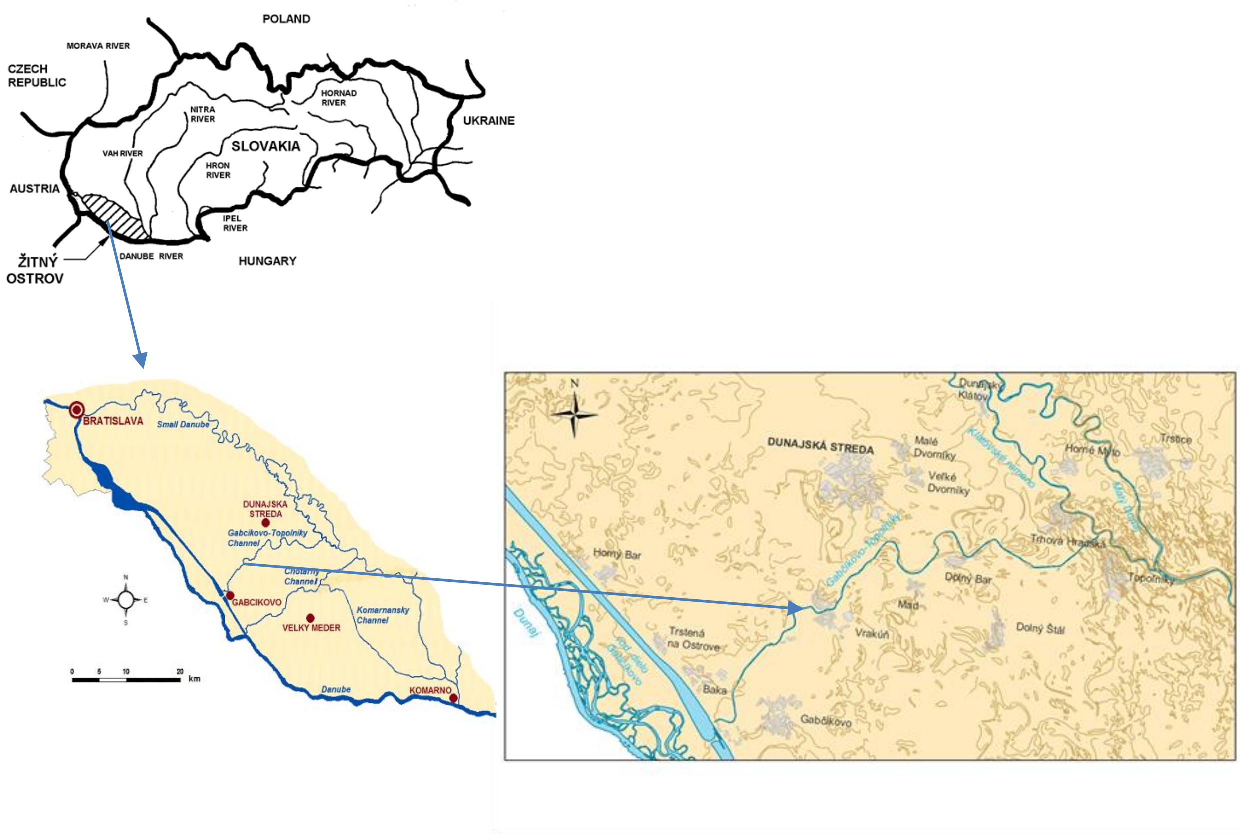

Fig. 1. Localisation of the Gabcikovo-Topolniky channel, Zitny ostrov, Danube Lowland.

vegetation, is small slope of the stream (and by this way low flow velocity) and fertilizers application in its surroundings. The settling of the carried particles in the flow occurs, thickness of bottom sediments increases and conditions for aquatic vegetation growth are better. All these aspects affect hydrodynamic conditions in the stream and also conditions and possibility to determine correct value of basic hydraulic parameters.

