A Four-Step Guide to Accurately Calculating Surface Water Discharge

Today, a wide range of government agencies, municipalities, utility companies, and private companies need to monitor water flow in rivers, streams, and canals for a variety of reasons ranging from predicting water availability and flood events to allocating water resources and planning for future development. At a high-level, these organizations are concerned with the water flow and discharge of the surface water in a particular area. More specifically, water discharge, which is the volume of water moving through the cross section of a stream or river during a particular unit of time, is typically computed by multiplying the area of water in a channel cross section by the average velocity of the water in that cross section. This measurement is commonly expressed in cubic feet per second or gallons per day. Discharge measurements also take into account any suspended solids, dissolved chemicals, or biologic materials that are transported in the water through the cross section as well.

This whitepaper will provide a general guide for taking the necessary steps to calculate accurate surface water discharge measurements, including considerations for selecting the most ideal monitoring site, the technologies available for various site conditions, and how to ensure your systems continuously provides accurate data through modern quality assurance and quality control (QA/QC) methods.

Step 1: Selecting the Ideal Site for Performing Surface Water Discharge Measurements

To calculate the most accurate surface water discharge measurements, there are several considerations one must make to select the most appropriate measurement site. The ideal measurement site should have as many of the following characteristics as possible:

- Reasonably straight for the greater of either 300 feet or 5 to 10 times the channel's width both upstream and downstream from the gage site
- Free from rocks, weeds, and other obstructions
- Flow that is parallel to the bank, avoiding cross flow or reverse flow
- A stable river bed and banks—if a cross section changes over time, the discharge measurement will change

Additionally, if you are using an acoustic instrument, which we will discuss in more detail later in this paper, further site considerations should be made, such as ensuring the water is not overly turbulent and avoiding areas with vortices, algal and weed growth, or irregular velocity distribution.

Step 2: Measuring the Geometry of the Channel Cross Section

Once a potential site is selected based on the visual characteristics described above, the next step is to determine the cross-sectional geometry. To calculate this, the width of the cross section and the depth at a certain vertical needs to be measured. For many streams or rivers, the width measurement can be done using a measuring tape or a tag line strung at a right angle across the cross section. However, if a river is too wide to perform measurements using a measuring tape or tag line by wading or from a boat or bridge, surveying techniques or a global positioning system with differential correction (DGPS) instruments can be used. Once the width is determined, the water resource professional should divide the river or stream into equal vertical subsections, where ideally no subsection includes more than 5 to 10 percent of the total discharge of the river or stream.

Next, the depth of the river or stream needs to be determined for each of the verticals. Stream depth is usually measured using a wading rod, sounding lines, and weights or depth sensors integrated into the instruments such as pressure cells or acoustic echo sounders. Once the depth and width of each subsection is known, the area of the subsections as well as the cross-sectional area can be calculated.

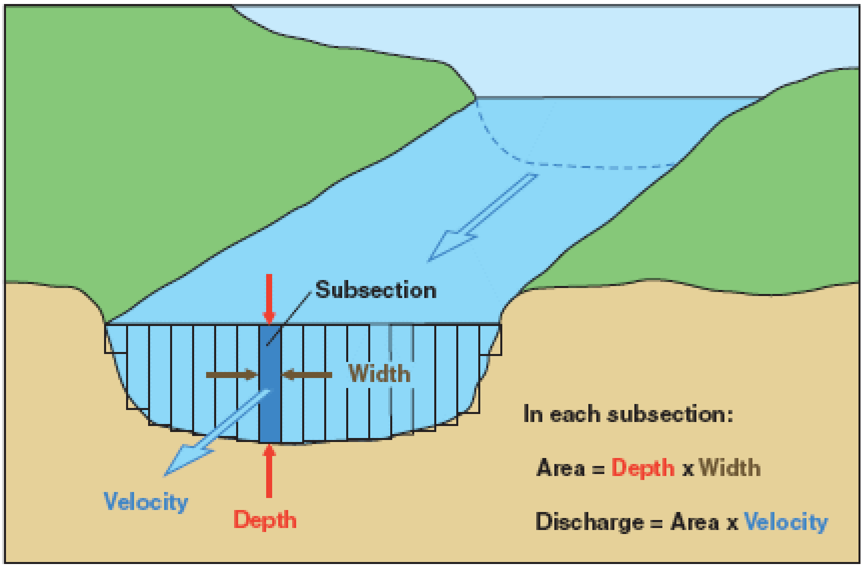

Figure 1. The identified river cross section is divided into equal verticals, then the depth of each vertical is measured to calculate the area for each one. Source: USGS, http://water.usgs.gov/edu/streamflow2.html

