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TRAINING OF TRAINERS
IN
HYDROMETRY

ESTIMATION OF DISCHARGE BY AREA-SLOPE METHOD

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1.0 INTRODUCTION :

Streamflow representing the run-off phase of the hydrologic cycle is the most important basic data for hydrologic studies precipitation, evaporation and evapotranspiration are all difficult to measure exactly and various methods of measurements 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 run-off from a specified basin drains. Streamflow is measured in units of discharge (m^3/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 topic deals with one of the many streamflow measurement techniques to provide an appreciation of this important aspect of engineering hydrology.

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 method
b) dilution techniques
c) electronic method
d) ultrasonic method

2. Indirect determination of streamflow :

a) Hydraulic structures, such as weirs, flumes and gated structures, and
b) Area-slope method

2.0 SCOPE AND APPLICATION OF THE AREA-SLOPE METHOD :

Area-slope method provides an approximate estimate of discharge in the streams and is used when measurement of discharge by accurate method like the area velocity method is not possible. Such situation may arise due to reasons like non availability or break down of means or equipment required for making current meter measurements, inaccessibility of the site due to floods, presence of debris and floating matter in the flood, flow preventing the use of current meter, etc. In flashy streams, high floods may pass without being measured due to their short duration. If the magnitude of such floods are required to be assessed after their occurrence, we resort to area slope method.

In the event of the failure of routine methods for measuring discharges in open channels, due to either rapid rise and fall of floods or lack of equipment required for discharge measurements, the slope-area method provides a rough estimate of the discharge in spite of many limitations, the major limitation being the difficulty of a correct assessment of the rugosity coefficient `n' for application of Manning's formula. The value of rugosity coefficient depends on stage of flow, bed material, the nature of the channel, etc.

This method can be used with some degree of accuracy in channels with stable bed and banks having relatively coarse bed material. This method may also be used in other cases, such as alluvial channels, subject to the acceptance of larger errors involved in the selection of the value of the rugosity coefficient `n'. It is, however, not desirable to use this method in the case of very large channels or channels with very flat slopes and high sediment concentration or channels with significant curvature.

The method explained here deals only with adhoc measurements of discharge and such discharge values should not be used for establishing rating curves.

3.0 PRINCIPLE OF THE METHOD OF MEASUREMENT

A measuring reach of the stream is chosen for which the mean area of such cross section and the surface slope of the flowing water in that reach are determined. The mean velocity is then worked out by using the known open channel flow formulated such as the Manning's formula by selecting appropriate rugosity coefficient depending on the physical conditions of the channel. The approximate discharge is then computed as the product of the mean velocity and the average cross-sectional area of the reach.

4.0 SELECTION OF SITE

1. The river reach should be fairly straight having stable bed and banks and uniform cross-section over a length of at least five times the width of the channel. In any case, the length should not be less than about 300m.

2. The slope should be such that surface drop is as large as possible but not less than a minimum of 15 cm. in the length of the reach selected.

3. The flow in the reach should be free from significant disturbances, draw-down or back-water effect of any structure or tributary joining upstream or down stream.

4. The orientation of the reach should be such that the direction of the flow is as closely as possible normal to that of the prevailing wind.

5. The flow in the channel shall be contained within its banks for all stages at which this method is used.

6. The site should not be unduly exposed to wind.

7. The site chosen should be easily accessible at all times.

8. If no uniform reach is available, the reach should preferably be converging rather than diverging.

5.0 MEASUREMENT OF SLOPE

Gauges should be installed at least in three cross-sections, on either bank of the river. If three cross-sections are chosen two should be at the ends of selected reach and one at the centre. The alignment of each cross-section should be normal to the general direction of flow.

Before the start of each discharge measurement, information regarding the date, time, weather conditions, direction of wind, current etc. should be recorded. All gauges should be observed at suitable intervals and recorded through the period of measurement including initial and terminal readings.

Slope of water surface is computed from the average of gauge observations at either of the reach. The intermediate gauge is used to confirm that the slope is uniform throughout the reach.

When accurate gauges do not exist or have been destroyed, flood marks on the banks may be used for estimation of the slope. In such cases, an effort should be made to locate, investigate and fix as many flood marks as possible in the reach with least possible delay after occurrence of the flood.

