

## INTRODUCTION

Streamflow representing the runoff phase of the hydrologic cycle is the most important basic data for hydrologic studies. It was seen in the previous chapters that precipitation, evaporation and evapotranspiration are all difficult to measure exactly and the presently adopted methods have severe limitations. In contrast the measurement of streamflow is amenable to fairly accurate assessment. Interestingly, streamflow is the only part of the hydrologic cycle that can be measured accurately.

A stream can be defined as a flow channel into which the surface runoff from a specified basin drains. Generally, there is considerable exchange of water between a stream and the underground water. Streamflow is measured in units of discharge ( $\text{m}^3/\text{s}$ ) occurring at a specified time and constitutes historical data. The measurement of discharge in a stream forms an important branch of *Hydrometry*, the science and practice of water measurement. This chapter deals with only the salient streamflow measurement techniques to provide an appreciation of this important aspect of engineering hydrology. Excellent treatises<sup>1, 2, 4, 5</sup> and a bibliography<sup>6</sup> are available on the theory and practice of streamflow measurement and these are recommended for further details.

Streamflow measurement techniques can be broadly classified into two categories as (i) direct determination and (ii) indirect determination. Under each category there are a host of methods, the important ones are listed below:

1. Direct determination of stream discharge:
  - (a) Area-velocity methods,
  - (b) Dilution techniques,
  - (c) Electromagnetic method, and
  - (d) Ultrasonic method.
2. Indirect determination of streamflow:
  - (a) Hydraulic structures, such as weirs, flumes and gated structures, and
  - (b) Slope-area method.

Barring a few exceptional cases, continuous measurement of stream discharge is very difficult. As a rule, direct measurement of discharge is a very time-consuming and costly procedure. Hence, a two step procedure is followed. First, the discharge in a given stream is related to the elevation of the water surface (Stage) through a series of careful measurements. In the next step the stage of the stream is observed routinely in a relatively inexpensive manner and the discharge is estimated by using the previously determined stage–discharge relationship. The observation of the stage is easy, inexpensive, and if desired, continuous readings can also be obtained. This method of discharge determination of streams is adopted universally.

## MEASUREMENT OF STAGE

The stage of a river is defined as its water-surface elevation measured above a datum. This datum can be the mean-sea level (MSL) or any arbitrary datum connected independently to the MSL.

### MANUAL GAUGES

**STAFF GAUGE** The simplest of stage measurements are made by noting the elevation of the water surface in contact with a fixed graduated staff. The staff is made of a durable material with a low coefficient of expansion with respect to both temperature and moisture. It is fixed rigidly to a structure, such as an abutment, pier, wall, etc. The staff may be vertical or inclined with clearly and accurately graduated permanent markings. The markings are distinctive, easy to read from a distance and are similar to those on a surveying staff. Sometimes, it may not be possible to read the entire range of water-surface elevations of a stream by a single gauge and in such cases the gauge is built in sections at different locations. Such gauges are called *sectional gauges* (Fig. 4.1). When installing sectional gauges, care must be taken to provide an overlap between various gauges and to refer all the sections to the same common datum.

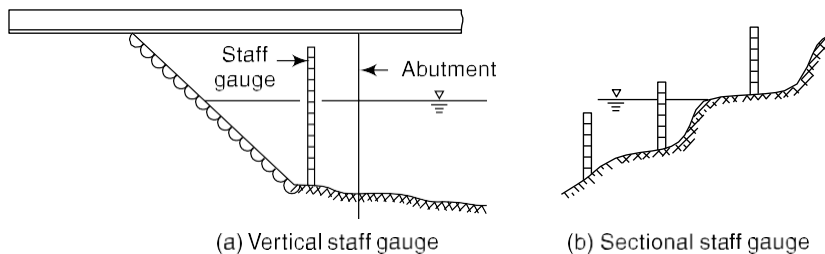


Fig. 1 Staff Gauge

**WIRE GAUGE** It is a gauge used to measure the water-surface elevation from above the surface such as from a bridge or similar structure. In this a weight is lowered by a reel to touch the water surface. A mechanical counter measures the rotation of the wheel which is proportional to the length of the wire paid out. The operating range of this kind of gauge is about 25 m.

