ECREEE
Towards Sustainable Energy

FIELD MANUAL

CURRENT METER STREAMFLOW MEASUREMENT BY WADING

By Dr. Greg Perzyna

ECOWAS Centre for Renewable Energy and Energy Efficiency
www.ecreee.org

AUSTRIAN DEVELOPMENT COOPERATION

MINISTERIO DE ASUNTOS EXTERIORES Y DE COOPERACIÓN

cooperación española

Imprint

Title: FIELD MANUAL - CURRENT METER STREAMFLOW MEASUREMENT BY WADING
Author: Dr. Greg Perzyna

Publisher: ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) - Praia, Cabo Verde
Contact: info@ecreee.org

November 2016

The field manual was funded by:

AUSTRIAN DEVELOPMENT COOPERATION

MINISTERIO DE ASUNTOS EXTERIORES Y DE COOPERACIÓN

cooperación española

Austrian Development Agency – ADA
Spanish Ministry of External Affairs and Cooperation - AECID

FIELD MANUAL

CURRENT METER STREAMFLOW MEASUREMENT BY WADING

Dr Greg Perzyna

November 2016

Preface

Quality of design and operation of water projects depends on reliable streamflow information. With a boosting up number of planned hydropower projects, agriculture, road construction, water supply and flood control projects the need for streamflow data and information will rapidly increase. These data are essential to both the planning and design of these projects and to the effective management of future infrastructure and installations.

The final reliability of hydrological information directly depends on the quality of the original field measurements. The good work of a person making these measurements is critical to accurately estimate the streamflow rates. Field operator has therefore the ultimate responsibility for the collection of discharge data of an adequate quality.

This manual is intended to be a quick and easy reference for you as you begin with discharge measurements in natural rivers. The manual concentrates on the current meter streamflow measurement by wading. The method is commonly used in initial investigations of potential mini and small hydropower sites. The subject of river discharge measurements is vast and complex and this manual do not pretend to comprehensively explore it. You should remember that theory can never replace the practical field experience.

The manual is an unofficial, internal publication of ECREEE which was prepared for the purpose of a training workshop. The distribution of this manual is meant to be limited. It should be noted that the document draws heavily on information provided by following fundamental works:

- The “Streamflow measurement” by Reginald W. Herschy, (2009),
- The USGS “Discharge measurements at gaging stations” (2010) by D. Phil Turnipseed and Vernon B. Sauer,
- The “Manual of British Columbia Hydrometric Standards” prepared by the British Columbia Ministry of Environment Science and Information Branch for the Resources Information Standards Committee, (2009).
- The WMO “Manual of stream gauging, Volume I Fieldwork” (2010),
- The ISO 748 “Measurement of liquid flow in open channels using current meters or floats” (2007).

Some parts of this manual were taken verbatim from these publications. Although some of these parts are not specifically referred to, credit is hereby given to authors of these publications.

Contents

List of Figures

List of Tables

1. Definitions

ADCP	Abbreviation for Acoustic Doppler Current Profiler. An instrument that uses acoustic signalling to measure velocity, depth and boat speed.
ADV	Abbreviation for Acoustic Doppler Velocimeter. A current meter that uses acoustic signalling to measure point velocity.
Accuracy	The degree of closeness of individual measurements or calculated quantity to its actual (true) value.
Bank, right or left	The margin of a river channel as viewed facing downstream.
Cross-section	A specified section of the stream that is normal to the direction of flow bounded by the wetted perimeter and the free water surface. The measurement cross-section is a vertical plane extending from one edge of the stream to the other and up from the stream bottom to the surface.
Cross-section width	The width of the water surface measured at right angles to the direction of flow and at a specific discharge.
Current meter	A piece of equipment used to measure the stream velocity at point.
Cumecs	Cubic metres per second (m3/s). International System of Units (SI Units) of measurement for instantaneous discharge (rate unit).
Depth of stream	The vertical distance below the free surface of a stream to the bottom of the stream at any point on a cross-section.
Dilution Gauging	Any gauging method in which the discharge is deduced from the determination of the ratio of the concentration of the injected tracer to that of the tracer at the sampling cross-section.
Discharge	The volume of liquid (water) flowing through a cross-section of the river, stream, open channel in a (given) unit of time. Term used interchangeably with streamflow.
Discharge measurement	Process of measuring the discharge of liquid (water) in a river or an open channel.
Float	Any natural or artificial body that is supported by buoyancy. Surface Float — Float with its greatest drag near the surface, used to determine surface velocities.
Flow	The movement of water in a channel without reference to rate, depth, etc.
Gauging	All of the operations necessary for the measurement of discharge. May also be used to refer to the combined result of the measurement.
Gauging section-measuring section	The cross-section of an open channel in the plane of which measurements of depth and velocity are made.
Left Bank	Bank to the left of an observer looking downstream.
Mean velocity at a cross-section	The velocity at a given cross-section of a stream, obtained by dividing the discharge by the cross-sectional area of the stream at that section.
Mid-section Method	Widely used technique for calculating stream discharge, the midsection method involves the calculation of discharge in individual measurement segments (sub-sections) in a cross-section.
Mid-Section Segment	Area at a vertical defined by the depth at that vertical multiplied by one-half of the distance between the preceding and succeeding verticals.
Monitoring site	A place where observations of the environment are made; typically a physical location where sensors are used to measure the properties of one or more features of the environment (e.g. depth of a river, velocity of the river etc.).
Open channel	The longitudinal boundary surface consisting of the bed and banks or sides within which the liquid flows with a free surface. The term "channel" generally means the deep part of a river or other waterway, and its meaning is normally made clear by a descriptive term, either stated or implied, such as "low water" channel, "main" channel, "artificial" channel.

Point method of velocity measurement	Method of measuring the velocity along a vertical by placing a current-meter at a number of designated points on the vertical. NOTE — The velocity is usually measured at one, two, three, five or six points on the vertical.
Point velocity meter (ADV)	A family of hand held acoustic based instrumentation used to measure water velocities and water depths during a discrete discharge measurement (gauging).
Propeller current meter	A current meter whose rotor is a propeller rotating around an axis approximately parallel to flow.
Propeller Pitch	Degree of inclination or slope of the blade, or the distance that a given propeller would advance in one revolution.
Reach	A straight length of a river channel. A length of an open channel between two defined cross-sections.
Right bank	Bank to the right of an observer looking downstream.
River	Any natural body of water that flows from a higher altitude to a lower altitude in a channel with defined banks. The term used interchangeably with stream.
Section	A portion of a cross-section for which velocity is measured or unmeasured.
Site	A place where observations are made; typically a physical location where sensors are used to measure the properties of one or more features of the river (e.g. depth, width, water level of a river.) NOTE: A synonym of monitoring site.
Sounding	The operation of measuring the depth from the free surface to the bed.
Spin Test	Test in which the rotor of a current-meter is spun, either with the fingers or by blowing into the cup or into the propeller, to check that it rotates freely and uniformly.
Stage or stage height	The elevation of the free surface of a stream, lake or reservoir relative to a gauge-datum. It is used interchangeably with the terms “gauge height” and “water level”.
Stream	The generic term for water flowing in an open channel, e.g., including creeks and rivers.
Streamflow	The flow of water in streams, rivers and other channels. Measurement of the streamflow is synonymous to the measurement of discharge.
Stream edge	The point on the stream bank where the stream water surface meets it.
Stream gauging	All of the operations necessary for measuring discharge.
Surface velocity	Velocity of a liquid at its surface at a given point.
Transect	One sweep across a water course from one bank to the opposite bank with an ADCP on a moving boat.
Velocity-area method	Method of discharge determination deduced from the area of the cross-section, bounded by the wetted perimeter and the free surface, and the integration of the component velocities in the cross-section.
Vertical	A vertical line on a cross-section where a measurement of depth or velocity is made.
Wading Rod	Light, hand-held, graduated rigid rod for sounding depth, and for positioning the current-meter for measuring the velocity in shallow streams suitable for wading.
Wetted perimeter	The wetted boundary of an open channel at a specified section.
Width of stream	The width of the water surface measured at right angles to the direction of flow and at a specific discharge.
Watercourse	A river, creek or other natural watercourse (whether modified or not) in which water is contained or flows (whether permanently or from time to time).
Weir	An overflow structure built across an open channel to measure the discharge in the channel. Depending on the shape of the opening, weirs may be termed rectangular, trapezoidal, triangular, etc.

2. Streams and Rivers

River is any natural body of water that flows from a higher altitude to a lower altitude in a channel with defined banks. A river shifts in shape, size, flow pattern of water, sediment content and colour, with time (seasonality) and space as one moves from river sources downstream.

Perennial or permanent (always flow)

Rivers (large- much water)

Intermittent or seasonal (periodic flow)

Creeks

Ephemeral or episodic(flow only during and after storms)

Brooks (very small)

FIGURE 2-1 RIVER CLASSIFICATION

Rivers, creeks and brooks are all names for water flowing in natural channels. The names are pretty much interchangeable but it is commonly assumed that brooks are the smallest of the three, with creeks being in the middle, and rivers being the largest.

The discharge (streamflow) in rivers is not constant and varies throughout the year. Seasonal distribution of rivers streamflow is closely related to the precipitation and evaporation regimes in their drainage areas. Every stream exhibits its own unique pattern of streamflow variation by month and season. Dependent of seasonal flow patterns river types include:

- perennial or permanent rivers (always flow). These rivers flow continuously, although discharge can vary a great deal over time,
- intermittent or seasonal rivers (flow periodically). These rivers flow only at certain times of the year. Many rivers in semi-arid regions are intermittent,
- episodic rivers or ephemeral rivers (flow seldom, only during and after storms). These rivers are actually the run-off channels of very dry regions. In these regions of the world, there are only slight amounts of rainfall and it evaporates quickly.

Different types of streams depending on their size and seasonality of flow are illustrated in Figure 2-1.

3. River (stream) Channel and its Features

All rivers (streams) flow in their channels. There is no official distinction between streams and rivers, but streams are commonly held to be smaller bodies. In this manual the terms “river” and “stream” are used interchangeably. Stream (river) channel is a relatively narrow depression that a stream follows as it flows downhill. A river in the channel is confined by banks.

FIGURE 3-1 VIEW OF STREAM CHANNEL (DEEP VALLEY)

The main features of river channels are:

Channel cross-section: A channel cross-section is essentially a "slice" through the channel, made at right angles to the flow. Data collected at a cross-section provides information on channel dimensions. Figure 3-2 describes the main components of channel cross-section.

Streambed (river bottom): is the part of the stream channel that is below the water surface. The riverbed is the ground at the bottom of the river - often made up of sand and stones.

Stream banks are parts of the stream channel that are above the water level, in other words these are the sides of a river or stream between which the water normally flows.

Stream edge is the point on the stream bank where the stream water surface meets it.

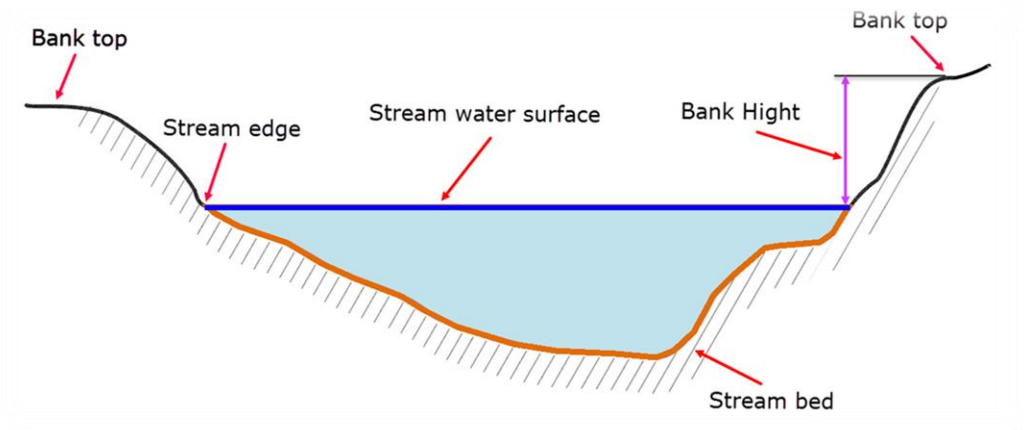


FIGURE 3-2 CHANNEL CROSS-SECTION ELEMENTS

Stream (river) cross-section (at measurement time) is a part of the channel cross-section bounded by the wetted perimeter and the free water surface.

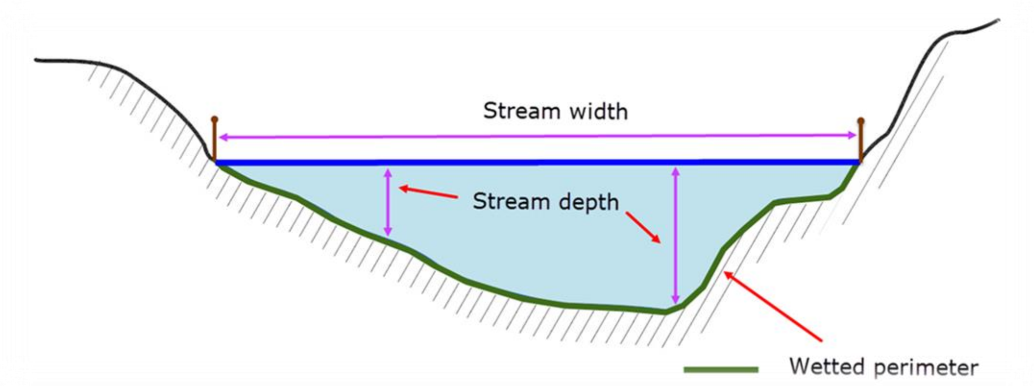


FIGURE 3-3 STREAM CROSS-SECTION – WIDTH AND DEPTH

Each cross-section can be described by a number of parameters. The main parameters of a stream cross-section are:

Wetted perimeter: the wetted perimeter is defined as the surface of the channel bottom and sides in direct contact with the stream. The wetted perimeter of a river refers to that part of the channel that is in contact with water.