Step 3: Choosing the Right Technology for Measuring Water Velocity

After the channel cross-section geometry is known, the next step is to determine the velocity of the flowing water. Mobile velocity meters usually apply the section-by-section method. This method requires the calculation of the mean velocity in each of the selected verticals. The mean velocity in a vertical is obtained by taking velocity measurements at many points in a vertical, but it is commonly approximated by taking just a few velocity measurements and using a known relationship between those velocities and the mean in the vertical. For example, in free-flowing streams, the mean velocity of a two-point-measurement is calculated by averaging the velocity measured at 0.2 and 0.8 of the depth. Continuous operating velocity meters usually apply the index-velocity-rating method. Index velocity ratings relate the velocity measured by an instrument (v_i) to the mean channel velocity (v_m).

To acquire the necessary data to calculate mean channel velocity, hydrographers can use either continuous or mobile measurement systems. Today, there are a variety of continuous and mobile measurements systems available from a multitude of companies to fit almost any flow measurement need you may have. Let's take an in-depth look at some of the commonly available mobile and continuous monitoring systems, particularly some of the products offered by OTT Hydromet, who has been a leader in flow meter technology for more than 100 years.

Continuous Monitoring Systems

Continuous monitoring systems monitor specific local velocities within a user-selected measurement volume in the water using stationary instruments. In these systems, water flow sensors are fixed on the bank of the river or stream and permanently left onsite. These instruments are typically powered with solar or a battery and perform measurements at defined intervals typically using one of two methods—the travel-time principle or the Doppler principle.

Flow measurement systems using the ***transit time principle*** consist of two acoustic transducers positioned across from each other diagonally on opposite sides of a river or stream bank. The transducers transmit ultrasound signals at the same time into the water and the signals are received by the transducer on the respective opposite side of the body of water. Acoustic pulses transmitted against the flow need more time to travel across the water than those that travel in the same direction as the flow. This delay time is measured and is proportional to the average velocity in the measuring path. This type of system is ideal for medium to large flowing waterways and can be used with transverse flows, however, if there is a lot of air or debris in the water, the acoustic signal can potentially be attenuated. The OTT Sonicflow is an example of a device that uses this method to provide reliable data, even with low water depths.

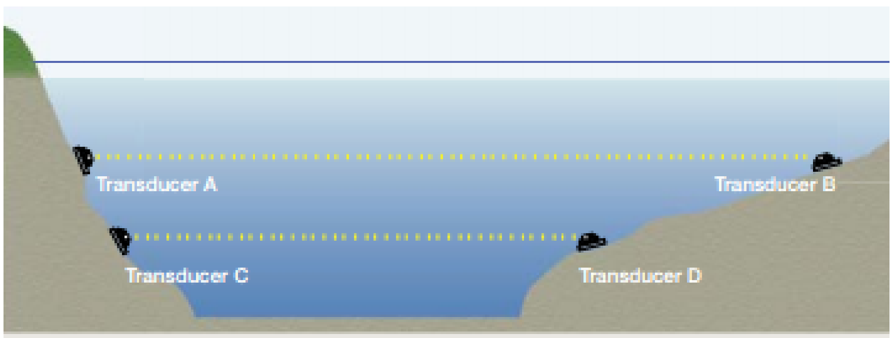

Figure 2. A multi-level monitoring system using the transit time principle.

Acoustic Doppler systems based on the ***Doppler principle***, which identifies that there is a change in the frequency of a wave for an observer moving relative to its source, are another type of commonly used stationary monitoring system. These systems only require one instrument to be placed on the bank of the river or channel being monitored. Two acoustic transducers transmit acoustic pulses into both directions upstream and downstream of the waterway, then the echo signals caused by the floating material and other water particles return to the transducer with a frequency shift, which is proportional to the water flow speed. Devices such as the OTT SLD are designed to not only measure water flow, but they can also measure water levels using a built-in vertical ultrasonic transducer and a patented algorithm to determine the distance between the water flow sensor and the water surface. This type of system is most suitable for small-to-medium sized waterways with large amounts of floating materials, but can be negatively impacted by large quantities of air in the water.