### AUTOMATIC STAGE RECORDERS

The staff gauge and wire gauge described earlier are manual gauges. While they are simple and inexpensive, they have to be read at frequent intervals to define the variation of stage with time accurately. Automatic stage recorders overcome this basic objection of manual

staff gauges and find considerable use in stream-flow measurement practice. Two typical automatic stage recorders are described below.

*FZOAT-CAYCE RECOrDEr* The Float-operated stage recorder is the most com-mon type of automatic stage recorder in use. In this, a float operating in a stilling well is balanced by means of a counterweight over the pulley of a recorder. Displacement of the float due to the rising or lowering of the water-surface elevation causes an angular displacement of the pulley and hence of the input shaft of the recorder.

Mechanical linkages convert this angular displacement to the linear displacement of a pen to record over a drum driven by clockwork. The pen traverse is continuous with automatic reversing when it reaches the full width of the chart. A clockwork mechanism runs the re-corder for a day, week or fortnight and provides a continuous plot of stage vs time. A good instrument will have a large-size float and least fric-

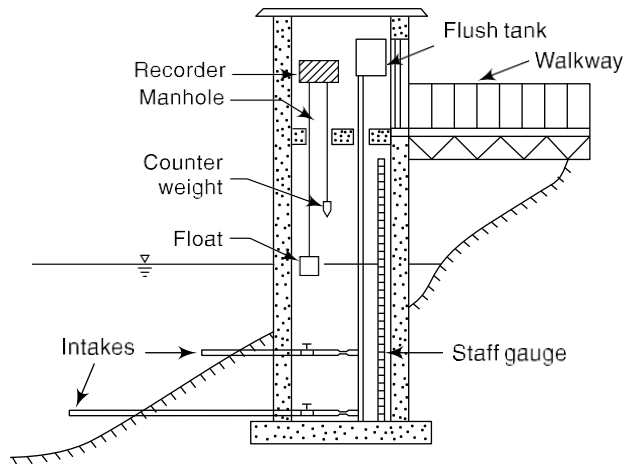
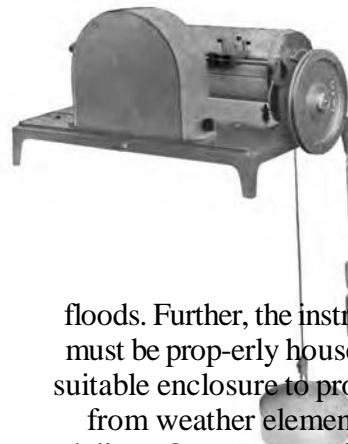


Fig. 2 Stilling well Installation



tion. Improvements over this basic analogue model consists of models that give digital signals recorded on a storage device or transmit directly onto a central data-processing centre. To protect the float from debris and to reduce the water surface wave effects on the re-cording, *stilling wells* are provided in all float-type stage recorder installations. Figure 4.2 shows a typical stilling well installation. Note the intake pipes that communicate with the river and flushing arrangement to flush these intake pipes off the sediment and debris occasionally. The water-stage recorder has to be located above the highest water level expected in the stream to prevent it from getting inundated dur-

ing floods. Further, the instrument must be properly housed in a suitable enclosure to protect it from weather elements and vandalism. On account of these, the water-stage-recorder installations prove to be costly in most instances. A water-depth recorder is shown in Fig. 3.

Fig. 3 Water-depth recorder—Stevens Type F recorder (*Courtesy: Leupold and Stevens, Inc. Beaverton, Oregon, USA*)

*BYBBZE CAYCE* In this gauge compressed air or gas is made to bleed out at a very small rate through an outlet placed at the bottom of the river [Figs. 4, 5 and 6]. A pressure gauge measures the gas pressure which in turn is equal to the water column above the outlet. A small change in the water-surface elevation is felt as a change in pressure from the present value at the pressure gauge and this in turn is adjusted by a servo-mechanism to bring the gas to bleed at the original rate under the new head. The pressure gauge reads the new water depth which is transmitted to a recorder.