Instruments and methods

Field measurements of the channel bathymetry were performed during the summer 2023. Measurements were carried out manually and with the ADCP - RiverSurveyor M9 from fi SonTek (Fig. 4).

Manual measurement of bathymetry was carried out from a boat using a doubled rod. One sub-rod is fixed in a plastic disc and was placed on the bottom (Fig. 2). By this way, the depth of water was determined. The second sub-rod is moveable and it is used for measurement of bottom sediment thickness. Measurements were done in steps of 1 m along the whole width of the channel.

The SonTek RiverSurveyor system is a robust and accurate ADCP system specifically designed to measure river discharge, 3-D water currents, depths, and bathymetry from a moving or stationary vessel. A nine-beam system is with two sets of four profiling beams (each set having its own frequency) and one vertical beam (Fig. 3). The M9 can be used in both shallow and deep channels.

For the depth or the discharge area measurement, the River Surveyor offers two options:

- Vertical Beam (VB) - using the echo sounder. According to the device manual (River Surveyor S5/M9 System Manual, 2022), a low-frequency, fast-sampling vertical beam with the maximum depth range of the system provides channel definition for river discharge measurements and bathymetric surveys. The vertical beam provides with the confidence that the proper depth will be measured also during extreme conditions such as high-sediment flows and floods.
- Bottom-Track (BT) - using the velocity transducers; the result is a 4-beam averaged depth. This option uses data from the four angled beams to determine the depth of the water column using the average depth from each beam.

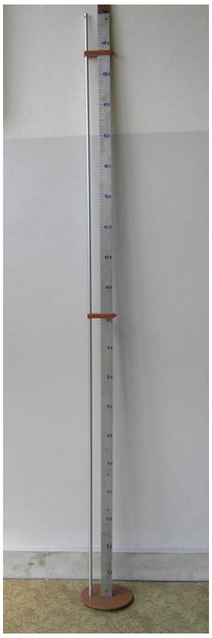

Fig. 2. Device (double rod) for manual measurement of the water depth in a cross-section profile of the channel.

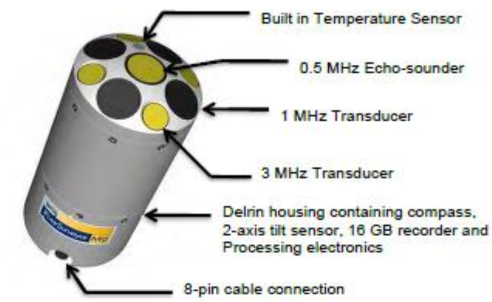

Fig. 3. Scheme of RiverSurveyor M9 (River Surveyor S5/M9 System Manual, 2022).

Fig. 4. Photos from measurements (left – manually, right – ADCP).

Both options are available for analysis or to recalculate discharge in post-processing (River Surveyor S5/M9 System Manual, 2022).
In most cases, VB is preferred to provide a depth reading directly below the instrument. If VB depth measurement is not available, then BT is automatically uses. Some environmental conditions (such as bed conditions or grass/weeds) may result in invalid depth detection or no depth-lock for either BT or VB. In case of the Gabcikovo-Topolniky channel, the aquatic vegetation occurrence results such problem: aquatic vegetation depending on its density, distorts the ADCP measurement results (see Fig. 5). For this reason, we try to evaluate the degree of inaccuracy by comparing the results of manual measurement and measurement by the River Surveyor, and both methods applied by this device.
Discharge area value was calculated as the sum of the partial areas between the measured verticals:

$$A_D = \sum_{i=1}^{n} A_{D_i} \qquad (1)$$

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]:

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

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].

