## Contents

1. Introduction ........................................................................................................................................... 3
2. Acoustic Doppler Current Profiler ........................................................................................................ 3
3. Point-in velocity measurements ............................................................................................................. 5
4. Volumetric method ................................................................................................................................. 7
5. Portable measuring weirs and flumes methods ....................................................................................... 7
6. Formulas for discharge estimation ......................................................................................................... 8
7. Large-Scale Particle Image Velocimetry ................................................................................................. 9
8. Radars ..................................................................................................................................................... 11
9. Induction based meter ............................................................................................................................ 13

References .................................................................................................................................................. 15
This study was prepared in the frame of the EEA Norway Grants project entitled: „Elaboration of hydromorphology field course for civil engineer and geophysicist students – EEA HydroCourse“, EGT/156/M4-0002 contract number.

1 Introduction

Discharge is the volume of water that flows past a certain point in a stream over a specific period of time, usually expressed in cubic meter per second. Also it can be computed by multiplying the area of water in a channel cross-section by the average velocity of the water in that cross-section.

Water discharge measurements can be done by numerous ways. These are the most commonly used methods:

- Acoustic Doppler Current Profiler
- Point-in velocity measurements
- Volumetric
- Portable measuring weirs and flumes
- Formulas for discharge estimation
- Large-Scale Particle Image Velocimetry
- Radars
- Induction based meters

2 Acoustic Doppler Current Profiler

The Acoustic Doppler Current Profiler (ADCP) (Figure 1) is one of the most frequently used devices for discharge measurement. Using this tool the reasonably accurate discharge measurement can be done in a fast and straightforward manner. The ADCP uses the principles of the Doppler effect to measure the velocity of the water by sending a sound pulse into the water and measuring the change in the frequency of that sound pulse reflected back to the ADCP by sediment or other particulates being transported in the water (see a more detailed description of the ADCP operation e.g. here: Baranya, 2010). As additional information, the device receives signals from the bottom of the stream so it also measures water depth.
ADCP is mounted onto a boat with its acoustic beams placed below the water surface looking down to the bottom (Figure 2). During measurement the instrument is guided across the river channel to measure velocities and depths. The river-bottom tracking capability of the ADCP acoustic beams or a Global Positioning System (GPS) is used to track the progress and provide width measurements.

Based on the depth and width measurements a post-processing software calculates the area for each measurement cell. Then using the discharge = area × velocity specific discharges are being calculated, and integrating them over the entire cross-section total discharge is resulted (Figure 3). There are other acoustic meters that can be permanently installed such as the Acoustic Doppler Current Meter (ADCM) and the Acoustic Velocity Meter (AVM). These instruments are capable of acquiring continuous data collection.
Due to the size and the measurement limitations of ADCPs it is rather the large streams and rivers where this method can be adequately used. For smaller streams of a width of couple of meters, preferably the methods presented in the following points are applied.

![Figure 3. Discharge calculation](http://water.usgs.gov/edu/streamflow2.html)

3 Point-in velocity measurements

In smaller and shallower streams, where the width of generally smaller than 5-10 m and the depth is smaller than 1 m, the above introduced method with ADCP is generally not applicable. In such cases it is e.g. the point-in velocity measurement method which can be used instead. In this technique current meters are used to measure velocities and sounding devices to measure depths at fixed locations on a cross-section. Width is generally measured using a wire or steel tape. If direct ways are not possible for some reason, the stream width can be measured with optical or electronical distance meters or using GPS. The velocity of the streamflow is measured using a current meter. The most commonly used one in the US is the Price AA current meter (Figure 4), but very similar ones are being used in Europe, too. It has a wheel of six metal cups that revolve around a vertical axis. An electronic signal is transmitted by the meter on each revolution allowing the revolutions to be continued and timed. The rate of the cups revolving is directly related to the flow velocity, hence the timed revolutions are used to determine the velocity. Price AA meter can be attached to a wading rod or suspended from a cable. Another example for current meters for shallow water is the Pygmy Price, which is attached to a wading rod. The size is somewhat smaller than the Price AA’s.
For point-in velocity measurements Acoustic Doppler Velocimeters (ADV) (Figure 5) can also be used. It works by the same principles as the ADCP, but ADV is attached to a wading rod and measures one single velocity value at a point (e.g. Voulgaris and Trowbridge, 1998). Computing discharge with current meter or ADV are both done by calculating the areas of each subsection from the width and depth measurements and then multiplying by the measured velocities. The total discharge comes from summing up the specific discharge values of each subsection.

![Acoustic Doppler Velocimeter](source: www.sontek.com)
4 Volumetric method

The volumetric method is a very simple way to measure discharge (Hajnal and Koris, 2014). It captures the flow into a container of known volume and measures the time taken to fill the container (Figure 6). The time is measured with a stopwatch. There are a couple of rules to note like the filling time has to be higher than ten seconds and the container has to be calibrated. At least ten separate filling measures are needed. Then the discharge = volume / time. Multiple measurements shall be averaged for the final discharge result.