Stream width: The width of the water surface measured at right angles to the direction of flow and at a specific discharge. The unit of a width measurement is usually meters (m)

Stream depth: (at the time of measurement) is the distance from the water surface to the bottom (river bed). The depth of the natural stream will usually vary within its cross-section. The unit of a depth measurement is usually meters or centimetres (m, cm)

Stream cross-section area: is the area of the of the cross-section surface covered by the water in the river channel. It is the product of the width of the channel, and the average depth of the river.

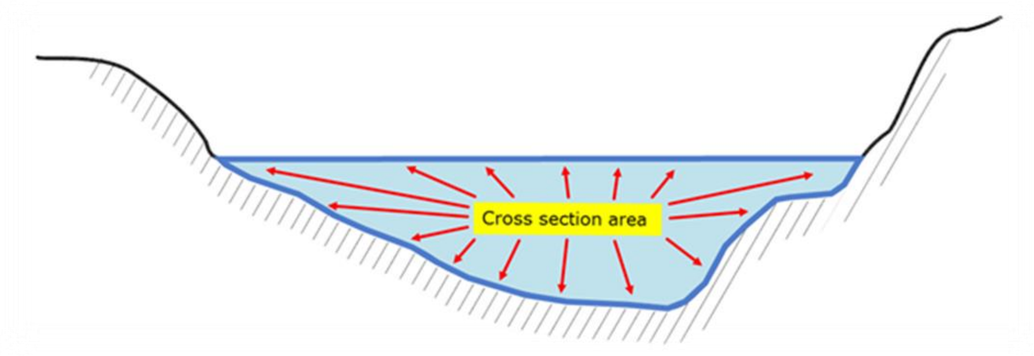


FIGURE 3-4 STREAM CROSS-SECTION AREA

Stream gradient is the change in elevation of the stream over a given horizontal distance and influences the velocity of stream. In the headwater (source) region a river will have usually a steeper gradient and higher velocity.

Rivers water level rise and fall in response to rainfall events and seasonal changes. The amount of water flowing throughout the cross-section of a natural stream is therefore not constant and varies seasonally. Similarly, the cross-section components such as: depth, width, wetted perimeter and cross-section area - will vary seasonally.

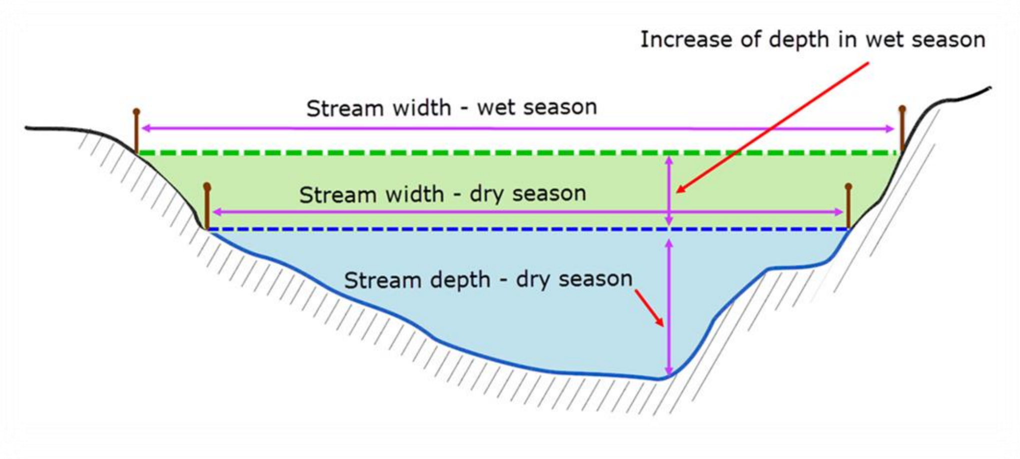
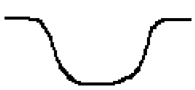
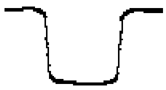
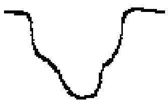
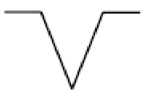
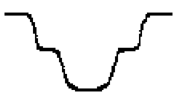
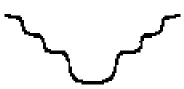
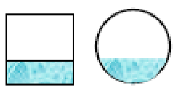


FIGURE 3-5 SEASONAL VARIATION OF CROSS-SECTION DIMENSIONS

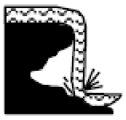
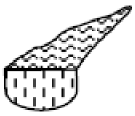
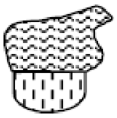
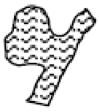
An important aspect of the river channel is that it is "self-formed" and "self-maintained". The flowing water carves the channel in which it flows. The water shapes the cross-section, influences the cross-section depth and width as well as the areal channel configuration, and the longitudinal channel profile. Table 3-1 and Table 3-2 include information on basic cross-sectional shapes and longitudinal river channel features.

TABLE 3-1 SHAPES OF RIVER CROSS-SECTION

	**U shape** Most common natural channel type		**Box** Commonly encountered with severe gully erosion
	**Flat U shape**		**Wide box**
	**Deepened U shape** May be naturally incised channels		**V shaped**
	**Widened or infilled**		**Trapezoid** Engineered channel shape
	**Two stage** Lowland channel with one bench		**Concrete V** Engineered channel shape
	**Multi stage** Lowland channel with >1 bench		**Culvert or pipe**

Source: Australian River Assessment System: AusRivAS Physical Assessment Protocol, Report no 22

TABLE 3-2 LONGITUDINAL RIVER FEATURES

	Waterfall Height > 1m Gradient > 60°
	Cascade Step height < 1m Gradient 5-60° Strong currents
	Rapid Gradient 3-5° Strong currents Rocks break surface
	Riffle Gradient 1-3° Moderate currents Surface unbroken but unsmooth
	Glide Gradient 1-3° Small currents Surface unbroken and smooth
	Run Gradient 1-3° Small but distinct & uniform current Surface unbroken
	Pool Area where stream widens or deepens and current declines
	Backwater A reasonable sized (>20% of channel width) cut-off section away from the channel

Source: Australian River Assessment System: AusRivAS Physical Assessment Protocol, Report no 22

4. Stream Velocity

The velocity of a river is the speed that water travels down the river channel. The unit of measurement is usually meters per second (m/s). River velocity depends on the stream gradient. Therefore, the velocity of the river is higher when the river reach is steep and it is lower if the river reach is flat.

Steep river gradient - fast velocity

Low (gentle) gradient – low velocity

FIGURE 4-1 EXAMPLES OF RIVERS WITH STEEP AND LOW GRADIENT

Velocity distribution within the cross-section

Stream velocity is not uniform across a river cross-section. The velocity for a cross-section varies both in vertical and horizontal directions. Usually, the velocity is greatest in the midstream near the surface and is slowest along the streambed and banks due to friction. The distribution of the velocity within the cross-section depends on the upstream and downstream channel conditions.

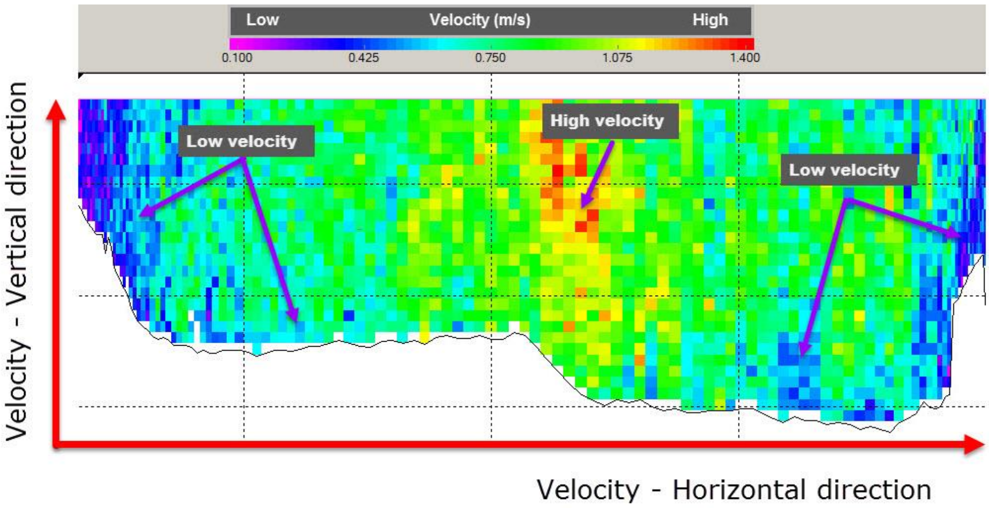


FIGURE 4-2 EXAMPLE OF DISTRIBUTION OF VELOCITY WITHIN RIVER CROSS-SECTION

⚠ Note that it is impossible to measure directly the average stream velocity within the cross-section. You can only determinate the flow velocity distribution in the cross-section by measuring the velocities in the pre-selected verticals or vertical depth cells.

Hydraulic theory and modelling showed that for non-turbulent streams the velocity typically varies in the vertical in a parabolic manner shown in Figure 4-3. We call it typical (ideal) velocity profile.

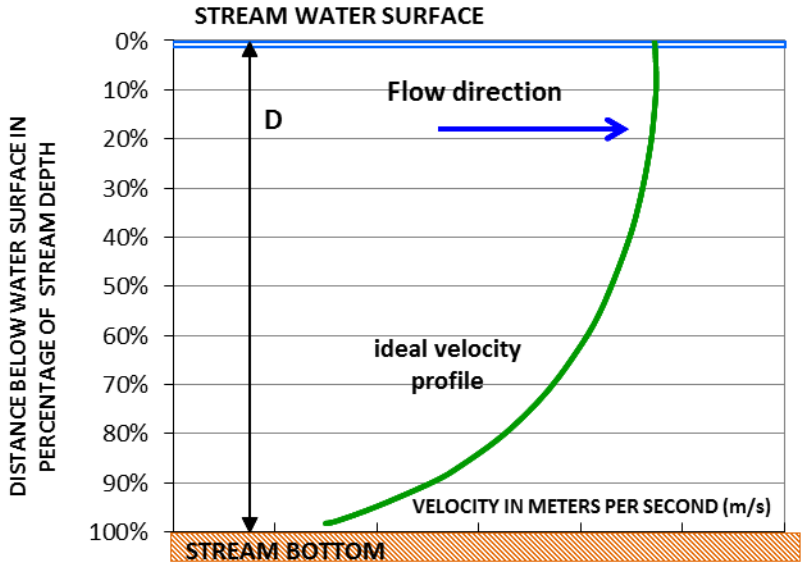


FIGURE 4-3 TYPICAL (IDEAL) VELOCITY CURVE AT THE VERTICAL

⚠ Conditions such river bottom material, weed growth on the streambed, large boulders within the cross-section, turbulence and other factors may alter this pattern and a velocity profile usually will differ from the "ideal" velocity profile which is illustrated in Figure 4-4.

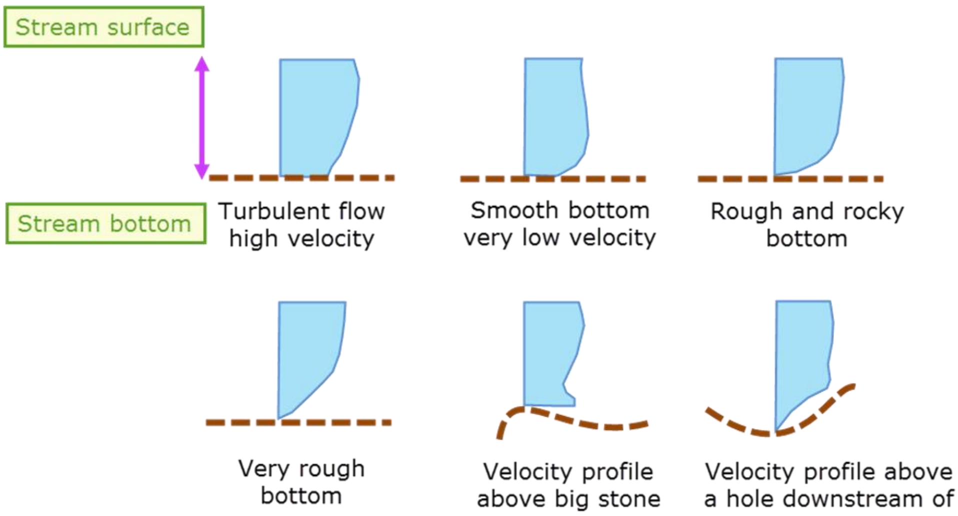


FIGURE 4-4 DIFFERENT SHAPES OF VELOCITY DISTRIBUTION CURVE IN VERTICAL

5. Stream Discharge (streamflow) and Methods of Discharge Measurement

In Hydrology, stream (river) discharge is defined as the volume of water passing through a particular river cross-section in a unit of time (second, month, year). Discharge is measured in units like cubic meters per second (m3/s or cumecs) or cubic feet per second (ft3/s or cfs).