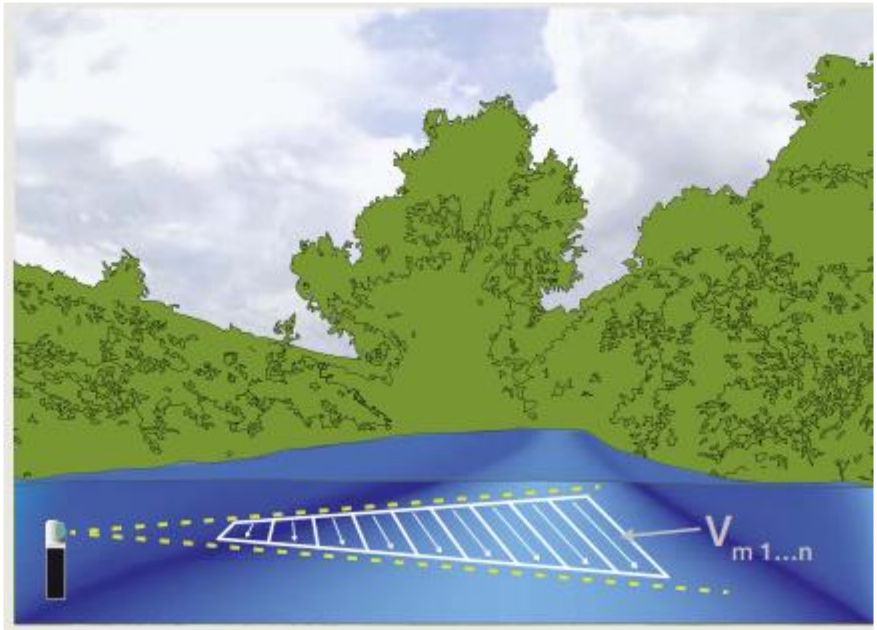

Figure 3. A representation of a system using the Doppler principle that is measuring local velocities within the measurement volume.

Mobile Systems

Water flow has been determined using mobile measurement systems since the invention of the basic mechanical meter in 1790, which hydrologists used to calculate flow by manually counting the number of rotations of the propeller. As with any technology, numerous iterations and methods have been developed over the years, not only resulting in automation of the counting of propeller rotations for current meters, but also to bring about newer, more sophisticated methods based on acoustic and magnetic principles. Today, most mobile instruments consist of a probe, sensor, and a rod for mounting the sensor. Some of these systems can store data and automatically calculate discharge based on the velocity and depth readings being taken.

Figure 4. Mobile System – Mechanical current meter / State of the art mobile instrument

Just like the acoustic method used for continuous monitoring systems, some mobile systems are based on the Doppler principle to measure point velocities in open channels using acoustic signals. Commonly known as acoustic Doppler current (ADC) meters, these handheld systems typically contain an electronic amplifier, receiver, clock, temperature sensor, and a digital display, in addition to the sensor, rod, and probe included in basic current meters. Besides measuring flow velocity, an ADC meter can measure depth of a vertical using an integrated pressure cell, allowing for real-time automatic calculation of discharge. For example, the ultrasound transducers in the OTT ADC transmit signals at short intervals that are reflected off of floating material in the water and returned as an echo. Using mathematical methods, the OTT ADC checks two sequential echoes for similarities and determines their time shift to then calculate flow velocity.

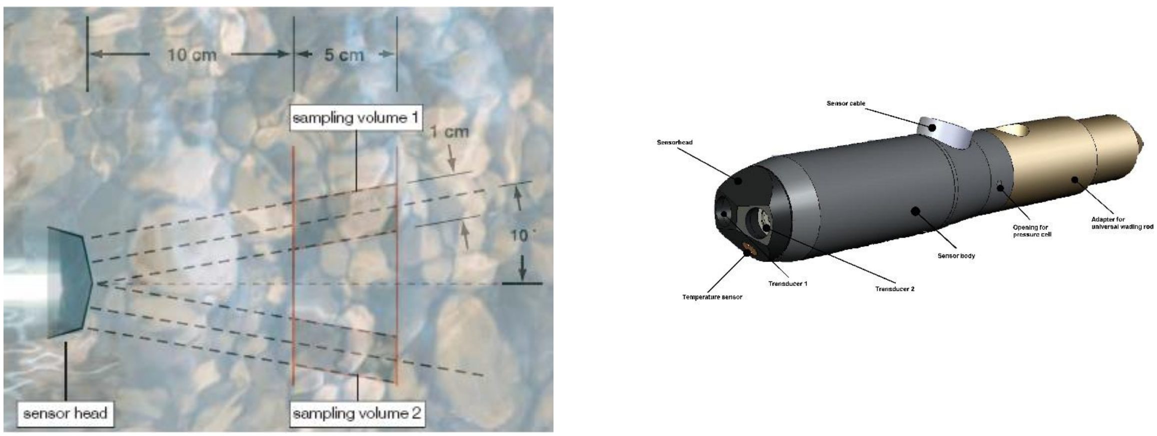

Figure 5. OTT ADC – Doppler current meter – acoustic measurement beams.