The bubble gauge has certain specific advantages over a float operated water stage recorder and these can be listed as under:

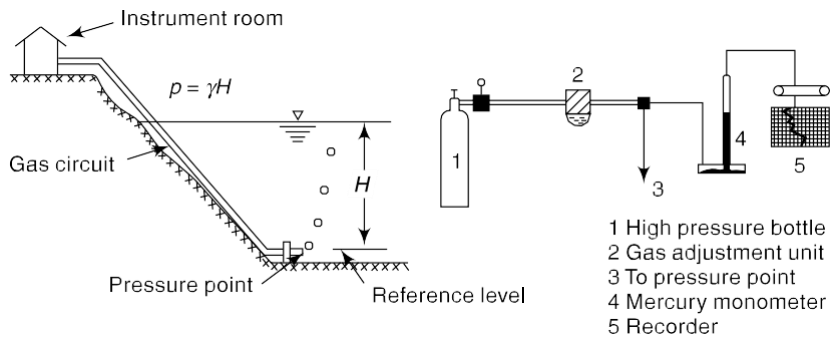


Fig. 4 Bubble Gauge



Fig. 5 Bubble Gauge Installation—  
Telemnip  
(Courtesy : Neyrtec, Grenoble,  
France)

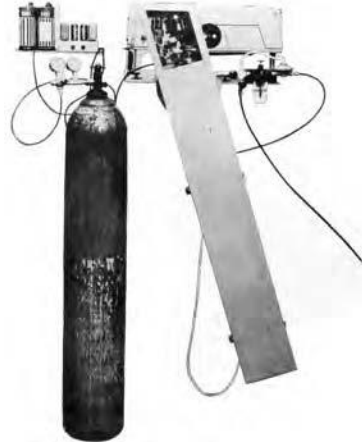
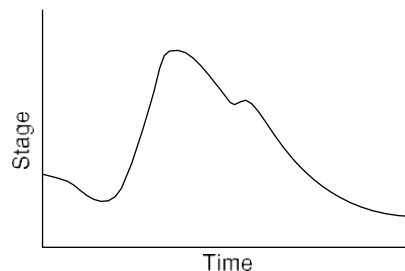


Fig. 6 Bubble Gauge—Stevens  
Manometer Servo  
(Courtesy : Leupold and Stevens,  
Inc.  
Beaverton, Oregon, USA)

3. there is no need for costly stilling wells;
4. a large change in the stage, as much as 30 m, can be measured;
5. the recorder assembly can be quite far away from the sensing point;  
and
6. due to constant bleeding action there is less likelihood of the inlet  
getting blocked or choked.

#### STAGE DATA

The stage data is often presented in the form of a plot of stage against chronological time (Fig. 4.7) known as *stage hydrograph*. In addition to its use in the determination of stream



discharge, stage data itself is of importance in design of hydraulic structures, flood warning and flood-protection works.

Reliable long-term stage data corresponding

Fig. 7 Stage Hydrograph

to peak floods can be analysed statistically to estimate the design peak river stages for use in the design of hydraulic structures, such as bridges, weirs, etc. Historic flood stages are invaluable in the indirect estimation of corresponding flood discharges. In view of these multifarious uses, the river stage forms an important hydrologic parameter chosen for regular observation and recording.

## MEASUREMENT OF VELOCITY

The measurement of velocity is an important aspect of many direct stream flow measurement techniques. A mechanical device, called *current meter*, consisting essentially of a rotating element is probably the most commonly used instrument for accurate determination of the stream-velocity field. Approximate stream velocities can be determined by floats.

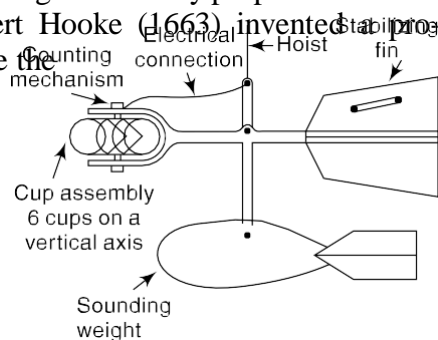
### CURRENT METERS

The most commonly used instrument in hydrometry to measure the velocity at a point in the flow cross-section is the current meter. It consists essentially of a rotating element which rotates due to the reaction of the stream current with an angular velocity proportional to the stream velocity. Historically, Robert Hooke (1663) invented a propeller-type current meter to measure the distance traversed by a ship. The present-day cup-type instrument and the electrical make-and-break mechanism were invented by Henry in 1868. There are two main types of current meters.