Information about the river discharge is important across a broad range of water resources sectors. Table 5-1 gives an overview of the importance of streamflow data for the different uses of surface water.

TABLE 5-1 IMPORTANCE OF STREAMFLOW DATA FOR VARIOUS WATER USES

USE	River streamflow
Renewable energy - Hydropower development	VITAL
Reservoirs	VITAL
Irrigation – surface water	VITAL
Flood control	VITAL
Flood protection	VITAL
Industrial water supply	VITAL
Pollution control	IMPORTANT
Catchment management	VITAL
Flood warning systems	IMPORTANT
Drought warning systems	VITAL

The hydrologists, engineers and other water resources users are usually interested in the following streamflow characteristics:

- How much water is flowing - statistics of streamflow (average, minimum, maximum) flow,
- When low and high flows occur - seasonality (low flow season, flood season),
- How long streamflow is higher or lower than given discharge (flow duration).

5.1 Discharge Measurement methods

Continuous measurement of streamflow past a river section is usually impractical or prohibitively expensive. There are, however, various methods and equipment for measuring discharge at discrete time (instantaneous discharge). The choice of most appropriate method will depend on a number of factors including:

- magnitude of flow
- size of the channel
- flow type (laminar, turbulent),
- flow velocity,
- the required accuracy,
- safety considerations.

Hydrological Services of different countries make each year a huge amount of streamflow measurements across its territories. The measured discharges range from litres per second in small brooks to more than thousands cubic meter per second in large rivers. The methods and equipment used differ between countries. Presently the most common methods of river discharge measurement are:

- Velocity-Area method, mechanical current meter – USA, France, Norway
- Velocity-Area method, Acoustic Doppler Velocitimeter (ADV) – USA, France
- Velocity-Area ADCP, moving boat or tethered boat - USA, France, Norway
- Dilution techniques – France, Norway
- Float gauging – India, France

This manual covers one, specific method of discharge measurement and provides guidelines for streamflow measurement in small and medium-sized streams by Area-Velocity method with help of mechanical current meter. The method is commonly used in initial investigations of potential mini and small hydropower sites.

6. The velocity-area method of streamflow measurement

The most common and direct method for the determination of discharge in rivers is the velocity-area method. In general, this method determines discharge from the product of mean (average) stream velocity and the channel's cross-sectional area.

Discharge (Q) = Cross-section area (A) x Average stream velocity within cross-section (V)

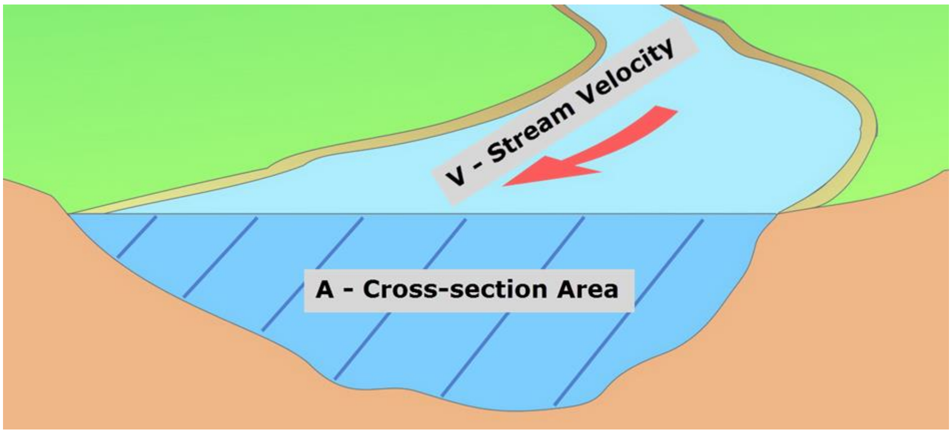


FIGURE 6-1 PRINCIPLE OF VELOCITY –AREA METHOD OF STREAMFLOW MEASUREMENT

In the velocity-area method the discharge is calculated as:

$$Q = V * A \tag{6.1}$$

where Q is the stream discharge (flow) in m^3/s,
V is the average stream velocity in m/s,
A is the stream's cross-sectional area (perpendicular to the predominant flow direction) in m^2.

Determination of the stream cross-section area, the average flow velocity and the computation of discharge are carried out in the following steps:

STEP1: river cross-section is subdivided into smaller sub-sections sometimes referred to as segments or subareas. Most natural channels must be broken down into 20 or 30 sub-sections to adequately characterize their shape.

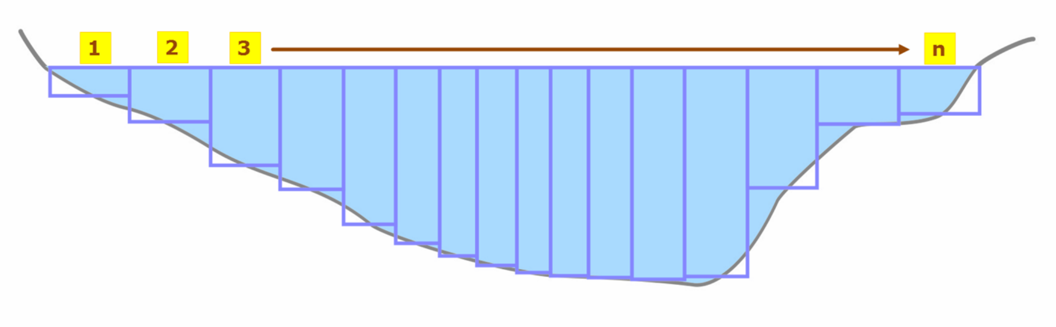


FIGURE 6-2 DIVISION OF RIVER CROSS-SECTION INTO SMALLER SEGMENTS (SUBSECTIONS)

STEP 2: the area of each sub-section is determined by directly measuring its width and depth. During wading measurements the depths are usually measured using marks on a wading rod of current meter. To measure stream width we normally use a measuring tape stretched across the stream.

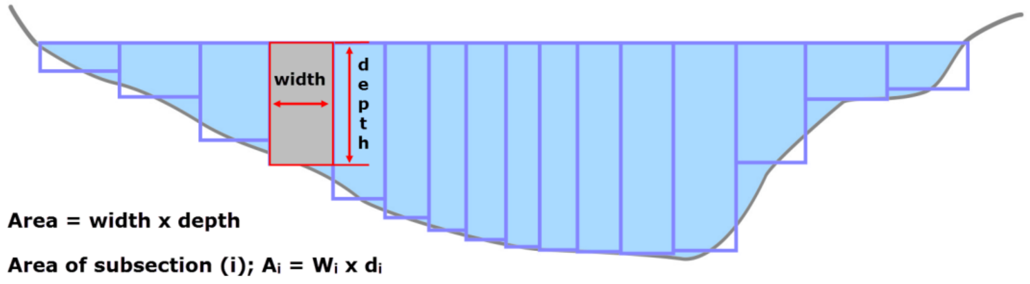


FIGURE 6-3 DETERMINATION OF SUBSECTION AREA

STEP 3: the velocity in each subsection estimated by use of appropriate method and instrument. For wading measurements we most frequently use Mechanical current meters and Acoustic Doppler meters (ADVs velocimeters).

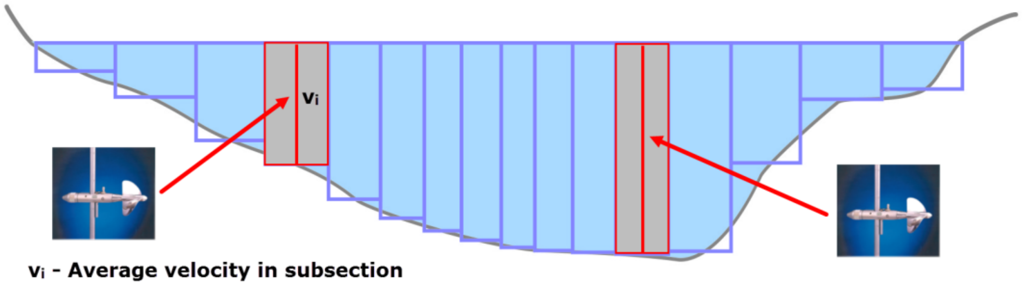


FIGURE 6-4 DETERMINATION OF VELOCITY IN THE SUBSECTION

STEP 4: Discharge of each subsection is calculated by multiplying subsection area (A_i) by average velocity in the subsection.

$$q_i = v_i * A_i \tag{6.2}$$

where q_i is the stream discharge of the subsection i,
v_i is the average stream velocity in the subsection i,
A_i is the subsection cross-sectional area.

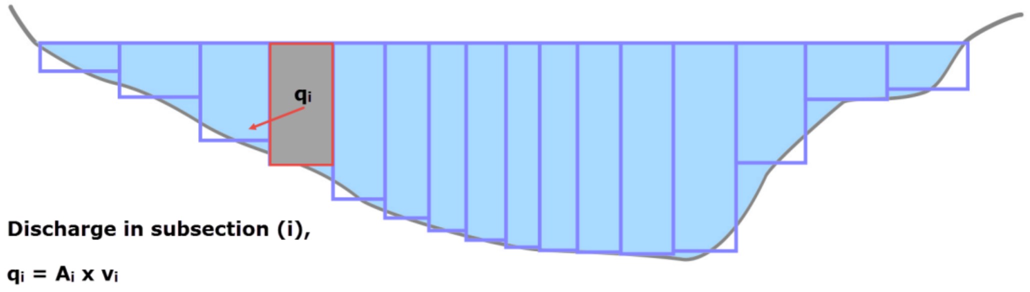


FIGURE 6-5 COMPUTATION OF DISCHARGE IN A SINGLE SUBSECTION

STEP 5: The total stream discharge (cross-section's discharge) is then obtained by adding together partial discharges in all subsections. The discharge across the whole cross-section will be:

$$Q = q_1 + q_2 + q_3 + \cdots + q_n \tag{6.3}$$

where Q is the total stream discharge through measurement cross-section,
$q_1, q_2, \ldots, q_n$ is the partial stream discharge of the subsections 1 (first),2 ,3,..., n (last)

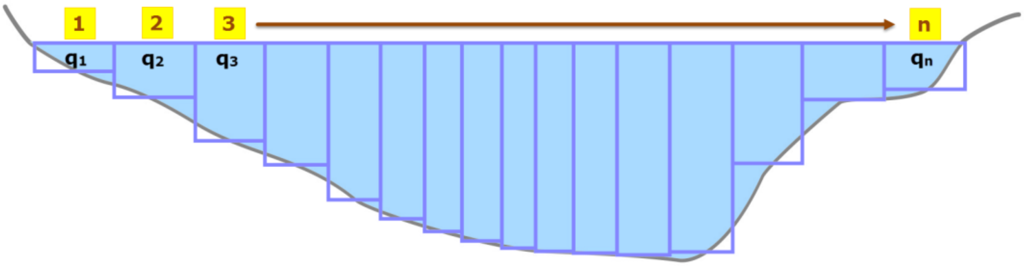


FIGURE 6-6 COMPUTATION OF TOTAL DISCHARGE IN THE RIVER CROSS-SECTION

⚠ Remember – according to the Velocity-Area method stream discharge (streamflow) is the sum of discharges in all subsections.

7. Current Meters

Current meters are still the most popular instruments used for streamflow velocity measurement. Current meters are precision instruments that measure velocity of the flowing water at a single point. The three most commonly used types of modern current meters are mechanical, acoustic and electromagnetic:

Mechanical current meters

The principle of operation for a mechanical current meter is based on the proportionality between the velocity of the water and the resulting angular velocity of the meter propeller (rotation speed of propeller).

By placing a mechanical current meter at a wading rod a point velocity in the vertical is determined by counting the number of propeller revolutions over a pre-selected time period and then computing velocity of water at that point from the meter rating equation.

Acoustic Doppler meters (ADVs velocimeters)

The acoustic current meter uses the Doppler Principle to determine velocities of water. It sends a continuous wave of sound at a known frequency into the flowing water. When that sound is reflected by a moving particle (suspended material) in the stream, the echo returns to the sensor at a different frequency. The returning signals are analysed and processed to deliver flow velocities.

Many acoustic current meters can be mounted on the standard wading rod to measure point velocities in a manner similar to the method for measuring velocity with a mechanical meter.

Electromagnetic current meter

The electromagnetic current meters function under the principles of Faraday's law of electromagnetic induction. According to this law, a conductor (water) that passes through a magnetic field produces a voltage that is linearly proportional to the water flow velocity.

As with conventional current meters, the sensor is guided through the measurement cross-section using the wading rod.

