Measurement of infiltration: Areal Measurement

As a watershed may be large with many different soil types land cover and land uses, areal estimate of infiltration is required. Areal infiltration estimation is accomplished by analysis of rainfall-runoff data from a watershed. For a storm with a single runoff peak, the rainfall hyetograph is integrated to calculate the total rainfall volume. Likewise, the runoff hydrograph is integrated to calculate the runoff volume. The infiltration volume is obtained by subtracting runoff volume from rainfall volume.

The average infiltration rate is obtained by dividing infiltration volume by rainfall duration.

The procedure resembles that of the calculation of ϕ index as discussed next.

Infiltration

Infiltration Indices

In hydrological analysis, it is convenient to use a constant value of infiltration rate for the duration of the storm. The average infiltration rate is called infiltration index and two indices are common: Φ-index and W-index.

Φ-index

The Φ-index is defined as the rate of rainfall above which the rainfall volume equals the runoff volume. Thus, the Φ-index divides the rainfall into runoff and losses (mainly infiltration but includes interception and depression storage).

If the Φ-index is larger than the rainfall intensity during an interval of time then the computed runoff during that period is zero.

For finding the Φ-index, assume a constant infiltration capacity throughout the storm (hyetograph). For given rainfall & runoff depths, solve iteratively for infiltration rate, ϕ.

$$\textit{Runoff depth} = \Delta t_1 (i_1 - \phi) + \Delta t_2 (i_2 - \phi) + \Delta t_3 (i_3 - \phi) + \Delta t_4 (i_4 - \phi) \text{ etc.}$$

W-index

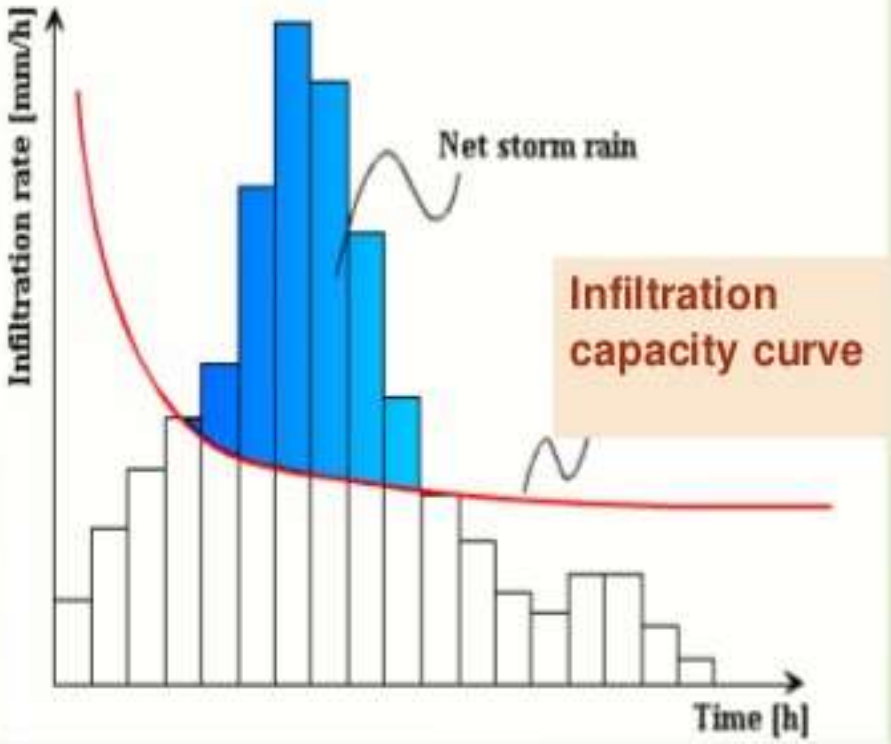
W-index is the same as Φ-index but here the initial losses (interception and depression storage) are substracted from the total rainfall. As the inital losses are difficult to estimate, use of W-index is not very common.

Infiltration Indices

Infiltration capacity of soil does not remain constant.

In hydrological computations for computing surface runoff and flood discharge, the use of infiltration capacity curve is not convenient .

It is more convenient to use an avg. constant value of infiltration rate.



