Comparison of the discharge and flow velocity values determined by ADV device and indicator method

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Abstract. The flow velocity and discharge are important characters of hydrodynamics of a stream. This article presents the results of measurements of discharge and flow velocity in a cross-section profile by ADV (Acoustic Doppler Velocimeter) device – Flow Tracker device (SonTek / YSI) and by indicator method. In principle, ADV device is used to measure the flow velocity (by the 3D probe) at various locations within a cross-section profile of a stream and the area to which each measurement refers is determined as well. Indicator method requires the instantaneous release of a known tracer concentration, and the subsequent measures of the tracer concentration in a downstream cross-section profiles measurement section. There were determined and compared the discharge value, mean velocity of discharge cross section (vm) and section velocity (vs) - mean velocity between two cross-section profiles. Measurements were carried out in four cross-section profiles (H0 – H3) in the Hron River (various distances → 720, 922 and 1109 meters). Results showed that values of discharge measured by ADV device are lower than by the indicator method (not for all cross-section profiles). When it comes to vm, values obtained by ADV device are lower than the vm values obtained by the indicator method for the first and second cross-section profile. In the third cross-section profile, the situation is reversed. This fact is valid for the vm and vs.

1. Introduction

Determination of flow velocities in a stream is necessary for assessment of hydrodynamics of a stream. Velocity is an important parameter also in the assessment of the factors influencing the interaction between surface water and groundwater, especially from point of view of the assessment of flow velocity and rate of deposition - production of bottom sediments. A large number of different experimental methods for determining the flow characteristics exist, which can be used in laboratory and field conditions.

Discharge measurements in natural streams are performed in order to determine the value of the surface outflow of a basin, its temporal variability, and the outflow characteristics. The methods conventionally used for these measurements utilize a current meter immersed in different points of a river cross-section, to acquire the mean flow velocity of the section. For example, determination of discharge by current meter described [1]. Next authors comprised current meter method for determination of discharge with indicator method [2-4]. Currently, instead of the current meter, we use ADV device (Acoustic Doppler Velocimeter) based on the Doppler principle [5-8]. This method has advantages in better precision, faster recording of measurement in comparison with the current meter.
Next method, which is used for determination of discharge, is the indicator method. This method requires the instantaneous release of a known tracer concentration in a section of the stream, and the subsequent determination of the tracer concentration in a downstream measurement section [9-13]. As a tracer material are used various materials as the fluoride [14], rhodamine [15], tritium [16], uranium [17] or sodium chloride, which is considered for an ideal tracer [3], [18].

Article shortly describes a way of determination of discharge and flow velocity - mean velocity of discharge cross section (\(v_m\)) and section velocity (\(v_s\)) by the indicator method, respectively tracer experiment. This way for determination of discharge and flow velocity is then compared with other ways of measuring discharge and mean flow velocity using the ADV device (SonTek / YSI Flow Tracker). In conclusion, there are evaluated advantages and disadvantages of both relation methods.

2. Theoretical basis

For the measurement of discharge, we can use the direct or indirect method. For direct measurement and determination of discharge, it is necessary to adjust the measured profile - we use the metal spillway or draining pipes. The direct measurement for determination of discharge, we carry out in the rivers with low discharge, respectively in the upper part of the river.

The indirect method of discharge determining means that discharge value does not measure the volume per unit time directly, but the flow velocity profile and discharge area are measured. According to ISO standard [19], USGS [20] and other discharge calculation is based on the known equation (3):

\[
Q = A \cdot \bar{v}
\]

where:

- \(Q\) - discharge (\(m^3.s^{-1}\));
- \(A\) – area of cross-section profile (\(m^2\));
- \(\bar{v}\) – flow velocity (\(m.s^{-1}\)).

2.1. Description of methods for determining flow characteristics

We know several different experimental methods for determining the flow characteristics. Applicability of this method depends on the conditions of their use. The majority of the devices are suitable for laboratory conditions, but today also for field measurement new approach exists. Differences are in their possibilities, accuracy and power requirements [21]. One kind of equipment, which is used both in laboratory and field conditions, is ADV device.