Result and discussion

The discharge area values in all measured profiles along the Gabcikovo-Topolniky channel were evaluated in the manner described above. The results are shown graphically in Fig. 6. As can be seen, the discharge area values determined from ADCP measurements are always lower than the values from manual measurement. These differences are mainly due to the presence of aquatic vegetation. While this vegetation does not affect manual measurement, in the case of ADCP using the influence of aquatic vegetation on the measured data is significant.
For example, there was dense aquatic vegetation at the time of measurement in the Profile 8 (see Fig. 7). The discharge area determined from manual measurements achieved a value of 26.8 m^2. In contrast, the discharge area determined from ADCP BT was only15,7 m^2 and from ADCP VB only 11,5 m^2. Thus, in the case of ADCP BT there was a reduction of 41% and in the case of ADCP VB up to 57% compared to the value of the discharge area determined from manual measurement. Since the manually measured water depth values were not affected by aquatic vegetation, the discharge area determined from these data was chosen as the reference value. In Fig. 8, differences and proportions between this reference value of discharge area and values determined from ADCP measurements in each cross-section profile along the Gabcikovo-Topolniky channel are shown. In general, according to the course of the differences and the proportion, it is possible to indicate which profiles are overgrown to what extent. Fig. 8 indicates that the least aquatic vegetation occurs in profiles 29 and 30, which was also confirmed by observation and records directly from the field.
Besides that, Profiles 11, 17 and possibly 24 also showed a low degree of overgrowth. In case of absence or slight overgrowth of the profile, both ADCP methods (VB and BT) give almost identical values (e.g. Profile 11, 12, 17, 24, 30). Other authors have also reached similar conclusions. For example, Biggs et al. (2021) performed the study running over a 3-month period, which was selected to coincide with scheduled weed cutting activities. This provided the opportunity to obtain data with no vegetation occurrence, as well as to investigate the effects of weed cutting on river hydraulics. For the correct evaluation of hydraulic conditions from ADCP measurements, it was recommended to clear the cross-sectional profile of aquatic vegetation. Bialik et al. (2014) showed that a major problem in measuring flow conditions is densely growing vegetation and, if possible, it should be removed before the measurements. Moreover, it is also important to make a proper selection of the location, and close attention should be paid to the probable obstacles above the cross-section to avoid interference, particularly when the ADCP is used. From our results and results of Bialik et al. (2014), Boldt and

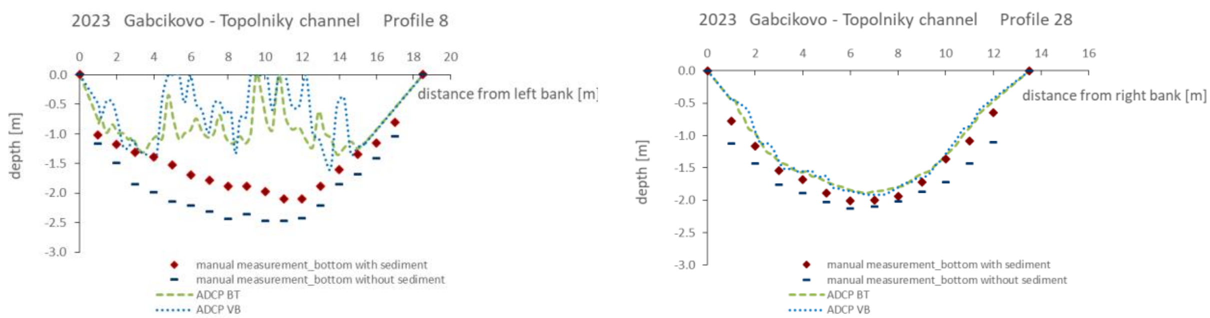

Fig. 5. Partial results of bathymetry measurements by various methods (densely overgrown profile – left, unovergrown profile – right).