7. Vertical-axis meters, and
8. Horizontal-axis meters.

**VERTICAL-AXIS METERS** These instruments consist of a series of conical cups mounted around a vertical axis

[Figs. 4.8 and 4.9]. The cups rotate in a horizontal plane and a cam attached to the vertical axial spindle records generated signals proportional to the revolutions of the cup assembly. The Price current meter and Gurley current meter are typical instruments under this category. The normal range of



velocities is from 0.15 to 4.0 m/s. The accuracy of these instruments is about 1.50% at the threshold value and improves to about 0.30% at speeds in excess of 1.0 m/s. Vertical-axis instruments have the disadvantage that they cannot be used in situations where there are appreciable vertical components of velocities. For

exam-ple, the instrument shows a positive ve-locity when it is lifted vertically in still water.

Fig. 8 Vertical-axis Current Meter

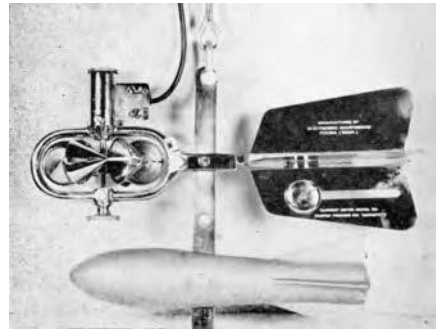


Fig. 9 Cup-type Current Meter with Sounding Weight—'Lynx' Type  
(Courtesy: Lawrence and Mayo (India) New Delhi)

### *HOrIZOmTAZ-AXIS METErS*

These meters consist of a propeller mounted at the end of horizontal shaft as shown in Fig. 10 and Fig. 11. These come in a wide variety of size with propeller diam-eters in the range 6 to 12 cm, and can register velocities in the range of 0.15 to

4.0 m/s. Ott, Neyrtec [Fig. 12] and Watt-type meters are typical instruments under this kind. These meters are fairly rugged and are not affected by oblique flows of as much as  $15^\circ$ . The accuracy of the in-strument is about 1% at the threshold value and is about 0.25% at a velocity of 0.3 m/s and above.

A current meter is so designed that its rotation speed varies linearly with the stream velocity  $v$  at the location of the in-strument. A typical relationship is

$$v = aN_s + b \quad (4.1)$$

) where  $v$  = stream velocity at the instru-ment location in m/s,  $N_s$  = revolutions per second of the meter and  $a, b$  = constants of the meter. Typical values of  $a$  and  $b$  for a standard size 12.5 cm diameter Price meter (cup-type) is  $a = 0.65$  and  $b = 0.03$ . Smaller meters of 5 cm diameter cup as-sembly called *pigmy meters* run faster and are useful in measuring small veloci-ties. The values of the meter constants for them are of the order of  $a = 0.30$  and  $b = 0.003$ . Further, each instrument has a



Fig. 10 Propeller-type Current Meter—Neyrtec Type with Sounding Weight

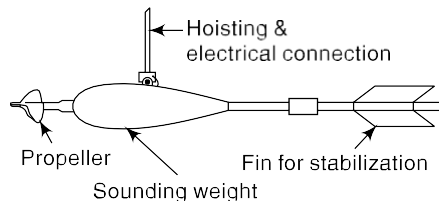


Fig. 11 Horizontal-axis Current Meter

threshold velocity below which Eq. (4.1) is not applicable. The

instruments have a provision to count the number of revolutions in a known interval of time. This is usually accomplished by the making and breaking of an electric circuit either mechanically or electromagnetically at each revolution of the shaft. In older model instruments the breaking of the circuit would be counted through an audible sharp signal (“tick”) heard on a headphone. The revolutions per second is calculated by counting the number of such signals in a known interval of time, usually about 100 s. Present-day models employ electromagnetic counters with digital or analogue displays.