7.1 Main types of mechanical current meters

All mechanical current meters have a rotating device. Rotating element current meters can be divided into two main types:

1. Vertical-axis current meters known as the cup-type current meters
2. Horizontal-axis meters known as the propeller type current meters

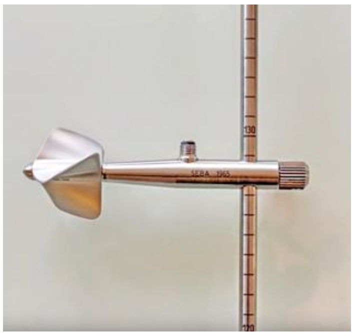
Vertical-axis, cup type current meter

The cup-type current meter has a rotor revolving about a vertical shaft. The rotor is generally constructed of six conical cups fixed at equal angles on a ring mounted on the shaft.

- The cup type current meters are most widely used in USA and India.
- The cups of vertical axes current meter are made of stainless steel, brass or bronze.
- It is reported that cup type meters operate at slightly lower velocities than propeller meters.
- The buckets and axis are more susceptible to damage by floating debris than propeller meters.
- A single rotor serves for the entire range of velocities.

Horizontal-axis , propeller type current meter

The propeller type current meter has a rotor revolving about a horizontal shaft. The rotor is a revolving propeller. Majority of horizontal-axis current meters come with a set of propellers to cover different water velocity ranges.



- The horizontal-axes current meters are most widely used in Europe and Australia.
- The propellers of horizontal-axes current meter are made of stainless steel or plastic.
- The propeller type meter disturbs flow less than the cup type meter;
- When used from a suspension cable, propeller meters appear to be more stable than cup current meters.

7.2 Major elements of mechanical current meter

Figure 7-1 illustrates major components of the current meter wading equipment. More detailed description of different current meter elements is given in Figure 7-2 and the following text.

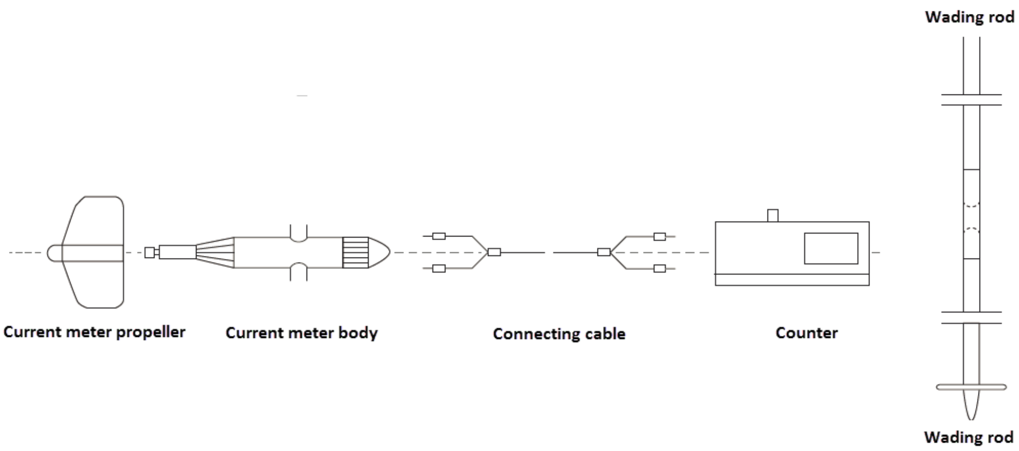


FIGURE 7-1 MAJOR ELEMENTS OF MECHANICAL CURRENT METER WADING SET
Source: Based on figure by OTT Hydromet, Leaflet OTT C31 Universal current meter

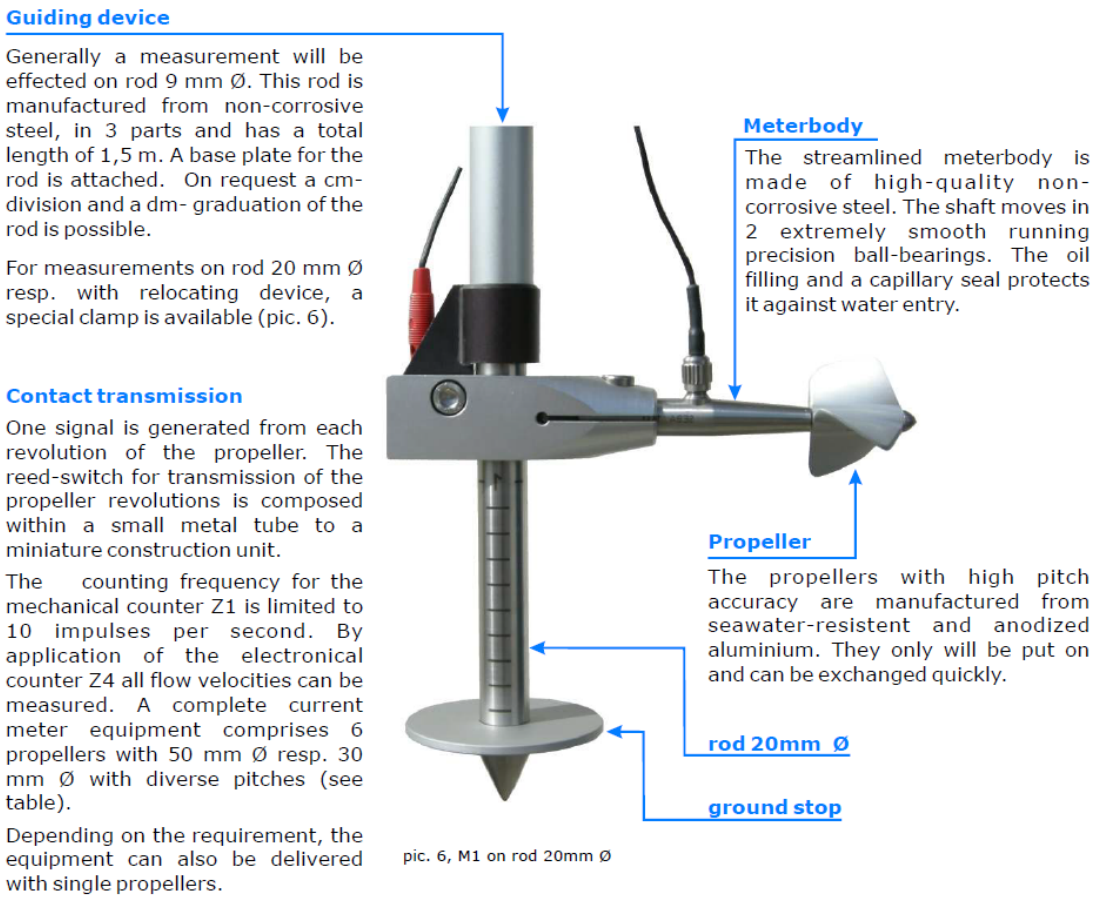


FIGURE 7-2 ELEMENTS OF CURRENT METER - EXPLANATION

Source: SEBA Hydrometrie, Leaflet Mini Current Meter M1 on rod 20mm Ø and relocating device

Propellers

The current meter propellers can be made off anodized aluminium, brass or impact resistant plastic. Propellers can differ in diameter and pitch. Common dimensions of propeller diameter may vary from 25 mm to 125 mm. The propellers pitch can differ from 50 mm to 1000 mm. The hydraulic pitch of a propeller corresponds to the travelling distance of a water particle during one revolution of the propeller. The ranges of velocities that can be measured with the particular propeller depend on the diameter and the pitch of the propeller.

FIGURE 7-3 CURRENT METER PROPELLERS WITH DIFFERENT DIAMETER AND PITCH

Source: SEBA Hydrometrie, Leaflet Mini Current Meter M1 on rod 20mm Ø and relocating device

Current meter wading rod

The wading rod is a steel bar with a linear graduation in centimetres or decimetres. At the bottom end of the rod you will normally find a base plate which prevents the rod from penetrating the river bed.

Usually the wading rod is made in three or four parts which have to be joined together.

The current meter body is mounted on the rod.

During wading measurement the rod is used to sound a stream depth.

7.3 Current meter working principle

River flow causes rotation of the current meter propeller. A magnet attached to the current meter propeller sends a signal (impulse) – one per revolution - through a water-tight sealed reed contact. The number of impulses (propeller revolutions) is proportional to the velocity of the water at the measuring point. The sequence of impulses is recorded by the connected counter.

The number of revolutions, measured during a certain time (exposure time) then gives the velocity, according to the calibration formula (current meter equation) of the propeller:

$$v = k \cdot n + C$$

where k is hydraulic pitch of the current meter propeller (angle of attack of the propeller blades) (m) which is determined by towing tests carried out in a rating tank

n is propeller rotation per second [1/s],

C is current meter constant [m/s] which was determined by towing tests carried out in a rating.

Remember: more revolution of the propeller in a given time – higher water velocity.

Propeller revolution counters

The current meter revolution counters can either be electro-mechanical or electronic counting devices. The simplest counter is making a bleeping noise at every revolution. The operator counts the number of bleeps by listening through headphones. The time is measured simultaneously with a stopwatch. It is recommended to terminate the use of this type of counters since miscounting of beeps by the operator is a frequent source of error.

The more advanced current meter systems include a digital counter. Some devices records only revolutions and show results of the LCD display. For this type of counter and a separate timing device (stopwatch) is required. If a simple counter is used it is essential to synchronise the counting and timing.

More sophisticated counters have built-in timing devices and record the number of revolutions for a pre-selected exposure time. These built-in timers allow the pre-setting of an appropriate exposure time e.g. 60 seconds. Some devices also have an additional facility where the number of pulses can be pre-set and the time recorded.

The most advanced counters will directly convert the revolutions to a velocity which is displayed on screen. Some will store minimum / maximum readings in memory. Some counter models are true data loggers which time stamp the data for downloading to a computer via RS-232 output.

Figure 7-4 shows the Seba Z6 digital revolution counter. This counter registers number of propeller revolutions for a pre-selected exposure time.

Revolution counters and timers should be checked on a regular basis. If it does not record the correct number of revolutions it should be taken out of operation for maintenance.

FIGURE 7-4 DIGITAL CURRENT METER REVOLUTION COUNTER

7.4 Care and checking of current meters

Current meters are scientific instruments. They should be handled with care, operated and maintained in accordance with the manufacturer's instructions. After measurement current meters should be kept securely in their carrying box or case.

Care should be taken to ensure that the propeller and propeller shaft are not damaged. If this occurs the meter shaft and propeller should be replaced and the meter re-calibrated. Current meters with bearings in oil should have the oil changed at least after every day of gauging.

You should perform a spin test of the propeller before each day of current meter use. The propeller should be spun by blowing along its axis. The propeller of the current meter should spin continuously for at least 20-30 seconds.

⚠ It is not a good idea to spin propellers (particularly miniature ones) with the finger as this could damage the shaft.

8. Flow Measurement by Wading

Current meter measurement by wading is a preferred method of streamflow measurement if river conditions permit. Wading measurements with current meter are normally more accurate than measurements with current meter suspended from cableways or bridges. During wading we have more control in the selection of river measurement cross-section, in the selection of verticals and measurement of the depth. This part of the Field Manual includes discussions of the following topics:

1. Selection of measurement site.
2. Measurement of cross-section width.
3. Determining number and spacing of verticals for velocity and depth measurement.
4. Measurement of depth in the vertical.
5. Measurement and determination of mean velocity in a vertical.

8.1 Selection of measurement site

Selection of the measurement site is a key step in the process and will have a large impact on the quality of the streamflow measurement. You should choose the cross-section for wading measurement with respect to flow conditions on the day of discharge measurement. It may differ from one measurement to the next. When gauging at the hydrometric station site, the location may be several hundred metres upstream or downstream from the water level gauge provided that there is no inflow or outflow in the intervening reach.

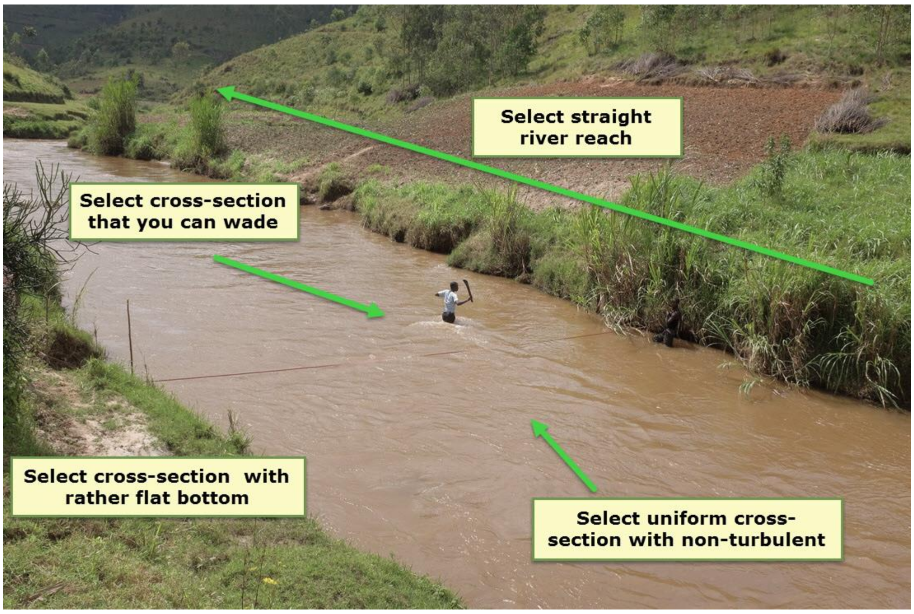


FIGURE 8-1 GOOD MEASUREMENT SITE - DETAILS TO CONSIDER

Where possible, a good wading streamflow measurement site (cross-section) should have following characteristics:

- Have a reach that is reasonably straight. Where the length of straight river reach is limited, the length upstream from the cross-section should be minimum twice the downstream length,
- The flow in the cross-section should be laminar (i.e. free of eddies, swirls, vortices, backward flow or dead zones,

- Cross-section should be uniform, stable and free from large rocks, weeds, sunken trees and other obstructions that would create turbulence or interfere with the current meter,
- Cross-section should have a rather flat, “U” shaped bottom,
- Cross-section should have sufficient depth of water for the effective immersion of the current meter (normally more than 0.1 m) and should not be deeper than 1.2 m,
- Direction of river flow should be perpendicular to the measurement cross-section in all verticals
- Cross-section should have a stable bed and channel margins for the period of measurement, and be accessible at all times with the measurement equipment.