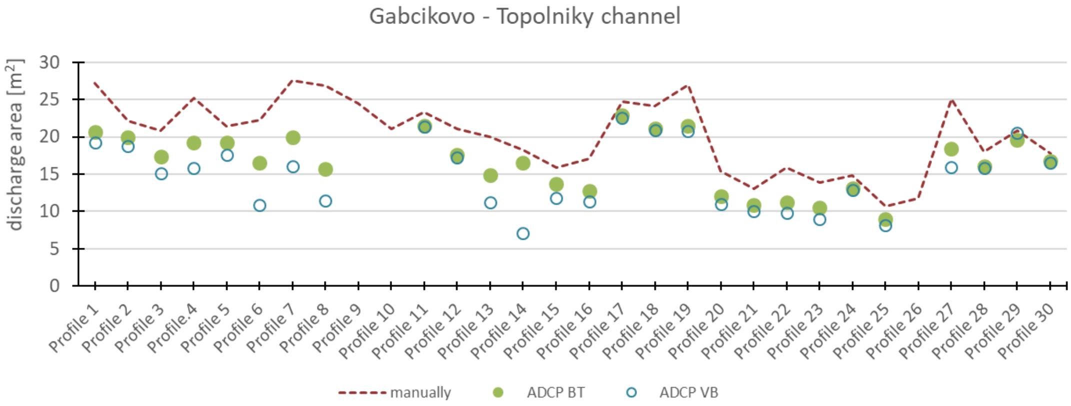

Fig. 6. Values of discharge areas measured along the Gabcikovo-Topolniky channel by various methods.

Fig. 7. Photo of overgrowth with aquatic vegetation in profile 8 (summer 2023).

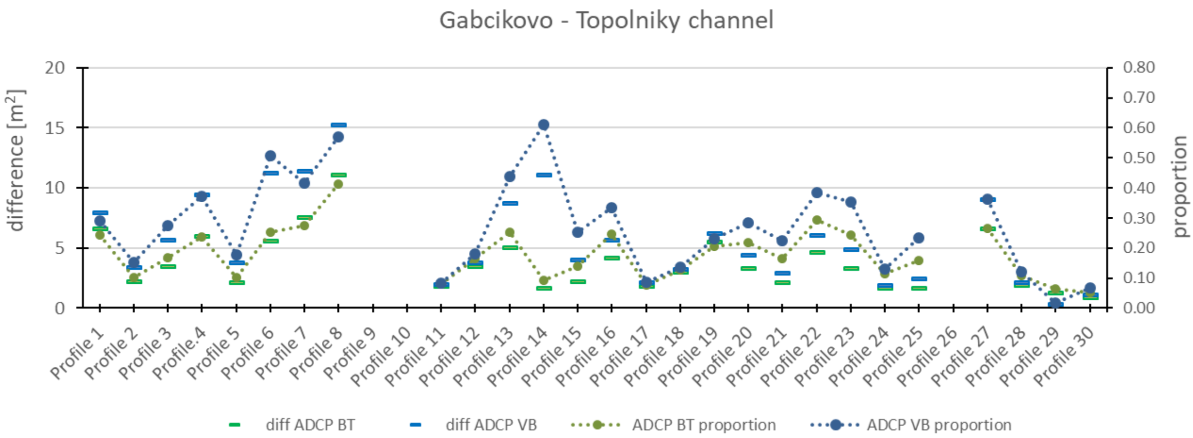

Fig. 8. Differences and proportions between discharge area values determined by different methods (manually = the reference value, ADCP BT, ADCP VB) along the Gabcikovo-Topolniky channel.

Oberg (2015), Le Coz et al. (2016), Biggs et al. (2021), Pugh et al. (2021), and others is clear that application of ADCP technique in the channels with aquatic vegetation has certain limits. When comparing the level of inaccuracies when using the BT and VB options, it turned out that in the case of the presence of aquatic vegetation in a stream, it is more appropriate to use the BT option than the VB. Fig. 9 also confirms this, as well as the coefficient of determination values.