#### CaLIBRATION

The relation between the stream velocity and revolutions per second of the meter as in Eq. (4.1) is called the *calibration equation*. The calibration equation is unique to each instrument and is determined by towing the instrument in a special tank. A *towing tank* is a long channel containing still water with arrangements for moving a carriage

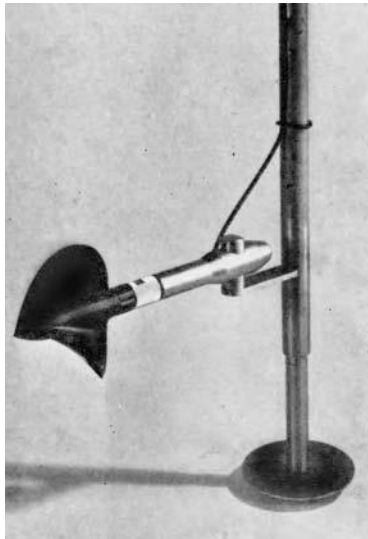


Fig. 12(a) Neyrtec Type Current Meter for use in Wading (Courtesy: Neyrtec, Grenoble, France)



Fig. 12(b) Neyrtec Type Meter in a Cableway

longitudinally over its surface at constant speed. The instrument to be calibrated is mounted on the carriage with the rotating element immersed to a specified depth in the water body in the tank. The carriage is then towed at a predetermined constant speed ( $v$ ) and the corresponding average value of revolutions per second ( $N_G$ ) of the instruments determined. This experiment is repeated over the complete range of velocities and a best-fit linear relation in the form of Eq. (4.1) obtained. The instruments are designed for rugged use and hence the calibration once done lasts for quite some time. However, from the point of view of accuracy it is advisable to check the instrument calibration once in a while and whenever there is a suspicion that the instrument is damaged due to bad handling or accident. In India excellent towing-tank facilities for calibration of current meters exist at the Central Water and Power Research Station, Pune and the Indian Institute of Technology, Madras.

#### FIELD USE

The velocity distribution in a stream across a vertical section is logarithmic in nature.

In a rough turbulent flow the velocity distribution is given by

$$(30 y)$$

$$v = 5.75 v^* \log_{10} \frac{y}{k_s} \quad (4.2)$$

where  $v$  = velocity at a point  $y$  above the bed,  $v^*$  = shear velocity and  $k_s$  = equivalent sand-grain roughness. To accurately determine the average velocity in a vertical section, one has to measure the velocity at a large number of points on the vertical. As it is time-consuming, certain simplified procedures have been evolved.

- In shallow streams of depth up to about 3.0 m, the velocity measured at 0.6 times the depth of flow below the water surface is taken as the average velocity  $v$  in the vertical,

$$\bar{v} = v_{0.6} \quad (4.3)$$

This procedure is known as the single-point observation method.

- In moderately deep streams the velocity is observed at two points; (i) at 0.2 times the depth of flow below the free surface ( $v_{0.2}$ ) and (ii) at 0.8 times the depth of flow below the free surface ( $v_{0.8}$ ). The average velocity in the vertical  $v$  is taken as

$$\bar{v} = \frac{v_{0.2} + v_{0.8}}{2} \quad (4.4)$$

- In rivers having flood flows, only the surface velocity ( $v_s$ ) is measured within a depth of about 0.5 m below the surface. The average velocity  $\bar{v}$  is obtained by using a reduction factor  $K$  as

$$\bar{v} = K v_s \quad (4.5)$$

The value of  $K$  is obtained from observations at lower stages and lie in the range of 0.85 to 0.95.

In small streams of shallow depth the current meter is held at the requisite depth below the surface in a vertical by an observer who stands in the water. The arrangement, called *wading* is quite fast but is obviously applicable only to small streams.

In rivers flowing in narrow gorges in well-defined channels a cableway is stretched from bank to bank well above the flood level. A carriage moving over the cableway is used as the observation platform.

Bridges, while hydraulically not the best locations, are advantageous from the point of view of accessibility and transportation. Hence, railway and road bridges are frequently employed as gauging stations. The velocity measurement is performed on the downstream portion of the bridge to minimize the instrument damage due to drift and knock against the bridge piers.

For wide rivers, boats are the most satisfactory aids in current meter measurement. A cross-sectional line is marked by distinctive land markings and buoys. The position of the boat is determined by using two theodolites on the bank through an intersection method. Use of total station simplifies the work considerably.

## SOUNDING WEIGHTS

Current meters are weighted down by lead weights called *sounding weights* to enable them to be positioned in a stable manner at the required location in flowing water. These weights are of streamlined shape with a fin in the rear (Fig. 4.8) and are connected to the current meter by a hangar bar and pin assembly. Sounding weights come in different sizes and the minimum weight is estimated as

$$W = 50 v d \quad (4.6)$$

where  $W$  = minimum weight in N,  $v$  = average stream velocity in the vertical in m/s and  $d$  = depth of flow at the vertical in metres.