Figure 6. Volumetric discharge measurements method [source: http://www.state.nj.us/dep/wms/shvanda_stream_gaging.pdf]

5 Portable measuring weirs and flumes methods

The most commonly used one of the portable flumes is the so called Parshall flume (Figure 7). It constricts the open channel flow for measurements of low flow on shallow, slow moving or steep gradient streams. There is a pre-defined relation between the water level upstream and flow through constriction.
6 Formulas for discharge estimation

There are indirect methods which are only to be used when the flow conditions are too dangerous to use the current meters and sounding devices for field measurements. Any of these discharge estimations cannot count as highly reliable methods. The so called “Slope-Area method” uses the Manning equation. The velocity in a reach is related to the slope of the channel and to the roughness of the bed material.

\[ Q = A \cdot V \]

\[ V = k \cdot R^\frac{2}{3} \cdot S^\frac{1}{2} \]

where \( A \) is the wetted cross-section area, \( V \) is the cross-section averaged velocity, \( k \) is the Manning-smoothness, \( R \) is the hydraulic radius and \( S \) is the slope. In case of detected water levels and known cross-section geometries at gauges along a stream reach the \( R \) and \( S \) parameters can be calculated and \( k \) is to be estimated based on the bed material and vegetation properties.

Another indirect method, the “Contracted-Opening” method uses the contraction of a stream channel by a bridge which creates an abrupt drop in the water surface elevation between an approach section and the contracted section under the bridge. This contracted section frames by the bridge abutments and the channel bed can be used to estimate flood flows. High water marks and the geometry of the bridge and the channel are used in this method.
7 Large-Scale Particle Image Velocimetry

The main idea of the LSPIV is to record the free-surface of the stream using high quality calibrated video camera(s). The main steps of the algorithm are the following: i) transform the images no a orthogonal coordinate system; ii) detect the movement of tracers on the surface using a suitable cross-correlation method; iii) calculation of instantaneous flow velocity vectors for image pairs; iv) estimating a so called index-velocity based on the spatio-temporal averaging of the vector fields. A relationship between the index-velocity and the actual discharge should be set up performing concurrent (calibration) discharge measurements. Once a strong relationship has been established the LSPIV method can be used for continuous discharge measurements. With this indirect technique discharge measurements can be carried out in cases where the conventional methods face difficulties, such as flash floods.

The determination of the free-surface velocity distribution is needed to make estimations on the flow discharge in this procedure. A calibrated video camera is needed with a fix place to record a certain area of the stream surface. If possible the video camera should be right above the stream or in an oblique angle from the river bank (bridge or high building). Even hundreds of square meters can be recorded. As one of the most crucial application criteria some sort of tracer is necessary for the video processing method to track. It can be natural material like sediments, foams, bubbles created by turbulence or it can be artificial material like plastic particles, candles, etc. As Figure 8 shows, once the video has been recorded the raw images need to be transformed onto a truly 2D system (this step is the “orthorectification”) and then the Particle Image Velocimetry procedure can be performed to reveal the surface velocity distribution.

![Figure 8. LSPIV measurement sequence (Muste, 2008)](image)

The video recordings are done from the river bank or from a bridge. In order to extract accurate flow data from the recorded images (i.e. to have undistorted, 2D images), they have to be rectified by an appropriate image transformation scheme. A conventional photogrammetric relation is applied to produce orthoimages using known coordinates of
ground control points in the real (X, Y, Z) and the image (x, y) coordinate systems, as shown in Figure 10. The relationship between the two systems is:

\[
x = \frac{A_1X + A_2Y + A_3Z + A_4}{C_1X + C_2Y + C_3Z + 1}, \quad y = \frac{B_1X + B_2Y + B_3Z + B_4}{C_1Y + C_2Y + C_3Z + 1},
\]

A minimum of 6 GCPs are needed (Figure 9). The control point selection is often dictated by accessible objects in the field (e.g., trees, power line poles, building corners).

**Figure 9. Relationship between camera and field coordinates (Muste, 2008)**

LSPIV algorithms use a pattern matching technique to image intensity distribution in a series of images as illustrated in Figure 10. The similarity index enclosed in a small interrogation area (IA) fixed in the first image is calculated for the same-sized window within a larger searching area (SA) selected in the second image. The window pair with the maximum value for the similarity index is assumed to be the pattern’s most probable displacement between two consecutive images. Once the distance between the centers of the respective small window is obtained, velocity can be calculated by dividing it with the time difference (dt) between consecutive images. This searching process is applied to all interrogation area in each image.