We repeated the measurement in each profile several

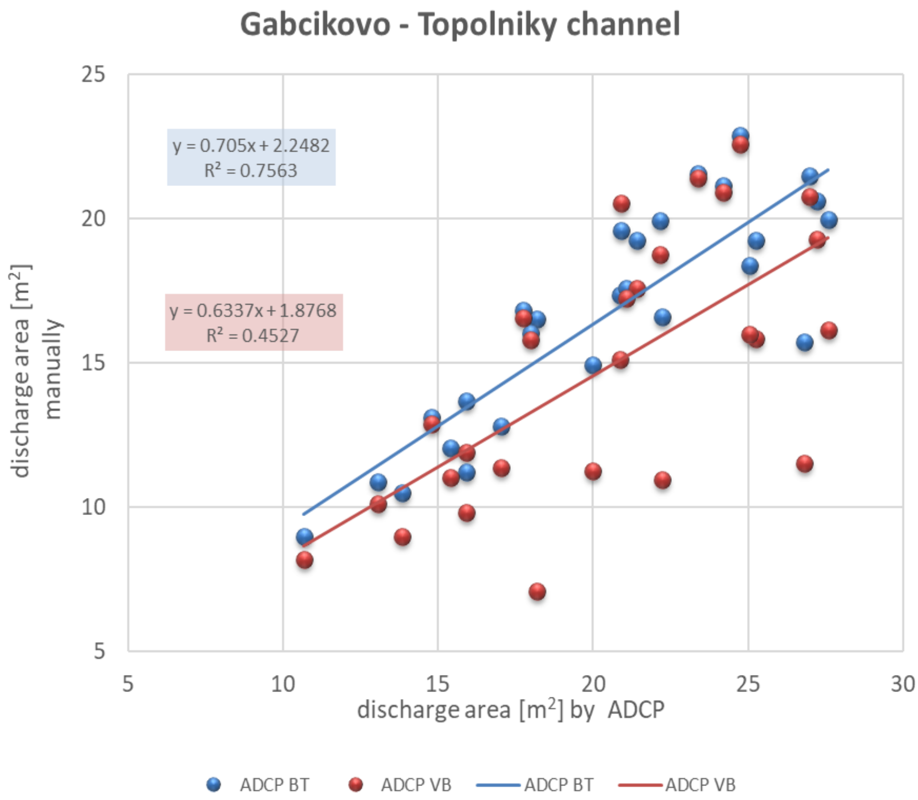

Fig. 9. Relationship between discharge area values determined by different methods.

times during field measurements, as long as the measured values did not have a difference of less than 5% with the option used. Anyway, in addition to everything mentioned so far, it is certainly necessary to emphasize, that multiple repetition of the measurement reduces the uncertainty and the size of the error of the measured hydraulic parameter, whether it is the discharge area or the velocity profile (Vermeulen et al., 2014; Pugh et al., 2021; Despax et al., 2023).

Conclusion

This study investigated the effect of aquatic vegetation on the accuracy of measuring lowland channel morphology using an ADCP (RiverSurveyor M9 from fi SonTek), as a basic information going to flow condition evaluation. Two options for setting the water depth measurements of this device were considered, namely so-called the BT and the VB. The results show that the density of aquatic vegetation greatly influences the accuracy and even the realism of the measurements. When compared with the results of manual measurement, the differences when applying the BT option were ideally 5%, but up to 41% in the case of dense vegetation. The VB option gave even less accurate results: in the ideal case the error was 7%, but with dense vegetation up to 61%.
It may seem that the ADCP method is not suitable for measuring flow characteristics and conditions in channels with aquatic vegetation. This statement is only partially correct, which is also confirmed by the works of several authors. In some cases, despite all the shortcomings, this method appears to be one of the optimal or possible (great depths, flood flows, etc.). In such cases, however, it is necessary to think about the limitations of this method and adapt the selection of measured locations (transverse profiles) to these limits (choose the profile with the least occurrence of aquatic vegetation, cleaning the profile from aquatic vegetation, etc.) The degree of inaccuracy can also be partially eliminated by a greater number of measurement repetitions in the transect.

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