6.0 CROSS-SECTIONAL AREA AND WETTED PERIMETER OF STREAM

Generally average area of cross-section in the observation reach is taken as the mean of three sections - two end sections and the central section. If for any reason, it is not possible to measure more than one cross-section, the central one only may be observed.

The cross-sections should be measured for each discharge observations at or as near the time as possible, at which the gauge observations are made. It is often not possible to meausre the cross section during flood and therefore, to this extent an error may be introduced due to an observed and temporary change in cross-sections. However, rivers with rocky bed and banks, and carrying little bed charge are least susceptible to these changes. In such cases, it will be sufficient to observe the cross-sections before and after the floods.

If the reach is substantially uniform and there are insignificant differences in the cross-sectional areas, A_1, A_2 _........ A_m at the chosen sections, the mean area of cross- section for the reach of the stream may be taken as

$$A = \frac{A_1 + 2A_2 + \dots\dots\dots\dots 2A_{m-1} + A_m}{2(m-1)}$$

Similarly, if P_1, P_2 .... P_m are the corresponding wetted perimeter of the chosen cross-sections, the mean wetted perimeter for the reach may be taken as

$$P = \frac{P_1 + 2P_2 + \dots\dots\dots\dots + 2P_{m-1} + P_m}{2(m-1)}$$

7.0 EVALUATION OF VELOCITY

The mean velocity representing the cross-section of the flow area in the reach may be computed using Manning's formula as given below :

$$\bar{V} = \frac{R^{2/3} S^{1/2}}{n} \quad \text{(Matric units)}$$

$$\bar{V} = \frac{1.486\, R^{2/3} S^{1/2}}{n} \quad \text{(FPS units)}$$

where

V - Mean velocity

R - Hydraulic mean depth = A/P

n - Rugosity coefficient having a value given in Table 1 & 2.

s - Slope corrected for the Kinetic energy difference at the two ends.

$$= \frac{Z^1 - Z^2 + \left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right)}{L}$$

L - Length of the reach

Z_1 & Z_2 are static heads (water levels) at the end sections.

$\frac{V_1^2}{2g}$ & $\frac{V_2^2}{2g}$ are the corresponding velocity heads

V_1 & V_2 are mean velocities at the end sections at (1) and (2) as shown in Fig. 1.

8.0 VALUE OF RUGOSITY COEFFICIENT :

Where a reasonable value of rugosity coefficient (also called roughness coefficient or retardation coefficient) can be determined from actual discharge measurements at the nearest lower stages by a more accurate method, say the area velocity method using current meter, the value so obtained may be chosen.

In the absence of measured data, the values given in table I may be assumed for open channels with relatively coarse bed material.

Table I Value of Rugosity coefficient 'n' for open channels with relatively coarse bed material not characterized by bed formation

Sl. No.	Type of bed material	Size of bed material equivalent diameter in mm	Rugosity coefficient 'n'
1	Gravel	4 to 8 8 to 20 20 to 60	0.019 to 0.020 0.020 to 0.022 0.022 to 0.027
2	Cobbles and Shingle	60 to 110 110 to 250	0.027 to 0.030 0.030 to 0.035

In the case of alluvial open channels with other than coarse bed material and channels having vegetations, clay and rocky banks etc. values given in Table II may be used as a guide.

9.0 COMPUTATION OF DISCHARGE :

The discharge shall be calculated by multiplying the mean velocity obtained from 7.0 by the mean cross-sectional area obtained from 6.0.