2.1.1. ADV (Acoustic Doppler Velocimeter) device. The digital handheld device for measuring the discharge and velocity profiles – Flow Tracker - SONTek/YSI (figure 1) measures the flow velocity on the principle of ADV [22]. Instead of a propeller current meter, this device uses 2D or 3D probe. ADV device measures the flow velocity at various, but known locations within a cross-section profile of a stream and the area to which each measurement refers is also determined by this way.

The FlowTracker ADV operates at an acoustic frequency of 10 \(Mhz\) and measures the phase change caused by the Doppler shift in acoustic frequency that occurs when a transmitted acoustic signal reflects off particles in the flow. The magnitude of the phase change is proportional to the flow velocity. The phase difference can be positive or negative, allowing ADVs to measure positive and negative velocities. According to the manufacturer, the FlowTracker can be used in water depths as shallow as 10 cm and in velocities in the range of 0.001 to 4.5 \(m.s^{-1}\) with an accuracy of ± 1 % of measured velocity. The length of measurement can be set in the range from 10 to 1000 seconds (SonTek, 2009). FlowTracker does not measure the velocity of the water directly. The device measures the velocity of solid particles, small organisms, and bubbles suspended in the water,
assuming that these particles travel with the same velocity as flowing water. Therefore, the quality of the measurement depends on the presence of particles in the stream that reflect a transmitted signal. FlowTracker records the signal-to-noise ratio SNR.

![FlowTracker device](image)

**Figure 1.** Flow Tracker device

The ISO standard ISO-748:2007(E) (ISO 2007) establishes the specifications regarding the correct measurement of the mean velocity for the different vertical locations, the calculation of the discharge using different graphical or arithmetic methods, and the choice of the smallest number of vertical locations. In each case, certain flexibility is necessary to adjust these specifications to the different conditions that are met at each site over time. The ADV device works at 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. The mid-section method has been the primary method for measuring discharge in institutes of hydrology.

### 2.1.2. Indicator method (tracer experiments)

The second method, which we applied to determine the flow characteristics of the stream is an indicator method. The indicator method for determination of discharge is one of the oldest hydrological methods. These methods are effective mainly for mountain streams, but they can be applied also in other kinds of streams. For this reason, we apply it in this study, as well. The indicator method means the application of tracer experiment by which the velocity of flowing water between the selected cross section profiles is detected. The principle of this method is based on the transport phenomenon of two or multicomponents liquid homogeneous mixture tracer in the stream.
The tracer should not come under physical, chemical and microbiological reactions, it should be so called conservative substance, non-toxic and easily measurable. Otherwise, we must take into account existing reaction in the process of mixing and transport in the form of equations for adsorption, decomposition or complicated process of exchange of the mass. As a tracer, there are used various substances, e.g. fluoride, rhodamine, tritium, uranium or sodium chloride (NaCl). This method requires the instantaneous release of a tracer with a known concentration in a measured reach of the stream, and the subsequent measurement of the tracer concentration in a downstream reach. The necessary amount of tracer released into the river is determined by the discharge value and by the detection limit of the monitoring equipment.

3. Description of field measurements

Field measurements were performed in the Hron River – the territory of the Brezno town (N48° 48′ 24″). The measurements were carried out approximately from 220.4 to 221.5 river kilometres (rkm), in details it means 1109 meters (cross section profiles H0 – H3). Basic data about the measured river reach are summarized in table 1.

| Cross-section profile | Width of stream (m) | Maximum depth (m) | Mean depth (m) | Position data (GPS) |
|-----------------------|---------------------|-------------------|----------------|---------------------|
| H0 (0m)               | 18,0                | 0,580             | 0,354          | N48° 48′ 070″, E19° 38′ 146″ |
| H1 (720m)             | 20,7                | 0,680             | 0,416          | N48° 48′ 260″, E19° 37′ 644″ |
| H2 (922m)             | 20,0                | 0,540             | 0,390          | N48° 48′ 316″, E19° 37′ 505″ |
| H3 (1109m)            | 19                  | 0,400             | 0,290          | N48° 48′ 346″, E19° 37′ 359″ |

Measurements were done along the Hron River reach by ADV device twice and by the indicator method 6 times in each cross-section profile (tracer was injected to the centre of the stream four times and from the right side of the stream two times). Flow Tracker measurements were performed in each cross-section profiles in 1 meter distances of verticals along the cross-section profile width. The discharges in the measured profiles were determined by ADV device directly in the field after completing the measurement, obtained values are given in table 2.