**Figure 10. Interrogation Area and Searching Area**

Muste and Fujita’s algorithm uses cross-correlation coefficient as a similarity index. Cross correlation is computed between the interrogation area (IA) in the first image and the interrogation areas located within the search area (SA) in the second image. The pair of
particles showing the maximum of cross-correlation coefficient is selected as a candidate vector. In this method, the cross-correlation method, \( R_{ab} \), is defined as

\[
R_{ab} = \frac{\sum_{x=1}^{MX} \sum_{y=1}^{MY} (a_{xy} - \bar{a}_y)(b_{xy} - \bar{b}_y)}{\left( \sum_{x=1}^{MX} \sum_{y=1}^{MY} (a_{xy} - \bar{a}_y)^2 \right)^{1/2} \left( \sum_{x=1}^{MX} \sum_{y=1}^{MY} (b_{xy} - \bar{b}_y)^2 \right)^{1/2}}
\]

where \( MX \) and \( MY \) are the sizes of the interrogation areas and \( a_{xy} \) and \( b_{xy} \) are the distributions of the gray-level intensities (0-255 for an 8-bit image). The overbar indicates the mean value of the intensity for the IA. For improving the measurement accuracy, subpixel peak detection methods using Gaussian fitting or parabolic fitting is applied to the cross-correlation distribution (Fujita et al, 1998).

The algorithm uses a variance normalized correlation, in which each pixel in the IA is equally weighted, such that the background is just as important as the particle images. A major advantage of the algorithm that it can estimate velocities from low-resolution images too, captured even with standard video cameras.

The raw LSPIV measurement outcomes are instantaneous vector fields. In the post-processing stage the LSPIV program can determine mean velocity field. The principle of Index-velocity method is to establish a rating for the relationship between the channel mean velocity \( (V) \) and Index-velocity \( (V_i) \). Water level may be also a parameter for the rating. After channel geometry measurements a relationship between the water level \( (H) \) and the wetted area \( (A) \). Discharge is calculated by: \( Q = A \cdot V \) (Figure 11). Only index-velocity and water level measurements are needed to estimate discharge using the LSPIV method.

Figure 11. Index-velocity

8 Radars

This method uses radars to measure river flow without touching the water with any instruments. The radar uses the principle of Bragg scatter from roughness elements of the water surface, such things as rain or wind effects. Radars can be: continuous wave microwave radar (with 24 Ghz center frequency), monostatic UHF Doppler radar (350 Mhz), pulsed Doppler microwave radar (9.36 Ghz), and groundpenetrating radar.
Radars can directly measure the parameters necessary to compute flow: surface velocity (converted to mean velocity) and cross-sectional area, thereby avoiding the uncertainty, complexity, and cost of maintaining rating curves. River channel cross sections were measured by ground-penetrating radar (GPR) suspended above the river (Figure 12). River surface water velocity can be obtained by UHF Doppler radars, and the surface velocity data are converted to mean velocity on the basis of detailed velocity profiles measured by current meters and hydroacoustic instruments. Both cross-section area and mean velocity values are reliable compared to acoustic and mechanical current meters.

Conductivity is the most significant problem faced during experiments. Between some conductivity value range (for some tested rivers 300-600 µS/cm) make the GPR interpretations of cross-section area difficult.

This method is recommended when other conventional methods are costly, time-consuming, and/or the stream or river is not accessible, frequently dangerous.

Figure 12. Radar of a noncontact discharge measurement system [source: http://www.ames.si/img/uploads/Items/rp_30.jp]
9 Induction based meter

This measurement method based on the Faraday principle (electromagnetic induction) which states that a moving conductor in a magnetic field will generate a voltage proportional to the speed of the conductor. The sensor of the meter generates a vertical magnetic field near the center of the probe using an electromagnet. This magnetic field is strongest near sensor body and diminishes approximately $1/D^2$ moving away from the sensor, where D is the diameter of the sensor. Water is a moving conductor and when velocity vectors flow straight into the sensor, the flow direction is perpendicular to magnetic field of the sensor. Within this magnetic field a voltage proportional to the speed of the water is produced. The sensor electrodes measure the voltage and the instrument calculates the speed of the water (Figure 13).

![Magnetic field](http://www.ott.com/blog/wp-content/uploads/2015/05/Sensor-Head.png)

*Figure 13. Sensor illustrating magnetic field and position used for measuring voltage.*

Generally it is not a problem to place a velocity sensor just below the water surface. To successfully complete a measurement, the sensor should be completely submerged. This means the minimum water depth is approximately 3 cm. The flow signals are the strongest near the sensor body and diminishes as you move away from the sensor.

A good rule of thumb is to keep the sensor 4 to 8 cm away from the physical boundaries, such as obstructions. The velocity lines should be parallel to the direction of flow and moving straight into the sensor (Figure 14).
Electromagnetic meters can be used in very low conductivity water such as springs or streams fed by show melt, however, there may be a trade-off with velocity errors if the conductivity of the water is less than 200 \( \mu \text{S/cm} \).

Sensors with depth option include an absolute pressure transducer to measure the maximum depth at each vertical.
References


5. Shvanda, J. Streamgaging: measuring stream velocity and discharge. USGS, New Jersey Water Science Center


8. OTT Hydromet Blog, Water Flow and Discharge Measurement with the OTT MF pro, 2015

