4.3 Direct Determination of Discharge

Discharge is the volume of water passing through a certain section in a unit time period. It is commonly expressed in cubic metres per second (m^3/s or cumec). The discharge at a site is a function of the cross-section area and flow velocity. The cross-section area, in turn, depends on river stage. At most stations, discharge is measured once a day; at important stations or during high flows, it might be measured more frequently.

Discharge measurement techniques can be broadly classified into two categories: (i) direct determination, and (ii) indirect determination. There are many methods under each category. The important ones are discussed here.

In the direct determination methods either discharge itself is measured or some variable on which discharge depends is measured. The commonly used methods are: velocity-area methods, dilution techniques, electromagnetic method, and ultrasonic method. The first two are described here.

4.4 Velocity-Area Methods

Discharge is the product of cross-sectional area and velocity of water. The velocity-area methods involve measuring the flow area and velocity and these are multiplied to get discharge:

$$Q = v * A \tag{4.1}$$

where Q = discharge [m^3/s], v = velocity [m/s], and A = cross-section of flow [m^2].

Since the velocity of flow at a cross-section varies laterally and with depth, it is not enough to measure the velocity at a single point. Depending on the accuracy required, the width of the stream is divided into a number of vertical portions (Fig. 4.7). In each of these portions, the velocity is measured at one or more points along the depth to get a representative velocity in that portion. The area of the individual portion can be easily calculated if the bed profile and stage are known. The velocity may be measured by a conventional method (for example, float or current meter) or by an advanced procedure, for example, the moving boat technique.

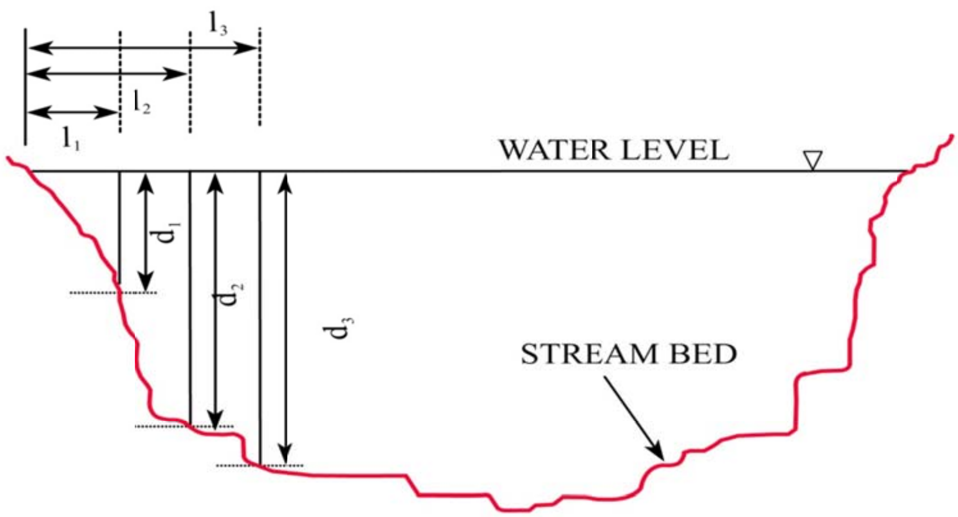
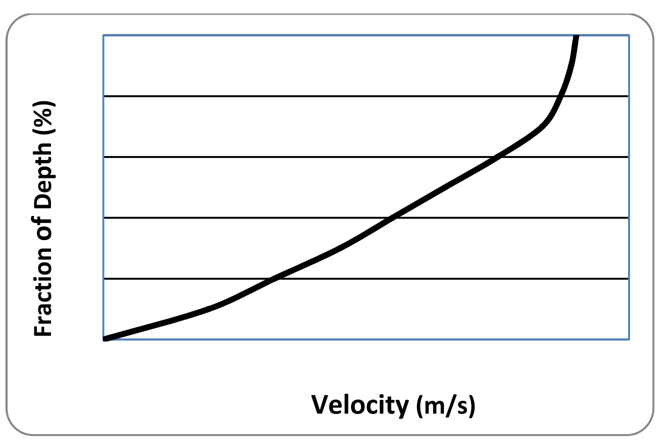


Fig. 4.7 Schematic sketch for a velocity-area station.

Water particles in a river cross-section travel at different velocities. They are subject to friction as they come into contact with the sides and bottom of the channel. Due to these frictional effects, water flows fastest near the surface and center of the channel (away from the immediate frictional influences). A typical velocity profile is shown in Fig. 4.8 where the velocity varies as a parabola from zero at the channel bottom to a maximum at (or near) the surface. Also shown are the contours of equal velocity in typical river cross section.