Where possible, sites showing any or all of the following characteristics shall be avoided:

- Cross sections immediately downstream from sharp bends or obstructions,
- Reaches with turbulent flow,
- Reaches with sudden changes in stream width and contributing side streams,
- Cross section nearby pumps, sluices or outfalls regardless of whether they are upstream or downstream,
- Do not place a measurement cross-section through a pool.

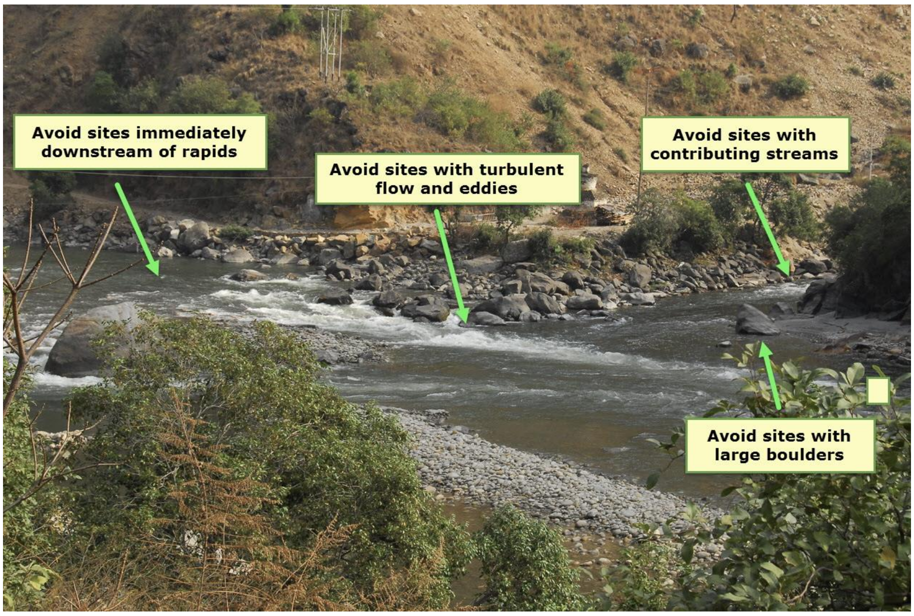


FIGURE 8-2 MEASUREMENT SITES TO AVOID

⚠ It is usually not possible to satisfy all these conditions. The best available site should be chosen or modified to provide acceptable measurement conditions.

⚠ Access to the streamflow measurement site should be secure and safe for the complete period of measurement. An agreement with any landowners whose land must be crossed to gain access to the site is recommended.

Safety first

The danger of working in the flowing water can never be underestimated. The safety record in streamflow measurement has been a good one but fatal drowning accidents have occurred. These accidents could have been avoided with the adequate safety measures. Prior to measurement try to walk across the stream using the wood stick for stabilization (in exceptional case you can gently use the wading rod without the current meter attached) and try to check:

- If the bottom of the channel is free of deep holes, sharp rocks, fallen logs, etc., that can cause foot entrapment, injury, or falls,
- If the stream is not too deep. Do not attempt to wade into a stream if the depth is larger than 1.2 m,
- If you discover that the stream or velocity is too high and you have problem to stay stable then return to the nearest bank and try to locate another measuring cross-section,
- Do not gauge if there is a potential for a thunderstorm.

⚠ A personal flotation device (life jacket) shall be always worn unless the stream is very shallow.

8.2 Measurement of cross-section width

Stream width is the width of the water surface at the time of measurement. To measure stream width you should do the following:

1. Wade across the stream and stretch the measuring tape across the stream at the chosen cross-section. Secure the tape on the banks by using pins, stakes or vegetation. The tape should be perpendicular to the flow (not necessarily at right angles to the whole channel) and about 0.3 m above the water surface. Make sure the tape is tight, level and does not touches the water.

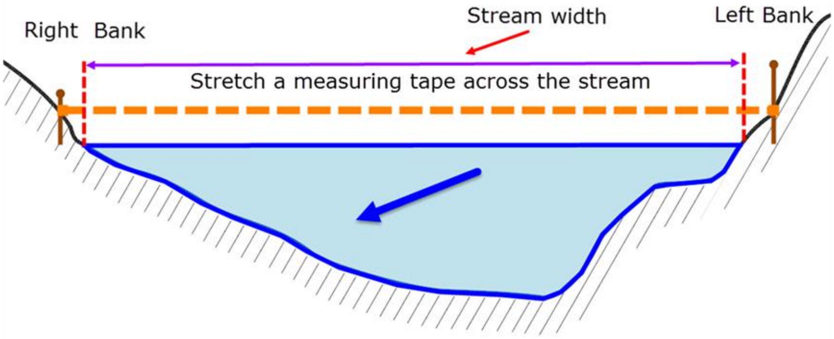


FIGURE 8-3 MEASUREMENT OF CROSS-SECTION WIDTH

2. Read the distance on the tape corresponding to the position of the start and the end water edge.

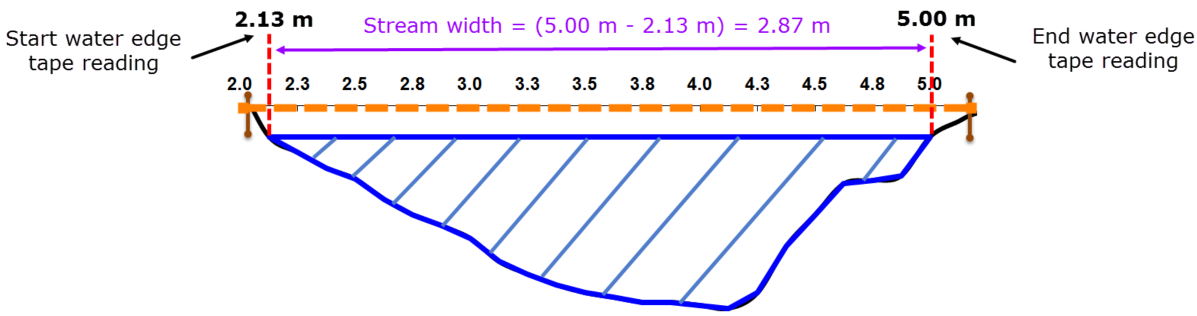


FIGURE 8-4 COMPUTATION PROCEDURE OF THE CROSS-SECTION WIDTH

3. Compute a total width of the stream water surface in cross-section by subtracting the tape reading for the start edge from the tape reading for the end water edge.

4. Write down the result.

⚠ By the start edge of the water surface in a cross-section we mean the edge with a lower distance reading on the tape.

8.3 Determining number and spacing of verticals for velocity and depth measurement

In order to completely describe the streambed shape (depths) and the horizontal and vertical velocity in the stream cross-section, an infinite number of verticals would be necessary. For practical reasons the stream depth and velocity is measured at a finite number of verticals. The spacing and number of verticals are crucial for the accurate measurement of the discharge. For this reason between 20 and 30 verticals are normally used. This practice applies to rivers of all widths except where the channel is so narrow that 20 or 30 verticals would be impracticable.

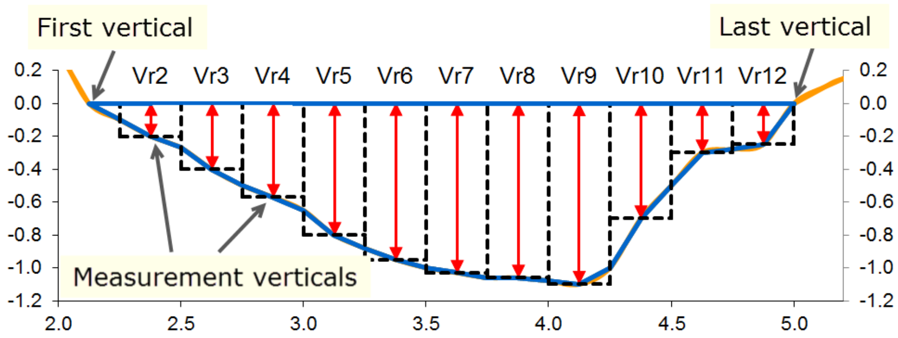


FIGURE 8-5 MEASUREMENT VERTICALS

<u>Streams with widths greater than 10 m (w > 10 m).</u>

Generally, there should be at least 20 verticals across the stream. If the width of the measured stream is more than 10 m wide it is recommended that:

- A minimum of 20 (preferably 25) verticals should be used
- Distance between the verticals should not be larger than:
  - 1/15th of the total stream width for a regular bed profile,
  - 1/20th of the total width for an irregular bed profile,
- Discharge in any one segment does not exceed 10% of the total discharge (preferably not more than 5%).

⚠ Note: it was proven that, independently of the width of the stream, using more than 30 measurement verticals will not improve much the overall accuracy of the measurement.

Stream with widths less than 10 m (w < 10 m).

For small rivers less than 10 meters in width you can use as a first guess the following selection criteria:

TABLE 8-1 SUGGESTED NUMBER OF VERTICALS IN RELATION TO STREAM WIDTH

Stream width w (m)	Number of verticals
0 < w < 0.5	3 to 4
0.5 ≤ w <1	4 to 5
1 ≤ w < 3	5 to 8
3 ≤ w < 5	8 to 10
5 ≤ w < 10	10 to 20
w ≥ 10	20

The number of verticals (column 2, in the Table 8-1) does not include two verticals close to each of the water's edges (banks).

If the stream is relatively uniform in depth and velocity, or if it is a very narrow, we can use fewer verticals. In very small streams with a small current meter we can measure at 0.25 m or 0.125 m intervals even if we only have five or ten measurement verticals.

Location of the first and last vertical

In natural streams the depth and velocity at water edge are normally zero (0 m) but in the man-made canals with vertical banks the depth and velocity may differ from zero. In both situations it is not possible to use the current at a water edge. Therefore, when making a discharge measurement, the first and last verticals should be located as close as possible to the water edge. The two edge sections will then be very small in proportion to the total measurement and an estimated discharge for these sections will introduce very little if any substantial error.

⚠ Remember – first and last verticals should be as close as possible to the cross-section water surface edges (locations where measurement of depth and velocity is technically possible)

Even or uneven spacing of verticals?

Measurement verticals can be evenly spaced if the streambed is uniform. Conversely, in streams with non-uniform flow or uneven channel structure (e.g. pools and shallow areas), sampling points shall be adjusted to best represent the stream flow. Therefore measurement verticals should be more concentrated in areas with faster or deeper flow.

⚠ Measurement verticals should be closer together wherever there is a lot of variation in the depth or velocity of the cross-section. Remember that discharge in any segment should not exceed 10% of the total discharge (preferably not more than 5%).

8.4 Measurement of depth in the vertical

During wading measurements stream depths are usually measured using marks on a wading rod which is the rod used to suspend the current meter. To measure the stream depth in the vertical you need to:

1. Find the position of the vertical on the measurement tape stretched across the stream cross-section.
2. Position the base of the rod on the streambed and keep rod vertically. The base of the rod should be as flat as possible on the bottom of the stream.
3. Mark stream water surface on the rod with a finger.
4. Read the water level from the marked point on the rod. You should estimate depth when velocity causes "pile-up" on rod.
5. Call out to data recorder on the bank the measured depth.

Measurement of depth should be made at a resolution of ± 5 mm (0.5 cm) for depths < 0.3 m, or ±10 mm (1 cm) for depths > 0.3 m.