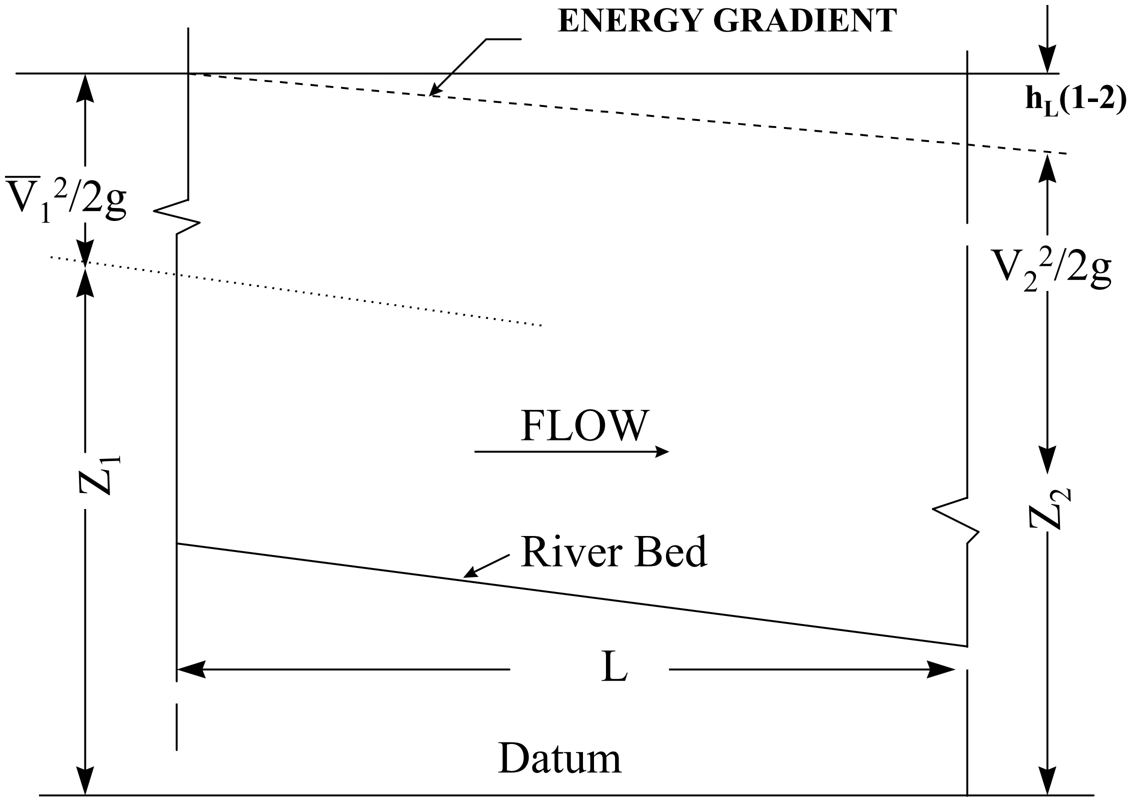
The discharge computation using energy gradient rather than water surface slope, has to be carried out by method of successive trials. To start with, discharge is computed by using surface slope in Manning's formula. With this discharge, knowing the upstream and downstream cross-sections, velocities and velocity heads are computed from which energy gradient is obtained. In the next trial, this energy gradient is substituted for water surface slope in the Manning's formula. A few more trials will give reasonably good result.

References :

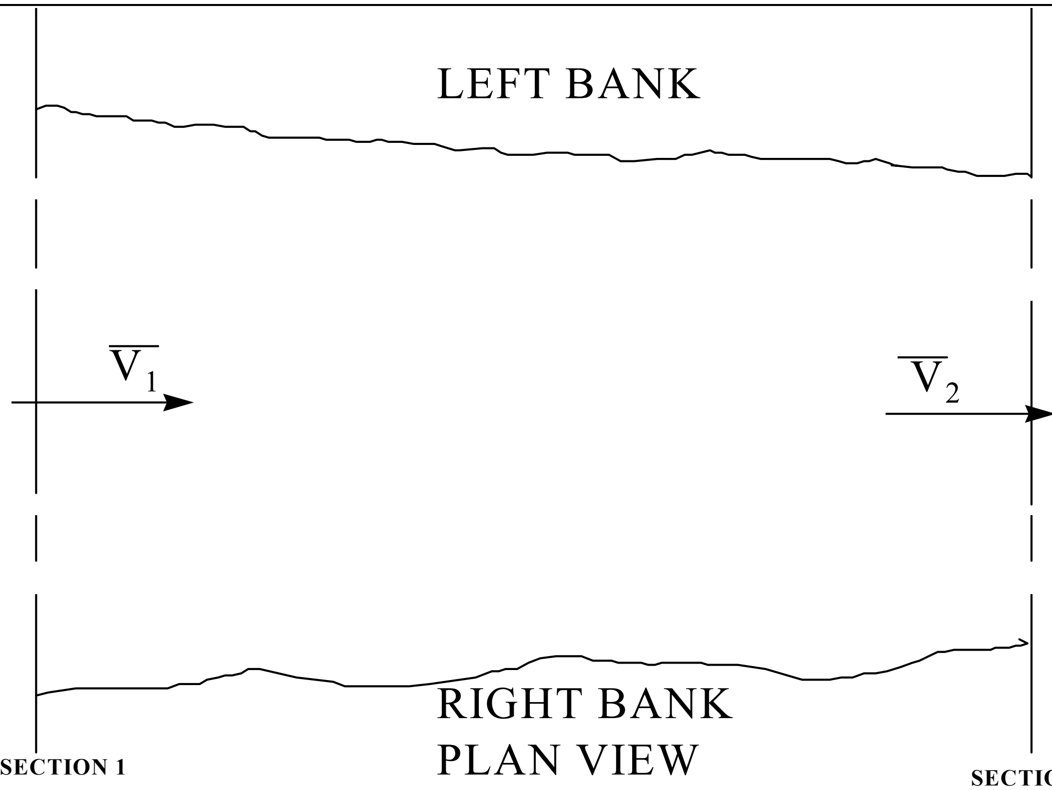
1. I.S. Recommendation for Liquid Flow Measurement in open channels by Slope-Area Method. (IS 2912-1964).
2. "Stream Gauging" Manual by H.G. Hiranandani and S.V. Chitale.
3. W.H.O. Operational Hydrology Report NO. 13, "Manual on stream gauging" Vol. I.
4. Chow, V.T., "Handbook of Applied Hydrology".
5. Subramanya K., "Flow in Open Channels".