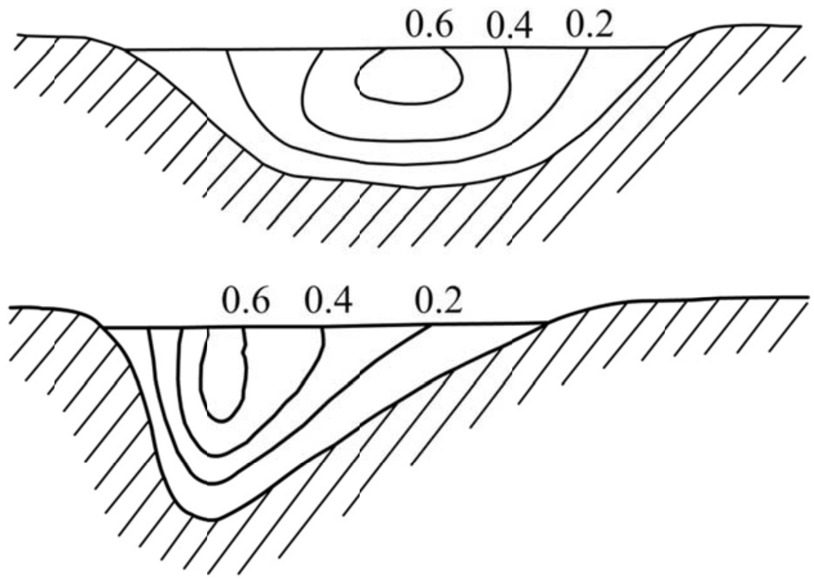


Figure 4.8 Typical velocity profile (top) and velocity distribution (isovels) in a channel (bottom).

4.4.1 Velocity Measurement by Floats

A float is a distinguishable article that floats on the water surface, such as a wooden log, a plastic bottle partly filled with water, or branch of a tree. Surface or near-surface floats are used for streamflow measurement. Normally, these are wooden cylindrical rods of nearly 0.5 m length. They are shaped such that they float nearly vertically with one third of the length protruding above the water surface. The floats are painted in bright colours for easy identification in muddy or turbulent water. At times, a floating article such as a lump of vegetation may be used as a float.

For a float measurement, two cross-sections sufficiently far apart on a straight reach of river are selected. The upstream and downstream cross sections should be sufficiently far apart for accurate assessment of float travel time (3 to 5 times the width of the river or a minimum of 20 seconds travel time). If there is a structure across the river (say a bridge), the upstream section should be sufficiently far from the structure to avoid its effects. Both the cross sections (upstream and downstream) should be clearly marked by placing markers so that the exact time when the float crosses the cross-section can be identified. The upstream channel cross section should be divided into a number (preferably an odd number) of equal segments as practically feasible in which the floats will be placed.

When doing measurements, an observer each is positioned at upstream and downstream ends of the reach such that they are visible to each other. The downstream observer acts as timekeeper and carries a stop watch. Floats are introduced across the stream width a short distance before the actual upstream cross-section so that they lose inertia and travel with the velocity of water when they cross the upstream cross-section. Floats may be tossed from a bridge or cableway; if there is no such facility than they can be thrown in the water from the river bank. When the float crosses the upstream cross-section, the upstream observer gives a signal to the downstream observer who notes the time taken by the float to cover the distance.

The velocity of the float is equal to the distance between the two cross-sections divided by the time taken by the float to cover this distance. The mean velocity in the vertical is determined as the float velocity multiplied by a coefficient which varies between 0.80 and 0.85. This coefficient depends on the shape of the velocity profile of the river and the depth of immersion of the float. Discharge for the segment is calculated as the segment area multiplied by the segment velocity. Total discharge is obtained as the sum of segment discharges and mean velocity of flow is computed as the total discharge divided by total area.

Floats can rarely be positioned at the desired location in the cross section. If these are thrown manually, it is difficult to throw them very far and hence only the velocity of water near the banks can be measured. Float measurements are not very reliable and this method is normally restricted to an emergency or to measure high discharges when current meter is not available or can't be used. Hence, floats should be used only when it is not possible to use any other better method.

4.4.2 Measurement of Flow Velocity by Current Meters

Current meter is the most commonly used instrument to measure the velocity of flowing water. Accurate measurements of the velocity profile of the stream cross section are made by current meters. A current meter consists of rotating element (rotor) whose movement is due to the reaction of the stream current. The angular velocity acquired by the rotor is proportional to the velocity of water. By placing a current meter at a point in a stream and counting the number of revolutions of the rotor during a time interval, the velocity of water at that point is determined. Current meters are of two types: those having a propeller rotating around a horizontal axis and those having a series of conical cups mounted around a vertical axis. The normal range of velocity which can be measured varies from 0.15 to 4.0 m/s.