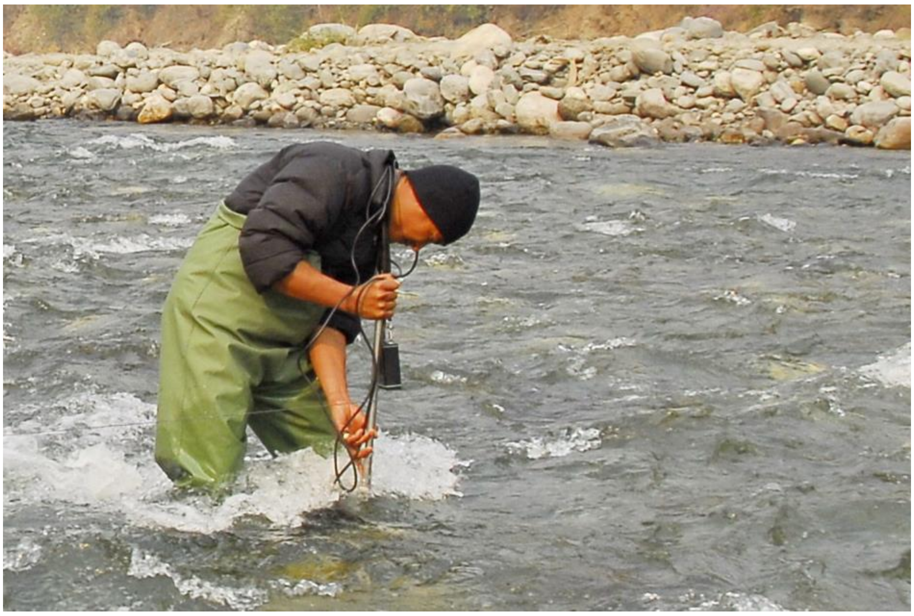


FIGURE 8-6 MEASUREMENT OF DEPTH WITH A WADING ROD

It is desirable to take at least two readings at each vertical. If the readings taken at a vertical differ by less than 5%, their mean value should be adopted. If the readings taken at a vertical differ by more than 5%, two more readings should be taken and the mean value of all four readings should be adopted.

Inaccuracies in depth readings are most likely to occur owing to the penetration of the bed by the wading rod. In sand-bottom streams, or in soft muck, it is sometimes difficult to keep the wading rod from sinking into the streambed.

⚠ You should measure the depth at all verticals in which velocity is measured i.e. the number of verticals at which the depth is measured should be the same as the number of verticals at which velocity is measured.

8.5 Measurement and determination of mean velocity in a vertical

Current meters measure the velocity of flowing water at a point. The measurement of discharge in a river (stream) requires the determination of mean velocity for each sampling vertical across the measuring section. If the flow in the stream is not turbulent it can be assumed that the velocity distribution in a vertical is close to the regular typical “ideal” form (see Chapter 4).

A number of methods are in use to define the mean velocity in a vertical and the choice of method will depend primarily on the depth in vertical but also on the width of the stream and the accuracy required.

The mean velocity in a vertical is normally obtained by measuring velocity at one, two or three points and thereafter applying a correct averaging procedure. The methods provide reliable estimates of mean velocity if the vertical velocity distribution is regular and close to the typical velocity profile.

One-Point Method

Velocity observations should be taken at each vertical by setting the current meter at 0.6 of the depth below the surface (see Figure 8-7). The observed value is considered as the mean velocity in the vertical. This method is generally used in shallow streams and when water depth in vertical is less than 1 m.

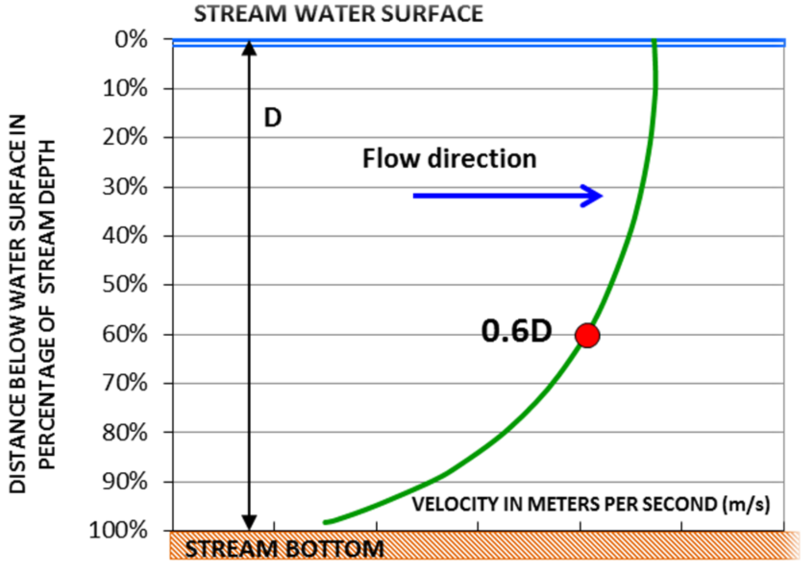


FIGURE 8-7 ONE-POINT METHOD OF VELOCITY MEASUREMENT

One-point method is the least accurate, and it is preferable to use two points in the vertical. However it is often necessary to use this method owing to depth limitations.

Two point Method

Velocities should be measured at 0.2 and 0.8 of the depth below the surface. The average of the two values is taken as the mean velocity in the vertical. This method is generally used when water depth in vertical is more than 1 m (see Figure 8-8).

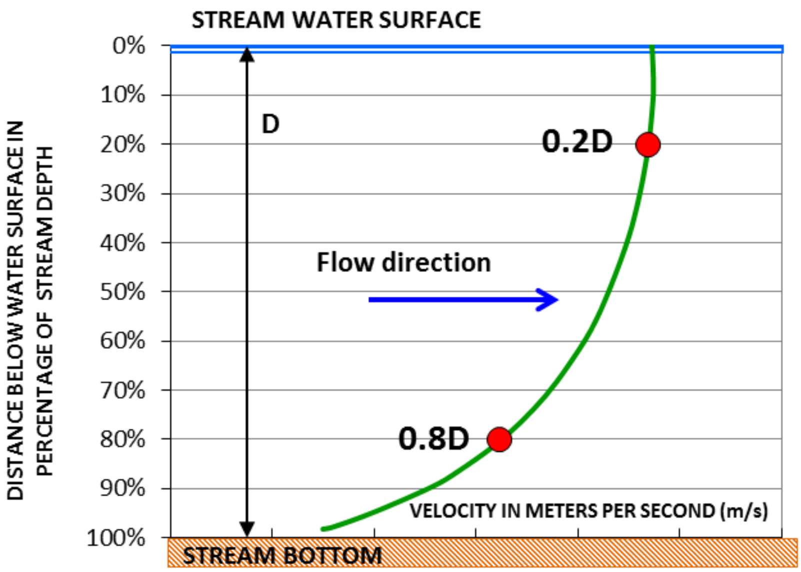


FIGURE 8-8 TWO-POINT METHOD OF VELOCITY MEASUREMENT

This method is widely used and is recommended as the minimum standard method where depth allows.

Three point method

Velocities should be measured at 0.2, 0.6, and 0.8 of the depth below the surface. The mean velocity in the vertical is calculated by first averaging the 0.2 and 0.8 measurements and then averaging the result with the 0.6 value (see Figure 8-9). Usually, the three point method is used when velocity in the vertical varies much and differs from the classical velocity profile.

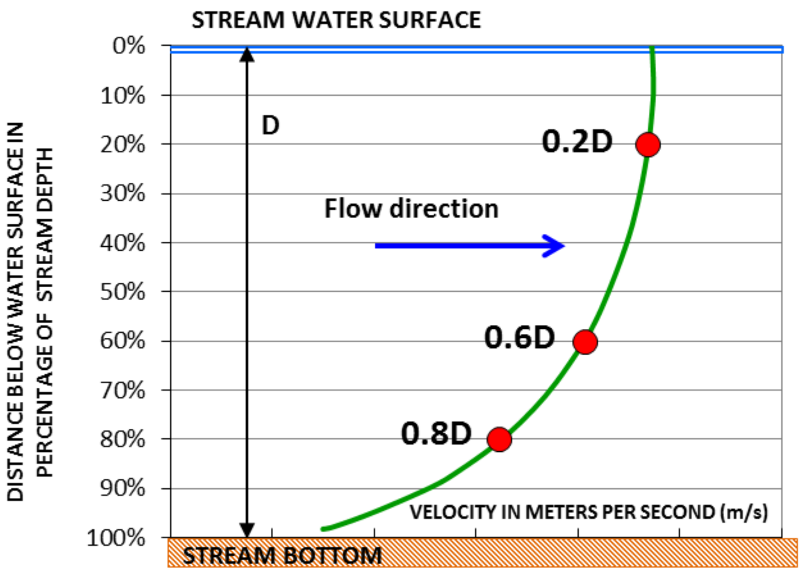


FIGURE 8-9 THREE-POINT METHOD OF VELOCITY MEASUREMENT

The three point method is used where more information on velocity profile is required or where there is some doubt about the regularity of the profile.

TABLE 8-2 SALIENT FEATURES OF THE THREE VELOCITY MEASUREMENT METHODS

Method of measurement	Calculation of mean velocity in a vertical	Water depth limits
One point	$V_{mean} = V_{0.6D}$	0.1 m – 1.0 m
Two point	$V_{mean} = \frac{V_{0.2D} + V_{0.8D}}{2}$	> 1.0 m
Three point	$V_{mean} = \frac{V_{0.2D} + 2V_{0.6D} + V_{0.8D}}{4}$	> 1.0 m

Note: Some sources refer to a depth 0.75 m as a limit for the 0.6 method

The rule of thumb is that:

- The One-Point method is used for depths less than 1.0 m
- Two- Point Method is used for depths greater than 1.0 m

One and two-point methods are commonly used for routine discharge measurement and give acceptable results.

In terms of reducing the overall uncertainty in the discharge measurement it is better to use more verticals than trying to measure more points in the vertical.

Current meter exposure time

The time over which the current meter revolutions are counted (point velocity in vertical is measured) is called exposure time. The selection of exposure time will depend on the physical characteristics of the river cross-section being measured. However, it is important that the time selected is sufficient to minimise errors due to pulsations.

Generally it is recommended to use a minimum exposure time of 40 seconds**.** It should be noted that if the velocities are very low and there are less than 20 revolution counts in 40 seconds the exposure time should be increased to 100 seconds.

Note: ISO748 sets the minimum exposure time at 30 seconds. The standard minimum exposure time recommended in Europe and USA is 40 seconds.

Field procedure for velocity measurement in vertical

The goal is to determine the average velocity in the vertical. To measure the velocities do the following:

1. Find the position of the vertical on the measurement tape stretched across the stream cross-section.
2. Measure the depth in the vertical.

DECIDE ON THE METHOD – ONE POINT 0.6D OR TWO POINTS 0.2D AND 08D. FOLLOW THE GUIDELINES IN

3. Table 8-2.
4. Compute the setting or settings of the current meter.
5. Move the current meter on the wading rod to the desired position.
6. Stand beside and downstream of the rod, keep the rod vertical throughout the measurement with the current meter parallel to the direction of the flow.
7. After the meter is in position allow the propeller to adjust to the stream velocity before starting the propeller revolution counting.
8. Start counting device (begin meter revolution counting).
9. Report number of revolution to the person on the bank.
10. If you are using two point method move current meter to the second position in the vertical (on the rod) and then repeat the procedure.

⚠ Before starting the counter, remember to allow the propeller to adjust to the stream velocity.

⚠ Remember that the current meter counter does not yield velocity at the measurement point but cunts a number of propeller revolutions at this point. In order to compute velocity at that point you need to use the current meter and propeller specific calibration equation. Follow the guidelines in section 7.3.

9. Field Procedure Summary - Discharge Measurements by Wading

Wading gauging is the simplest, usually the least costly and the quickest method of gauging. In the shallow rivers and streams it can usually be carried out by one person. Also, in many instances it can produce the most reliable results.

9.1 Field measurement - step by step procedure

1. Choose a measurement site. Follow the guidelines in Section 8.1.
2. Do visual check of the wading rod, current meter, and the counting device. Repair damage to equipment and replace batteries in counting device if necessary.

3. Perform spin test of the selected current meter. The propeller of the current meter should spin continuously for at least 20-30 seconds
4. Attach the current meter to the wading rod and connect the counting device. Check the electric connection between the current meter and counting device by spinning propeller on the current meter and observing readings of the counter.

5. Make a preliminary crossing of the cross-section before stretching the surveyor tape. Use the wading rod as a support when crossing the river. Turn the rod so that the current meter is on the high end, or remove the meter from the rod to avoid damage. Try to obtain an overall impression of the depths and velocities while wading. This is also a good time to look for rocks and debris that might be removed from the channel bed to improve the metering section.

6. Anchor surveyor's tape firmly on one of the banks. Wade across the river stringing the surveyor tape at a right angle to the direction of the river current. Anchor the tape on the second bank. You can put wood stakes on each side of the stream to attach the tape so it stretches across the entire stream. Provide at least 0.3 m of clearance between the water surface and the tape. Follow the guidelines in section 8.2.

7. Record the stream width. Follow the guidelines in section 8.2. Report the measured width to the person on the bank that is recording measurement data.
8. Determine the number of discharge measuring segments (spacing of verticals). Follow the guidelines in Section 8.3. For a stream wider than 10 m you should use 20 to 30 verticals. Reduce

the distance between verticals in parts of the stream cross-section containing the majority of flow.

9. The measurement starts at the water edge of the near bank. Person wading in stream calls out to data recorder on shore the distance reading on the tape for the start edge of stream water surface.

10. Choose the location of first vertical. You should follow the guidelines in Section 8.3.
11. Person wading the stream calls out to data recorder on shore the distance reading on the tape for the first measuring vertical (location of vertical).
12. Measure the depth in the vertical. You should follow the guidelines in Section 8.5.