The velocity was determined by the indicator method in the same distances from the bank which were carried out measurements by ADV device. As the tracer a solution of the sodium chloride (NaCl) was used. The procedure was following: water from the river was pumped by a pump into the mobile tank located on the river bank. Then we added into the tank 50 kilograms of NaCl. For each experiment, we recorded the course of tracer conductivity in the tracer injection cross-section profile. The $v_m$ in the cross-section profiles from tracer experiments we evaluated by three different ways (following a, b, c).

In general, velocity is defined as a ratio of distance and time. Distance in all cases was represented with a distance between boundary cross-section profiles of the evaluated river reach. The time belongs to the median of conductivity values from the relevant part of the time - conductivity course. The boundaries of the relevant part of the time – conductivity course (following a, b, c) were determined: a) Ascending branch of the time – conductivity course starts at the moment when the difference of conductivity is more than 5% of difference between background and maximum conductivity values and closes at the moment when the difference of conductivity is less than 5% of difference between background and maximum conductivity values (black line on figure 2); b) Stable branch of the time -
conductivity course starts at the moment when the difference of conductivity is less than 5% of difference between maximum and stable conductivity values and closes at the moment when the difference of conductivity is more than 5% of difference between maximum and decreasing conductivity values (black chain line on figure 2); c) Sum of ascending and stable branch of the time-points $a$ and $b$ (black line on and black chain line on figure 2).

Similarly as measurements by ADV device the values of $v_m$ were evaluated from the measured values by the entire width of the cross-section profiles, through the weighted mean of data.

**Figure 2.** Rising and steady parts of the time-conductivity course

### 4. Results and discussion

In all of the studied sites, different sets of measurements were performed concurrently with ADV device and indicator method. The measured data provided the different results between the flow characteristics of the Hron River.

Table 2 shows the values of discharge obtained by ADV device and by the indicator method. The values obtained by ADV device are compared with values obtained by the indicator method. As the reference values of discharge were considered data obtained by ADV device. These were compared with values of discharge obtained by an alternative method – indicator method. When we compare the values of mean discharge obtained with both methods, we can say that neither method shows an extreme of fluctuation values of discharge. The values of discharge determined by ADV device are lower than by the indicator method for all cross-section profiles. This fact can be explained by the high sensitivity of the ADV device. At the indicator method, it can happen some uncertainty in the measurements, which will be reflected in the calculation of the discharge. Figure 3 shows the relationship between the values of discharge and the values of distances of cross-section profiles in the Hron River.

**Table 2. Summary values of discharges in the Hron River**

| HRON River | Test no. | Cross-section profile | Plane (m²) | Discharge (m³/s) ADV (aver.value) | Discharge (m³/s) IND.M | Difference val. (%) |
|------------|---------|----------------------|-----------|-----------------------------------|-----------------------|-------------------|
| Inject. centre 1 | H1(720) | 7,488 | 4,192 | 4,188 | -0,09 |
| | H2(922) | 7,955 | 4,369 | 4,687 | +7,27 |
| Inject. centre 2 | H1(720) | 7,488 | 4,192 | 4,269 | +1,83 |
Table 3 shows the mean velocities of discharge cross section in the profile ($v_m$) and mean section velocities ($v_s$) between the measured cross-section profiles in the Hron River obtained by ADV device (figure 4). For the evaluation of measurements, we took into account the measured data from the upper third of the depth of vertical (0.8 times the depth from the bottom). Velocity of discharge cross section we determined from data obtained from the entire width of the examined cross-section profile. Value of $v_m$ was determined through a weighted mean of data (1/4 of the width of flow to the right and the left side from the centre line of the stream), when the values in the middle of the stream had a higher weight than the values in the edges (1/4 of the width on both sides).