Horizontal-axis meters consist of a propeller mounted at the end of a horizontal shaft (Fig. 4.9). These are available in a range of propeller diameters. Propellers made up of plastic have been introduced recently. These are cheaper and respond more quickly to changes in velocity. Some current meters come with propellers of different pitch and diameter to suit various flow conditions. The horizontal axis rotor with valves cause less disturbance to flow than vertical axis rotors. Furthermore, due to axial symmetry with the flow direction, the rotor is less likely to be entangled by debris than vertical axis rotors and the bearing friction is less compared to the vertical axis rotors. The vertical axis rotor with cups or valves can operate in lower velocities than the horizontal axis meters, the bearings are well protected from silty water, and a single rotor serves for a range of velocities.

In the propeller-type current meters (Figure 4.9), a propeller rotates about a horizontal axis due to force applied by flowing water. The revolutions per time interval are recorded. The relation between revolutions per second N of the current meter and the water velocity v is given by following equation

$$v = a + b*N \tag{4.2}$$

where b = constant of proportionality and a = starting velocity or velocity required to overcome mechanical friction. These constants differ from one current meter to the other as a result of manufacturing variations as well as change with time due to wear and tear. Therefore, each current meter should be recalibrated periodically.

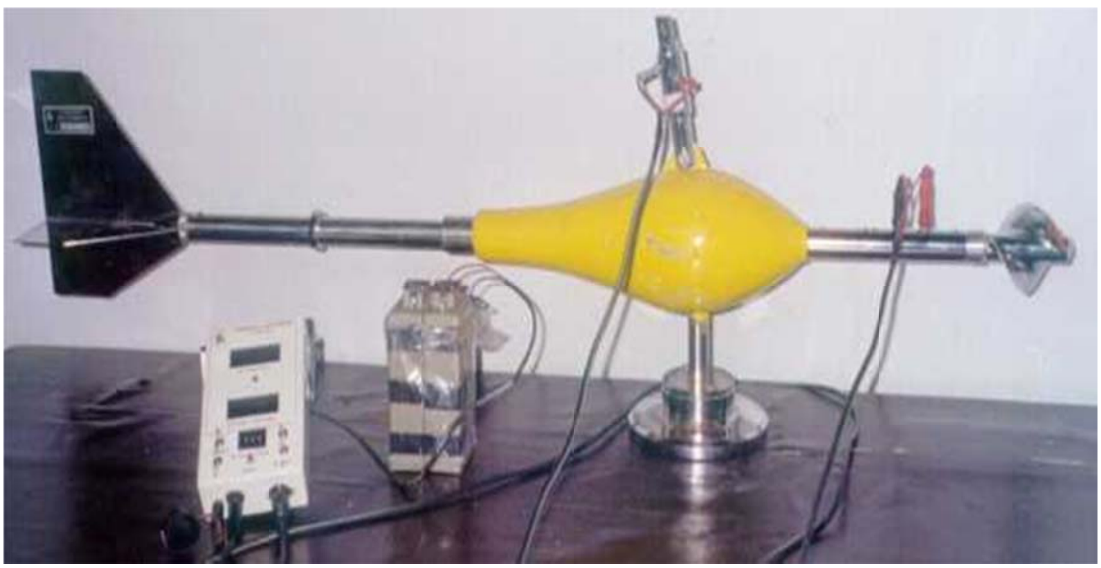


Figure 4.9: Propeller-type current meter

The velocity measurements made by using current meters are usually classified in terms of the means used to cross the stream during measurements, such as wading, cableway, bridge, or boat. Wading is possible in small streams of shallow depth only; the current meter is held at the requisite depth below the surface by an observer who stands in the water. In narrow well-defined channels, a cableway is stretched from bank to bank well above the flood level. A carriage moving over the cableway serves as the observation platform. Bridges are advantageous from the viewpoint of accessibility and transportation, although these are not the best locations from hydraulic point of view. The velocity measurement is performed on the downstream of the bridge to minimize the instrument damage due to drift and knock against bridge piers. Boats are most satisfactory for measurements in wide rivers.

The section line at the gauging site is marked by permanent survey markings. The cross-section along this section line is determined by surveying with the help of sounding rods or sounding weights. When the depth of water is more or if quick and accurate depth measurements are needed, an echo sounder is used.

A discharge measurement requires determination of *sufficient point velocities* in a river cross section to permit computation of *an average velocity* in the stream. The stream is divided into a number of vertical sections. The sum of cross-sectional area of each section multiplied by the average velocity of each section gives the total discharge:

$$Q_{total} = \sum_{i=1}^{n} Q_i = \sum_{i=1}^{m} (A_i - \bar{v}_i) \qquad (4.3)$$

where Q_{total} = total discharge, m = number of sections, Ai = cross area of section I, vi = mean velocity of section i, Qi = discharge in section i.