Table II Value of Rugosity Coefficient 'n' for open channels with other than coarse bed material

Type of channel and Description	Rugosity Coefficient 'n'
Excavated or Dredged	
a) Earth, straight and uniform	
1) Clean, recently completed	0.016 to 0.020
2) Clean after weathering	0.018 to 0.025
3) With short grass, few weeds	0.022 to 0.033
b) Rock Cuts	
1) Smooth and Uniform	0.025 to 0.040
2) Jagged and Irregular	0.035 to 0.050
Natural Streams	
a) Minor streams (top width at flood Stage less than 30 m (or 100 ft.)	
1) Streams on plains - clean, straight full stage, no rifts or deep pools	0.025 to 0.033
b) Flood on plains	
1) Pasture, no brush	
i) Short grass	0.025 to 0.035
ii) High grass	0.030 to 0.050
2) Cultivated areas	
i) No crop	0.020 to 0.040
ii) Nature row crops	0.025 to 0.045
iii) Nature field crops	0.030 to 0.050
3) Brush	
i) Scattered brush, heavy weeds	0.035 to 0.070
ii) Light brush and trees (without foliage)	0.035 to 0.060
iii) Light brush and trees (with foliage)	0.040 to 0.080
iv) Medium to dense brush (without foliage)	0.045 to 0.110
v) Medium to dense brush (with foliage)	0.070 to 0.260
4) Trees	
i) Cleared land with tree stumps, no sprouts	0.030 to 0.050
ii) Same as above, but with heavy growth of sprouts	0.050 to 0.080
iii) Heavy stand of timber, a few down trees, little undergrowth flood stage below branches	0.080 to 0.120
iv) Same as above, but with flood stage reaching branches	0.100 to 0.160
v) Dense willows, summer, straight	0.110 to 0.200



LONGITUDINAL PROFILE



RIVER REACH SELECTED FOR SLOPE AREA METHOD

PROBLEMS

1. During a high flow water-surface elevations of a small stream were noted at two sections A and B, 10 km apart. These elevations and other salient hydraulic properties are given below:

Section	Water-Surface elevation (m)	Area of cross-section (m^2)	Hydraulic radius (m)	Remarks
A	104.771	73.293	2.733	A is upstream of B
B	104.500	93.375	3.089	n = 0.020

The eddy loss coefficient of 0.3 for gradual expansion and 0.1 for gradual contraction are appropriate. Estimate the discharge in the stream.

2. A small stream has a trapezoidal cross section with base width of 12 m and side slope 2 horizontal : 1 vertical in a reach of 8 km. During a flood a flood the high water levels recorded at either ends of the reach are as below :

Section	Elevation of bed	Water surface elevation	Remarks
Upstream	100.20	102.70	Manning's n = 0.030
Downstream	98.60	101.30	

Estimate the discharge in the stream.

3. During a flood flow the depth of water in a 10 m wide rectangular channel was found to be 3.0 and 2.9 m at two sections 200 m apart. The drop in the water-surface elevation was found to be 0.12 m. Assuming Manning's coefficient to be 0.025, estimate the flood discharge through the channel.