| Inject. | H1(720) | H2(922) | H3(1109) |
|---------|---------|---------|----------|
| Inject.right 3 | 7,488   | 7,955   | 6,01     |
|          | 4,192   | 4,369   | 4,301    |
|          | 4,168   | 4,551   | 4,362    |
|          | +0,57   | +4,16   | +1,41    |
| Inject.right 4 | 7,488   | 7,955   | 6,01     |
|          | 4,192   | 4,369   | 4,301    |
|          | 4,27    | +4,16   | -1,43    |
| Inject.centre 5 | 7,488   | 7,955   | 6,01     |
|          | 4,192   | 4,369   | 4,301    |
|          | 4,27    | +1,41   | +1,81    |
| Inject.centre 6 | 7,488   | 7,955   | 6,01     |
|          | 4,192   | 4,369   | 4,301    |
|          | 4,27    | +1,41   | +1,25    |

Figure 3. Values of mean discharge by ADV device and indicator method

The highest values of $v_m$ were determined in the zero profile (H0), which had the smallest width of the cross-section profiles at the Hron River. The lowest values of $v_m$ were determined in the profile H1 (the widest cross-section profile). If we consider the maximum deviations of studied cross-section profiles parameters, then profile H1 is narrower about 15 %, more shallow about 43,44 % than the profile H0. Also, the value of $v_m$ is about 49.55% higher than in the profile H1.
Table 3. Mean velocity of discharge cross section ($v_m$) and section velocity ($v_s$) by ADV device

| Cross-section profile | Distance (m) | Mean velocity of discharge cross section (m/s) | Dist. from previous profile (m) | Section velocity (m/s) |
|----------------------|--------------|----------------------------------------------|-------------------------------|-----------------------|
| H0                   | 0            | 0.836                                        | 0                             | x                     |
| H1                   | 720          | 0.559                                        | 720                           | (csp 0/1) 0.686        |
| H2                   | 922          | 0.549                                        | 202                           | (csp 1/2) 0.553        |
| H3                   | 1109         | 0.715                                        | 187                           | (csp 2/3) 0.620        |

Table 4 shows the values of mean velocities of the discharge cross section ($v_m$) in the Hron River obtained by the indicator method (figure 4). The data show a gradual reduction of flow velocity values if we take into account the different parts of the curve expressing the course of indicator concentration at a given location in the measurement profile. The letter x indicates the cross-section profiles in which the measurement was not implemented to this experiment. The highest values of the $v_m$ are recorded for using the ascending branch of time-conductivity course, lower values for using the ascending and steady branch of time-conductivity course and the lowest values for using the steady branch of time-conductivity course, expressing the conductivity of indicator (figure 3). The difference of $v_m$ values at the measured cross-section profiles is negligible. Table 4 shows dispersion values and standard deviation, too for all tests and all cross-section profiles in the Hron River.

Generally, if we compare the values of $v_m$ in the Hron River, so higher values of $v_m$ were measured by the indicator method (figure 4), than by ADV device (ratio 2:1 for an indicator method). We took into account the values of the $v_m$ from the steady branch of time-curve conductivity, expressing the course of indicator conductivity at a given location in the cross-section profile. It is interesting that the highest $v_m$ (in the cross-section profiles also section velocities) were measured in the last profile, respectively between the penultimate and the last profile (figure 5). This fact is recorded in table 3.

Table 4. Values of the mean velocity of the discharge cross section ($v_m$) and by the indicator method