DECIDE ON THE METHOD OF VELOCITY MEASUREMENT IN VERTICAL – ONE POINT 0.6D OR TWO AND 08D. FOLLOW THE GUIDELINES IN

13. Table 8-2.
14. Data recorder or the person wading the stream computes setting or settings of the current meter.
15. Person wading the stream adjusts current meter on the wading rod to the desired position.

16. Start velocity measurement. Keep the rod vertical throughout the measurement with the meter parallel to the direction of flow. After the meter is in position allow the propeller to adjust to the stream velocity before the count of the propeller revolution is started. This may take only a few seconds where velocities are over about 0.3 m/s but a longer period is necessary when velocities are lower.

17. Person wading the stream starts the counting device (begins meter revolution counting) for a minimum of 40 s. You should follow the guidelines in Section 9.5.

18. Person wading the stream reports number of revolution to the person on the bank.

19. If you are using the two point method move current meter to the second position in the vertical (on the rod) and then repeat the velocity measurement procedure.

20. Data recorder writes down the information collected in the vertical i.e. distance tape reading, depth and velocity data in the field form.

21. Person wading the stream moves to the next measurement vertical. At each measurement vertical you need to read and record the distance on the tape and the water depth. Subsequently you take the velocity measurement in vertical.
22. Repeat procedure at each vertical until you have reached the end water edge on the opposite bank.

9.2 Tips and Advice

Position of current meter operator and the current meter.

The position of the operator is important to ensure that his body does not affect the flow pattern around the current meter. Try to stand and take measurements on the downstream side of the tape. The best position is to stand facing one or other of banks, slightly downstream from the meter and at arm's length from it.

Hold the wading rod in a vertical position and the current meter parallel to the direction of the flow while making the velocity observation. Any deviation from the vertical position of the rod will introduce an error in velocity measurement.

Improving the measurement cross- section

Where necessary, take the time to improve the measurement cross- section by removing boulders and debris from the measurement cross-section and the area immediately upstream the cross-section. Remove weeds for a distance of about three times the depth from the area upstream and downstream from the section. On smaller watercourses it may be possible to construct small dikes to cut off sections of shallow flows and dead water.

After the modifications are made, be certain to allow sufficient time for conditions to stabilize before continuing with the measurement. All improvements to the measurement cross- section should be completed before starting the measurement, i.e. do not make changes to the section (such as moving rocks) during the course of the discharge measurement.

9.3 Field notes

It is important that you record clear, detailed notes prior to, during, and after the measurement. Future evaluations of a measurement depend on the complete and systematic notes. For each discharge measurement the following information should be recorded:

- Party (person conducting measurement listed first, person recording notes listed second),
- The name of a river,
- The location of the discharge measurement site, GPS coordinates,
- The distance upstream or downstream from the reference staff gauges (if any),
- Weather conditions including wind speed and direction (whether upstream or downstream),
- The date and time of commencement of gauging and concurrent staff gauge heights where they exist,
- The current meter model and the serial number of the meter body and propeller,
- The current meter rating equation,
- Thoroughly describe channel, cross-section and flow conditions. Include descriptions of:
  - shape of the channel
  - level of turbulence
  - areas of slack water and eddies
  - presence of boulders, logs, and other barriers influencing depth and velocity measurements
  - presence of any upstream or downstream structures affecting flow velocity,
- Identify the stream banks: left bank (LB) or right bank (RB) respectively when facing downstream.
- In the discharge measurement form for each measurement vertical include following:
  - location of the vertical (distance reading on the tape)
  - depth of the stream in the vertical
  - exposure time for velocity measurement (duration of revolution counting)
  - number of propeller revolutions at each point of velocity measurement in the vertical
- Prior to submittal of notes for review, enter the measurement number, and initials of person compiling the notes.

10. Discharge Calculation by Mid-Section Method

After finishing velocity measurement you need to calculate the total stream discharge. The first calculation of discharge should normally be carried out by the gauging team at the streamflow measurement site. To calculate the discharge we recommend the mid-section method that was adopted in USA and many other countries as a standard computation procedure for the current meter streamflow measurements.

The mid-section method of discharge calculation assumes that the mean velocity in each vertical represents the mean velocity in a subsection (segment). The mean velocity in each vertical is determined by one of the methods described in Chapter 8.5. For each vertical the segment area extends laterally from half the distances from the preceding vertical to half the distance to the next vertical and from the water surface to the sounded depth in the vertical. Subsection's areas are marked by the blue rectangles in Figure 10-1.

When using the mid-section method you will need to calculate discharge separately for each subsection and thereafter to sum up the individual subsection's discharges to obtain the total river discharge (see Paragraph 6).

Figure 10-1 shows diagrammatically the measurement cross-section of a river. The cross-section is defined by observation (measurement) verticals at locations 1, 2, 3, 4, . . . , n. At each location, the depths are sounded with the wading road and the velocities are sampled by current meter to obtain the mean of the vertical distribution of velocity. The partial discharge is now computed for any subsection (segment) as:

$$q_i = v_i \left[\frac{(L_i - L_{i-1})}{2} + \frac{(L_{i+1} - L_i)}{2} \right] d_i \quad = \quad v_i \left[\frac{(L_{i+1} - L_{i-1})}{2} \right] d_i \qquad (10.1)$$

where
- q_i discharge through partial section (segment) i,
- v_i mean velocity in vertical i,
- L_i distance from initial point to vertical I
- L_{i-1} distance from initial point to preceding vertical,
- L_{i+1} distance from initial point to next vertical,
- d_i depth of water at vertical i.

The procedure is slightly different for the first and the last segments in cross-section. The main difference is in the determination of the widths. Because at the beginning (first) and the end (last) subsections there is no preceding or following vertical, the width becomes one-half the distance from the edge (bank) to the first vertical or from the last vertical to the edge (bank). For the first segment (1) shown shaded blue in Figure 10-1 the discharge is computed as:

$$q_1 = v_1 \left[\frac{L_2 - L_1}{2} \right] d_1 \qquad (10.2)$$

where
- q_1 discharge through segment 1,
- v_1 mean velocity in vertical 1,
- L1 distance on the tape corresponding to location of vertical 1 (start water edge)
- L2 distance on the tape corresponding to location of vertical 2,
- d_1 depth of water at vertical 1 (at start bank water edge).

and for the last subsection (n) as:

$$q_n = v_n \left[\frac{L_n - L_{(n-1)}}{2}\right] d_n \qquad (10.3)$$

where
- q_n discharge through segment n,
- v_n mean velocity in vertical n,
- L(n-1) distance on the tape corresponding to location of vertical n-1,
- L(n) distance on the tape corresponding to location of vertical n,
- d_n depth of water at vertical n (at end bank water edge).

10.1 Calculation example

Referring to Figure 10-1, which shows diagrammatically the stream cross-section and the computation example in Table 10-1 we used twenty two (22) measurement verticals to gauge a stream width the width of 11.2 m. Two additional edge verticals: start bank water edge (SBWE) and end bank water edge (EBWE) complete the measurement.

TABLE 10-1 EXAMPLE OF COMPUTATION OF A CURRENT METER DISCHARGE MEASUREMENT

Sec. number No.	Dist. to initial point	Width	Meas. depth	Rev 0.2D	Rev 0.6D	Rev 0.8D	Time	Vel. At 0.2D point	Vel. At 0.6D point	Vel. At 0.8D point	Mean vel.	Area	Discharge	section flow
	m	m	m				sec	m/s			m/s	m2	m3/s	%
SBWE	0.20	0.40	0.00				30							
2	1.00	0.65	0.45		10		30		0.095		0.095	0.293	0.028	**1.2**
3	1.50	0.50	0.74		14		30		0.128		0.128	0.370	0.047	**2.1**
4	2.00	0.50	0.70		10		30		0.095		0.095	0.350	0.033	**1.5**
5	2.50	0.50	0.75		10		30		0.095		0.095	0.375	0.036	**1.6**
6	3.00	0.50	0.86		14		30		0.128		0.128	0.430	0.055	**2.5**
7	3.50	0.50	0.97	29		18	30	0.251		0.161	0.206	0.485	0.100	**4.5**
8	4.00	0.50	0.94	39		29	30	0.334		0.251	0.293	0.470	0.138	**6.1**
9	4.50	0.50	1.04	50		19	30	0.424		0.169	0.297	0.520	0.154	**6.9**
10	5.00	0.50	0.98	55		14	30	0.467		0.128	0.297	0.490	0.146	**6.5**
11	5.50	0.50	0.82		37		30		0.317		0.317	0.410	0.130	**5.8**
12	6.00	0.50	0.64		46		30		0.391		0.391	0.320	0.125	**5.6**
13	6.50	0.40	0.78		45		30		0.383		0.383	0.312	0.120	**5.3**
14	6.80	0.35	0.77		67		30		0.569		0.569	0.270	0.153	**6.8**
15	7.20	0.35	0.68		65		30		0.552		0.552	0.238	0.131	**5.9**
16	7.50	0.40	0.78		53		30		0.449		0.449	0.312	0.140	**6.3**
17	8.00	0.50	0.68		45		30		0.383		0.383	0.340	0.130	**5.8**
18	8.50	0.50	0.70		45		30		0.383		0.383	0.350	0.134	**6.0**
19	9.00	0.50	0.68		28		30		0.243		0.243	0.340	0.083	**3.7**
20	9.50	0.50	0.57		65		30		0.552		0.552	0.285	0.157	**7.0**
21	10.00	0.50	0.44		50		30		0.424		0.424	0.220	0.093	**4.2**
22	10.50	0.50	0.52		41		30		0.350		0.350	0.260	0.091	**4.1**
23	11.00	0.45	0.20		19		30		0.169		0.169	0.090	0.015	**0.7**
EBWE	11.40	0.20	0.00				30		0.095			0.000		
Total		**11.20**									**0.298**	**7.529**	**2.240**	**100**

To gauge the streamflow in cross-section we used the Seba mini current meter M1 and a propeller with a diameter of 50 mm and pitch 250 mm. The rating equation (calibration equation) of this propeller is:

$$v = 0.2473 * n + 0.0123 \qquad 0.00 < n < 1.74 \qquad (10.4)$$

$$v = 0.2568 * n - 0.0042 \qquad 1.74 \leq n < 10.0$$

where v Velocity at measurement point in meter per second (m/s),
n Number of propeller rotation per second (1/s),

To compute the value of n you have to divide number of revolutions registered by the counter per the exposure time i.e. the time over which the current meter revolutions are counted. In the example measurement (Table 10-1) the 30 s exposure time was used.

For the majority of verticals we used the 0.6D method of velocity measurement. The two point method (0.2D and 0.8D) was used in four (4) verticals with depths close to 1 m. It should be noted that that the discharge in any one of subsections (segments did not exceed 10% of the total discharge.

The formula 10.1 may look complicated but a computation procedure is in fact quite simple. Referring to the Table 10.1 we will illustrate this procedure for the segment no 5 (heavily outlined in Figure 10-1)

From equation 10.1, the discharge passing through segment 5 can be calculated as:

$$q_5 = v_5 \left[\frac{L_6 - L_4}{2}\right] d_5 \qquad (10.5)$$

where q_5 discharge through segment 5
v_5 mean velocity in vertical 5
L4 distance on the tape corresponding to location of vertical 4,
L6 distance on the tape corresponding to location of vertical 6,
d_5 depth of water at vertical 5

The step by step calculation procedure is presented below.

The width (W_5) of segment 5 is calculated as follows:

$$W_5 = \left[\frac{L_6 - L_4}{2}\right] = \left[\frac{3.00\ m - 2.00\ m}{2}\right] = 0.5\ m \qquad (10.6)$$

where W_5 width of segment 5
L4 distance on the tape corresponding to location of vertical 4,
L6 distance on the tape corresponding to location of vertical 6,

Next, since the measured depth in segment 5 is 0.75 m the area of the segment 5 can be calculated as:

$$A_5 = \left[\frac{L_6 - L_4}{2}\right] d_5 = W_5 * d_5 = 0.5\ m * 0.75\ m = 0.375\ m^2 \qquad (10.7)$$

where	A_5	Area of segment 5,
	W_5	Width of segment 5
	d_5	depth of water at vertical 5
	L4	distance on the tape corresponding to location of vertical 4,
	L6	distance on the tape corresponding to location of vertical 6,

To determine the discharge in segment 5, we need to estimate the average velocity in this segment. The depth of stream in the vertical 5 (0.75 m) is less than 1 m and therefore we used the one point method to calculate the mean velocity in a vertical. With the current meter set on the wading rod at 0.6 of the depth below the surface (see Figure 8-7) and for 30 s long current meter exposure time the registered (measured) number of propeller revolutions in vertical 5 was 10.