#### VELOCITY MEASUREMENT BY FLOATS

A floating object on the surface of a stream when timed can yield the surface velocity by the relation

$$\underline{v} = \frac{s}{t} \quad (4.7)$$

where  $S$  = distance travelled in time

$t$ . This method of measuring velocities while primitive still finds applications in special circumstances, such as: (i) a small stream in flood, (ii) small stream with a rapidly changing water surface, and (iii) preliminary or exploratory surveys. While any floating object can be used, normally specially made leakproof and easily identifiable floats are used (Fig.

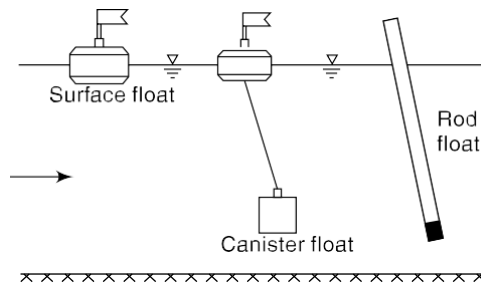


Fig. 4.13 Floats

4.13). A simple float moving on stream surface is called *surface float*. It is easy to use and the mean velocity is obtained by multiplying the observed surface velocity by a reduction coefficient as in Eq. (4.5). However, surface floats are affected by surface winds. To get the average velocity in the vertical directly, special floats in which part of the body is under water are used. *Rod float* (Fig. 4.13), in which a cylindrical rod is weighed so that it can float vertically, belongs to this category.

In using floats to observe the stream velocity a large number of easily identifiable floats are released at fairly uniform spacings on the width of the stream at an upstream section. Two sections on a fairly straight reach are selected and the time to cross this reach by each float is noted and the surface velocity calculated.

#### AREA-VELOCITY METHOD

This method of discharge measurement consists essentially of measuring the area of cross-section of the river at a selected section called the *gauging site* and measuring the velocity of flow through the cross-sectional area. The gauging site must be selected with care to assure that the stage-discharge curve is reasonably constant over a long period of about a few years. Towards this the following criteria are adopted.

- The stream should have a well-defined cross-section which does not change in various seasons.
- It should be easily accessible all through the year.
- The site should be in a straight, stable reach.
- The gauging site should be free from backwater effects in the channel.

At the selected site the section line is marked off by permanent

survey markings and the cross-section determined. Towards this the depth at various locations are measured by sounding rods or sounding weights. When the stream depth is large or when quick and accurate depth measurements are needed, an electroacoustic instrument called *echo-depth recorder* is used. In this a high frequency sound wave is sent down by a transducer kept immersed at the water surface and the echo reflected by the bed is also picked up by the same transducer. By comparing the time interval between the transmission of the signal and the receipt of its echo, the distance to the bed is obtained and is indicated or recorded in the instrument. Echo-depth recorders are particularly advantageous in high-velocity streams, deep streams and in streams with soft or mobile beds.

For purposes of discharge estimation, the cross-section is considered to be divided into a large number of subsections by verticals (Fig. 4.14). The average velocity in these subsections are measured by current meters or floats. It is quite obvious that the

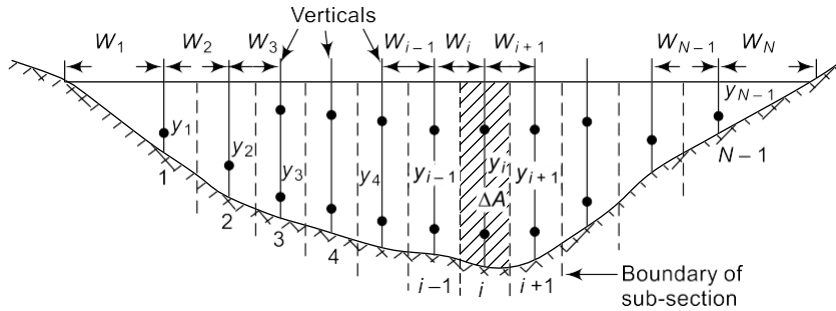


Fig. 14 Stream Section for Area-velocity Method

accuracy of discharge estimation increases with the number of subsections used. However, the larger the number of segments, the larger is the effort, time and expenditure involved. The following are some of the guidelines to select the number of segments.