| Cross-section profile | Distance (m) | Part of curve | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 | Average | Dispersion value | Standard deviation |
|----------------------|--------------|--------------|-------|-------|-------|-------|-------|-------|---------|-----------------|------------------|
| HRON River           |              |              |       |       |       |       |       |       |         |                 |                  |
| 1                    | 720          | rise         | 0.717 | 0.762 | 0.479 | 0.511 | 0.9   | 0.78  | 0.692   | 0.02693         | 0.16411          |
|                      |              | rise + steady| 0.697 | 0.708 | 0.484 | 0.481 | 0.762 | 0.695 | 0.638   | 0.01507         | 0.12277          |
|                      |              | steady       | 0.697 | 0.702 | 0.397 | 0.399 | 0.654 | 0.687 | 0.589   | 0.02224         | 0.14914          |
| 2                    | 922          | rise         | 0.71  | 0.747 | 0.58  | 0.584 | x     | x     | 0.655   | 0.00738         | 0.08593          |
|                      |              | rise + steady| 0.681 | 0.692 | 0.532 | 0.58  | x     | x     | 0.621   | 0.00608         | 0.07798          |
|                      |              | steady       | 0.675 | 0.675 | 0.454 | 0.444 | x     | x     | 0.562   | 0.01704         | 0.13054          |
| 3                    | 1109         | rise         | x     | x     | x     | 0.634 | 0.72  | 0.677 | 0.00369 | 0.06081         |
|                      |              | rise + steady| x     | x     | x     | 0.627 | 0.69  | 0.659 | 0.00198 | 0.04454         |
|                      |              | steady       | x     | x     | x     | 0.616 | 0.645 | 0.631 | 0.00042 | 0.02050         |

Note – letter x marks cross-section profiles, in which the measurement of the existing experiment not been implemented
Table 5 shows the values of mean section velocities ($v_s$) between the measured cross-section profiles in the Hron River obtained by ADV device and indicator method (figure 5). If we compare the values of $v_s$ in the Hron River, so higher values of $v_s$ were measured by the indicator method than by ADV method except for cross-section profile $H3$.

**Table 5. Mean section velocity by ADV method and indicator method**

| Section | Section distance (m) | Section velocity AVD (m/s) | Section velocity IND.M (m/s) |
|---------|----------------------|----------------------------|-----------------------------|
| H0/H1   | 720                  | 0.686                      | 0.702                       |
| H1/H2   | 202                  | 0.553                      | 0.575                       |
| H2/H3   | 187                  | 0.620                      | 0.591                       |

In Table 6, there are recorded values of the $v_m$ in the cross-section profiles determined by both methods, percentage difference of $v_m$ values between the two methods, the dispersion of $v_m$ values determined by the indicator method (for example of the stable branch of time-conductivity course) determined only for indicator method, whereas 2-6 experiments for each cross-section profile was done in this method and standard deviation. Table shows, that largest dispersion is in the nearest cross-section profile.
Table 6. The values of velocities of the discharge cross section by ADV device, indicator method and differences

| Profile | ADV    | IND.M   | Difference val. (%) | Dispersion value | Standard deviation |
|---------|--------|---------|---------------------|------------------|--------------------|
| Hron River |
| H1      | 0,559  | 0,589   | +5,36               | 0,02224          | 0,14914            |
| H2      | 0,549  | 0,562   | +2,36               | 0,01704          | 0,13054            |
| H3      | 0,715  | 0,631   | -11,74              | 0,00042          | 0,02050            |

5. Conclusion

The results showed the differences in measured discharge and velocities of the discharge cross section and section velocities used by two methods.

In tables 2 to 5, there are summarized the mean values of discharge and the $v_m$ in the cross-section profiles and also $v_s$ from both methods of measurements, in both parts of the Hron River. When it comes to discharging, the values of discharge measured by ADV device are lower than by the indicator method. We can explain by imperfect mixing of the indicator across the width of the profile. In the profile more closely to the discharge profile, the indicator can occur with certain time delay at the river banks, so that ultimately the value of the flow velocity is lower. At a $v_m$, the situation is following. The values obtained by ADV device are lower than the $v_m$ values obtained by the indicator method for the first and second cross-section profile. In the third cross-section profile, the situation is reversed (table 4, table 5).

Each method has its advantages and disadvantages and limits. We can say that the method using ADV device is able to measure correctly the $v_m$ and discharge also in difficult flow conditions. Of course, for the application of this device, it is necessary to choose the most appropriate profile, respectively localities. The indicator method gives only orientational values, especially for the difficult flow conditions and in the case of long distance (or flow depth changes), its application is questionable and very limited. This method can be used with certainty in a straight river or canal reach, without
significant vegetation or other singularities in the measured section. Nevertheless, both methods showed the possibility of using in the existing measurement conditions at selected sections of rivers.

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