Simultaneously, the integrated pressure cell automatically determines the immersion depth of the probe for estimating the water depth of the vertical and the position of the measurement points. Thus, a hydrographer can easily measure the velocity and depth of each vertical across a flowing body of water and end up with an automatic discharge calculation before even returning to the lab.

Figure 6. The measurements presented on the handheld display on the OTT ADC.

For instances where the water may be too deep or dangerous for measurements to be performed using the typical rod and sensor method, there are floating devices available that allow measurements to be performed either wirelessly or using cabling methods by hydrologists on the shore. For example, the OTT Qliner 2 uses Doppler technology to measure both the vertical velocity distribution and the water depth at the required vertical positions. All measured data is transferred to the onshore operator’s mobile device via Bluetooth. After the measurement is complete, the discharge is available immediately.

Figure 7. The OTT Qliner 2 is used to perform automatic discharge measurements in rough waters up to 20 m deep.

Systems that use ***magnetic-inductive sensors*** are based on Faraday's law of induction, which is the basic law of electromagnetism. For a measurement rod using this technology, a magnetic coil in the sensor head creates a magnetic field. When water passes by the sensor head, the water ions create a voltage that relates to the flow velocity. The OTT MF pro uses this technology to automatically calculate discharge based on USGS and ISO methods. The velocity is graphed in real time on the meter's color display, allowing trends to be visualized quickly. This device can be used in some of the toughest environments, including weed-infested and dirty waters and turbulent flows, and, because it does not have moving parts, it is virtually maintenance free.

Figure 8. The OTT MF Pro is a user-friendly, low maintenance electromagnetic current meter for cost-efficient in-stream discharge measurement.

Step 4: Ensuring Data Quality

Useable data is critical for any water monitoring program. Measurement process variations are the biggest hindrance water resource professionals face because these variations impair the quality of their data. At a high-level, as the automation of water flow measurements has become more prevalent, the International Organization for Standardization developed the ISO 748 standard, which specifies methods for determining the velocity and cross-sectional area of water flowing in open channels without ice cover, and for computing the discharge from those measurements. While it is helpful to have a governing body initiate standardization efforts, it is important to ensure you are further minimizing data discrepancies and ensuring accuracy within your organization by establishing a quality assurance (QA) program. This QA program should involve testing your measurement devices at several different points throughout their life span, including when the device is first purchased prior to use, after a firmware or hardware upgrade is performed, after any repair is made, and at regular periodic intervals when no changes have been made.

For continuous monitoring systems placed in the field, during initial set-up, measurements should be taken with handheld instruments to establish baseline quality control (QC) points and develop the index velocity ratio. These QC points serve as reference points for monitoring system accuracy when periodic checks using the same mobile instruments are performed. Additionally, it is critical to ensure the accuracy of your mobile instruments. To do this, laboratory testing methods can be used.

Finding the Right Fit

Whether you are a municipality that needs to manage water resources, a power company monitoring water conditions at a dam, or a weather service hydrologist monitoring potential flood conditions, it is critical to understand the multitude of water flow meters available and best practices for using these tools. Part of this process is selecting to work with a company that is dedicated to providing accurate instrumentation that will also help you discover the best fit for your application needs. Accurate flow and discharge measurement has been a core competency of OTT Hydromet since it created its first flow meter in 1875. Since this time, the company has evolved to offer a variety of portable and stationary measurement options using different measurement technologies, including mechanical, magnetic, acoustic, and Doppler. The table below shows just some of OTT Hydromet's available flow measurement systems.

	Usage Type	Measurement Technology	Parameters Measured	Discharge Calculation Method	Minimum Water Depth	Power	Best Use Cases
OTT Sonicflow	Fixed	Acoustic	Flow Velocity	Automatic	16 cm	Battery or solar	Rivers 5 to 200 m wide
OTT SLD	Fixed	Acoustic	Flow Velocity, water level	Automatic	0.30 m	Battery or solar	Small-to-medium waterways with high levels of floating matter
OTT ADC	Spot/Mobile	Acoustic	Flow velocity, Depth	Automatic	4 cm	14 -hour battery life	Variety of situations including rivers, streams, canals
OTT Q Liner2	Spot/Mobile	Acoustic	Flow velocity, Depth	Automatic	0.35 m	Battery powered for 1 Day	Rough or deep waters that cannot safely be entered by humans
OTT MF pro	Spot/Mobile	Electro-magnetic	Flow velocity, Depth	Automatic	3.18 cm	Battery powered for 18 hours	Weed-infested or dirty water with turbulent flow conditions

CTA: **View a more complete list of OTT Hydromet Technologies Available for Water Discharge Measurements**