Subsequently, we calculated the number of revolutions by second in vertical 5 (n_5) by dividing the total measured number of revolutions by the current meter exposure time:

$$n_5 = \left[\frac{Rev\ 06D}{T}\right] = \left[\frac{10}{30s}\right] = 0.330\ \frac{1}{s} \qquad (10.8)$$

where	Rev 06.D	Registered (measured) number of propeller revolutions at 0.6 depth below the surface for a given exposure time,
	T	Set exposure time of current meter,

In the next step we computed the velocity at 0.6 of the depth below the surface by using the rating equation 10.4. Since n_5 equals 0.330 1/s and this value is less than 1.74, to estimate velocity in the vertical 5 we have used the first of two Seba M1 rating equations:

$$v = 0.2473 * n + 0.0123 \qquad 0.00 < n < 1.74 \qquad (10.9)$$

$$v_5 = 0.2473 * 0.330 + 0.0123 = 0.095\ \frac{m}{s} \qquad (10.10)$$

Finally, we calculated the total discharge in segment no. 5 as:

$$q_5 = v_5 \left[\frac{L_6 - L_4}{2}\right] d_5 = v_5 * A_5 = 0.095\ \frac{m}{s} * 0.375\ m^2 = \mathbf{0.036}\frac{\mathbf{m^3}}{\mathbf{s}} \qquad (10.12)$$

where	q_5	discharge through segment 5
	v_5	mean velocity in vertical 5
	L4	distance on the tape corresponding to location of vertical 4,
	L6	distance on the tape corresponding to location of vertical 6,
	d_5	depth of water at vertical 5
	A_5	area of segment 5,

Table 10-1 reveals that the total discharge in the measurement cross-section is **2.24 m^3/s**. The share of the discharge in segment 5 is then 1.6% and it was calculated as follows:

$$\left[\frac{q_5}{Q}\right] = \left[\frac{0.036\ \frac{m^3}{s}}{2.240\ \frac{m^3}{s}}\right] = \mathbf{1.6}\ \% \qquad (10.13)$$

where	q_5	partial discharge through segment 5
	Q	Total discharge in the measurement cross-section

The same procedure was repeated to calculate partial discharges in all segments from 2 to 23.

For the first segment and the last segment of the measurement cross-section the discharge was calculated according to equations 10.2 and 10.3 respectively. The first vertical at the beginning of the cross-section is in our example is considered coincident with the start bank water edge (SBWE) and the last vertical at the end of the cross-section is considered coincident with the end bank water edge (EBWE). The width of segment 1 and is 0.4 m and the calculated width of the last segment is 0.2 m.

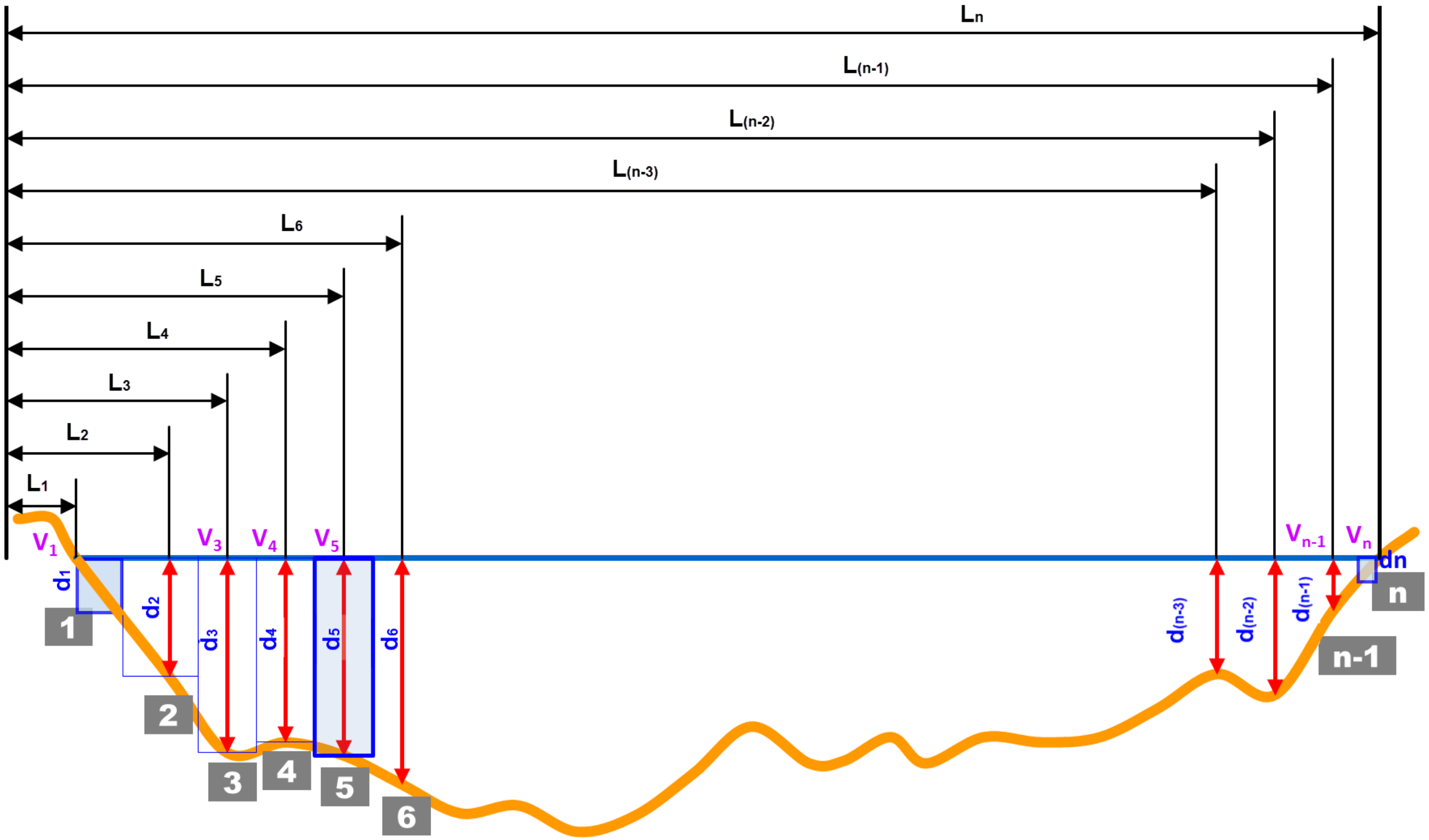
$$W_1 = \left[\frac{L_2 - L_1}{2}\right] = \left[\frac{1m - 0.2\ m}{2}\right] = 0.4\ m \qquad (10.14)$$

$$W_{24} = \left[\frac{L_{24} - L_{23}}{2}\right] d_1 = \left[\frac{11.4\ m - 11.0\ m}{2}\right] = 0.2\ m \qquad (10.15)$$

In our example the depth at the first and at the last vertical is zero and therefore the corresponding discharge both in the first (q_1) and the last segment (q_{24}) is 0 m^3/s.

In man-made canals with vertical sides (banks) the velocity at the boundaries verticals may not be zero (follow guidelines in section 8.3).

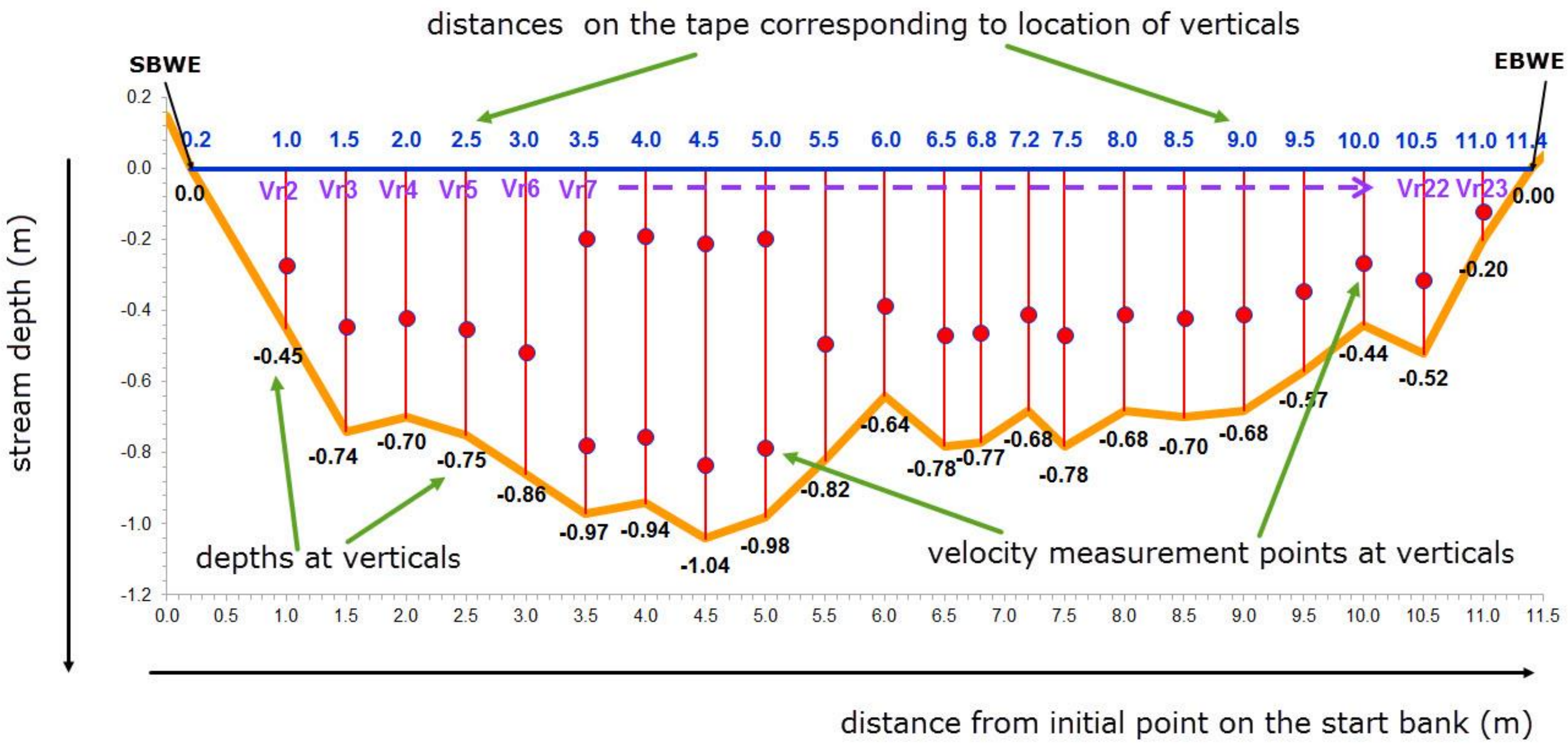
FIGURE 10-1 DEFINITION GRAPH OF THE MID-SECTION METHOD OF COMPUTING DISCHARGE.



Explanations

Observation verticals	1,2,3,…,n-1, n
Measured distance from initial point to the vertical	$L_1, L_2, L_3, \ldots, L_{(n-1)}, L_n$
Depth of the water in meters at the observation vertical	$d_1, d_2, d_3, \ldots, d_{(n-1)}, d_n$
Mean velocity in vertical	$V_1, V_2, V_3, \ldots, V_{(n-1)}, V_n$
Boundaries of subsections	blue lines

FIGURE 10-2 REFERENCE GRAPH FOR THE COMPUTATION EXAMPLE OF DISCHARGE IN TABLE 10.1 (MID-SECTION METHOD)



Appendix 1 – Summary of discharge measurement methods

Method/Application	Pros	Cons	Limitations
Floats Where none of the other methods are possible or for quick reconnaissance measurement. Accuracy: (+/- 20%)	Simple , easy to use& cheap. Can be used when current meter gauging is not possible.	Less accurate than other methods Estimating position of float in river section can be problematic	An estimate of flow can usually be made using floats for all but the very lowest flows
Velocity-area mechanical current meter – wading Low flow investigations, Accuracy: (+/- 10 %)	Simple, can be undertaken by only one person, cheap.	Shallow rivers only.	Low flows, depth < 1.2 m 0.03m/s < V < 1.2 m/s
Velocity-area Acoustic Doppler Velocimeter (ADV) - wading Low flow investigations, Accuracy: (+/- 10 %)	Very high velocity precision based on pulse-coherent Doppler processing. Outstanding shallow water and low-velocity capability. Comprehensive processing software.	Shallow rivers only. Can't be used in streams with very low sediment content. Needs calibration each three years. Considerably more costly than conventional current meter	Low flows, depth < 1.2 m 0.03m/s < V < 1.2 m/s
ADCP Tethered and Boat mounted Entire flow range of medium and large rivers, Accuracy: (+/- 10 %)	Becoming increasingly popular. Reliable and accurate. Very fast discharge measurement even on very wide river cross-sections. Ideally suited for use on medium and larger rivers.	Equipment costly and technologically advanced. Requires a relatively, highly skilled operator. Sensitive to calibration. Major repairs must be done by the equipment provider. Can't be used in streams with very low sediment content. Not possible to use from boat above 4.0 m/s for safety reasons.	Depths > 0.6 m V < 4.0 m/s Upper velocity limit is based on safety considerations and not due to limitations of the technique
Tracer Dilution gauging Relatively small, steep rivers with turbulent flow, Accuracy: (+/- 10 %)	The method is recommended only for those sites where conventional methods cannot be employed owing to shallow depths, extremely high velocities, or excessive turbulence.	The accuracy of the method critically depends upon complete mixing of the injected solution before the sampling site is reached.	Amount of tracer to be added
Weirs and flumes Smaller rivers and creeks Accuracy: (+/- 5 %)	Highly accurate. Require very little checking by current meter if working within their limits of application. Can provide sensitive and stable controls	High capital cost. Only suitable for smaller rivers.	Limited flow range gauging dependent on the range of controlled stage.

NOTES

NOTES