A current meter measures the velocity at a point. However, the mean velocity in each of the selected vertical segment is required to estimate discharge. The mean velocity in a vertical is determined from velocity observations at one or more points in that vertical. Current meters are held down and positioned at the required location in flowing water by sounding weights. The weights are connected to the current meter by a hanger and pin assembly.

The number of velocity determinations is limited to those which can be made within a reasonable time. If the river stage is changing rapidly, one should quickly complete the measurement with a minimum change in water stage.

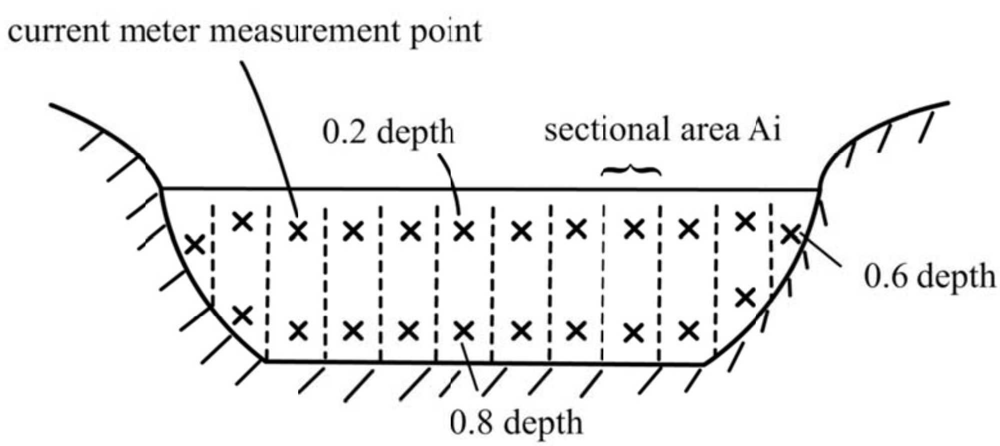


Figure 4.10: Procedure for a current meter measurement

Usually there are national guidelines detailing how the vertical sections should be chosen and in which depth the velocity measurements should be made to determine the mean velocity in the vertical profile. These guidelines aim to ensure homogenous data sets. Two methods that are frequently used to determine the mean velocity over the vertical profile are:

Two point measurement: The variation for most channels is such that the average of the velocities at 0.2d and 0.8d below the surface equals the mean velocity in the vertical.

One point measurement: The velocity at 0.6d depth below the surface closely approximates the mean in the vertical. The adequacy of these assumptions for a particular stream can be tested by making a detailed vertical velocity measurement.

4.4.3 Stage-Discharge Gauging Stations in Natural Channels

When records of water level are to be used as a basis for computation of discharge, the relation between water level and flow must be determined. In a stable channel with an appropriate control feature which is stable and sensitive, a single relation may exist between water level and discharge. In this case, the relation can be determined by taking discharge measurements throughout the range of levels and flows required to be measured. Several techniques are available for this purpose including, current meter gauging and float gauging, dilution gauging transit time acoustic methods, the use of Doppler velocity meters (fixed hydro-acoustic installations) or the Acoustic Doppler Current Meters. The frequency of any maintenance or operational performance shall be such that the accuracy and timeliness of data provision meets the users' requirements.

4.4.4 Discharge Measurements

Discharge measurements using the above techniques shall be related to a stage reading taken at the beginning and end of the discharge measurement and during the measurement if the stage is changing rapidly or inconsistently. When sufficient numbers of discharge measurements have been taken, a stage discharge relationship can be computed. Subsequent to the formulation of this stage-discharge relationship, only occasional discharge measurements need be taken at flows in the normal range to confirm the robustness of the relationship unless the site is subject to shifting control conditions.

Opportunities should be taken to carry out discharge measurements in extreme events in order to extend the stage discharge relationship. Discharge measurements made using the velocity-area methods can be performed using rotating-element current meters, acoustic Doppler velocimeters, or acoustic Doppler current profilers. These can be made by wading the stream or small river with the meter mounted to a wading rod or by suspending the meter and a sounding weight from a bridge, cableway or static boat. Velocity-area methods using floats is another option when the presence of floating debris or very turbulent conditions precludes the use of meters.

Acoustic Doppler current profilers deployed from powerboats, remote-control boats, or tethered rafts also can be used. Tethered rafts typically are deployed from bridges or cableways. Another variation of velocity area methods is the slope-area method, which is typically used to compute flood discharge indirectly by surveying the cross-sectional properties and water-surface profile after the flood. Where a pre-surveyed cross-section is used for the purpose of discharge measurement, then the section shall be checked following any major events e.g. over and above a bank full flow.