- The segment width should not be greater than 1/15 to 1/20 of the width of the river.
- The discharge in each segment should be less than 10% of the total discharge.
  - The difference of velocities in adjacent segments should not be more than 20%. It should be noted that in natural rivers the verticals for velocity measurement are not necessarily equally spaced.

The area-velocity method as above using the current meter is often called as the *standard current meter method*.

### CALCULATION OF DISCHARGE

Figure 4.14 shows the cross section of a river in which  $N - 1$  verticals are drawn. The velocity averaged over the vertical at each section is known. Considering the total area to be divided into  $N - 1$  segments, the total discharge is calculated by the *method of mid-sections* as follows.

$$Q = \sum_{i=1}^{N-1} \Delta Q_i \quad (4.8)$$

where  $\Delta Q_i$  = discharge in the  $i$ th segment

$$\begin{aligned} &= (\text{depth at the } i\text{th segment}) \times \left( \frac{1}{2} \text{ width to the left} \right. \\ &\quad \left. + \frac{1}{2} \text{ width to the right} \right) \times (\text{average velocity at the } i\text{th vertical}) \\ \Delta Q_i &= y_i \times \left( \frac{W_{i-1} + W_i}{2} + \frac{W_i + W_{i+1}}{2} \right) \times v_i \quad \text{for } i = 2 \text{ to } (N-2) \end{aligned} \quad (4.9)$$

For the first and last sections, the segments are taken to have triangular areas

and area  
calculated as

$$\Delta A_1 = W_1 \cdot y_1 \left( \frac{W_1}{2} \right)^2$$

where  
e

$$\bar{W}_1 = \frac{W_1 + \frac{2}{2}}{2W_1}$$

and

$$\Delta A_N = \bar{W}_{N-1} \cdot y_{N-1}$$

where

$$\bar{W}_{N-1} = \frac{\left( W + \frac{W_{N-1}}{2} \right)^2}{2W}$$

to get

$$\Delta Q_1 = v_1 \cdot \Delta A_1 \text{ and } \Delta Q_{N-1} = v_{N-1} \Delta A_{N-1} \quad (4.10)$$

**EXAMPLE a.1** The data pertaining to a stream-gauging operation at a gauging site are below.

The rating equation of the current meter is  $v = 0.51 N_S + 0.03$  m/s where  $N_S =$  revolutions per second. Calculate the discharge in the stream.

Distance from left water edge (m)	0	1.0	3.0	5.0	7.0	9.0	11.0	12.0
Depth (m)	0	1.1	2.0	2.5	2.0	1.7	1.0	0
Revolutions of a current meter kept at 0.6 depth	0	39	58	112	90	45	30	0
Duration of observation (s)	0	100	100	150	150	100	100	0

**SOLUTION:** The calculations are performed in a tabular form. For the first and last sections,

Average width,

$$\bar{W} = \frac{\left( 1 + \frac{2}{2} \right)^2}{2 \times 1} = 2.0 \text{ m}$$

For the rest of the segments,

$$\bar{W} = \frac{\left( 2 + \frac{2}{2} \right)^2}{2 \times 2} = 2.0 \text{ m}$$

Since the velocity is measured at 0.6 depth, the measured velocity is the average velocity at that vertical ( $v$ ).

The calculation of discharge by the mid-section method is shown in tabular form below:

Distance from left water edge (m)	Average width $W$ (m)	Depth $y$ (m)	$N_s = \frac{N}{d}$ Rev./second	Velocity $\bar{v}$ (m/s)	Segmental discharge $\Delta Q_i$ (m <sup>3</sup> /s)
0	0	0			0.0000
1	2	1.10	0.390	0.2289	0.5036
3	2	2.00	0.580	0.3258	1.3032
5	2	2.50	0.747	0.4110	2.0549
7	2	2.00	0.600	0.3360	1.3440
9	2	1.70	0.450	0.2595	0.8823
11	2	1.00	0.300	0.1830	0.3660
12	0	0.00			0.0000
				Sum =	6.45393

Discharge in the stream = 6.454 m<sup>3</sup>/s