1. Ø - Index

It is the average rate of rainfall above which the rainfall volume is equal to the surface runoff volume.

$$\emptyset = \frac{P - R}{t_e}$$

Ø - Index - cm/hr
P – total rainfall in cm
R – runoff in cm
t_e = time period for rainfall excess in hr

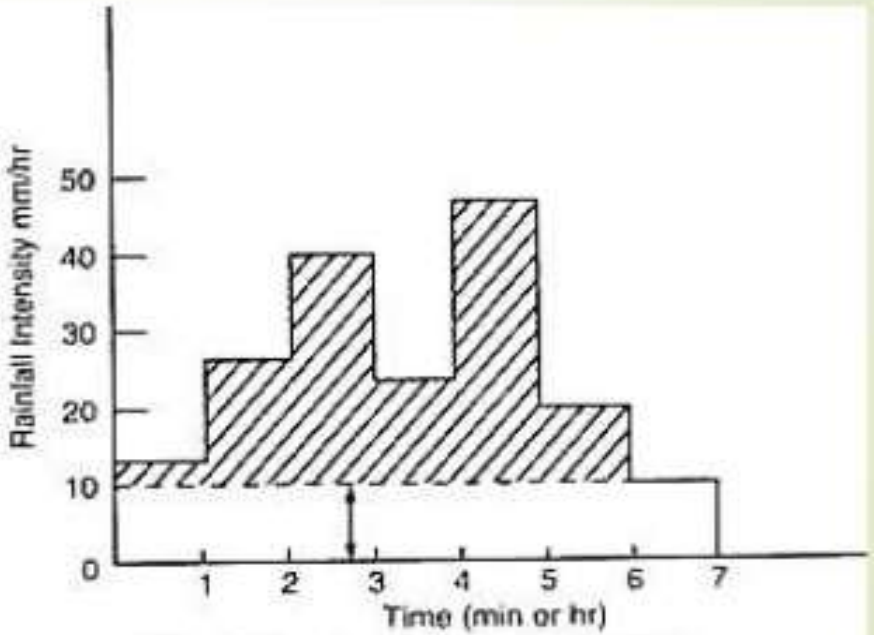
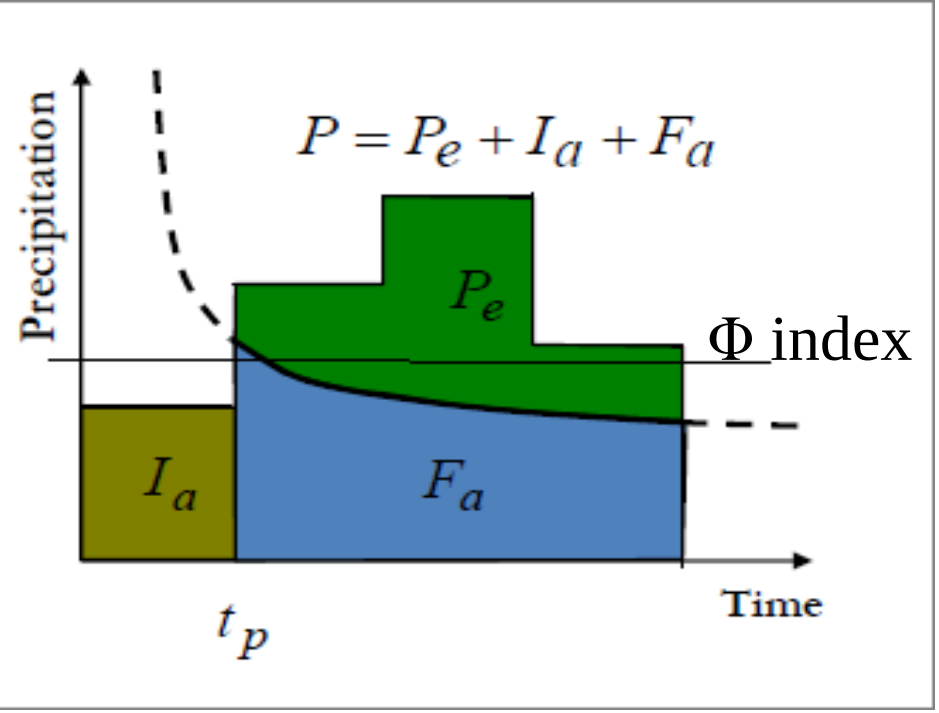
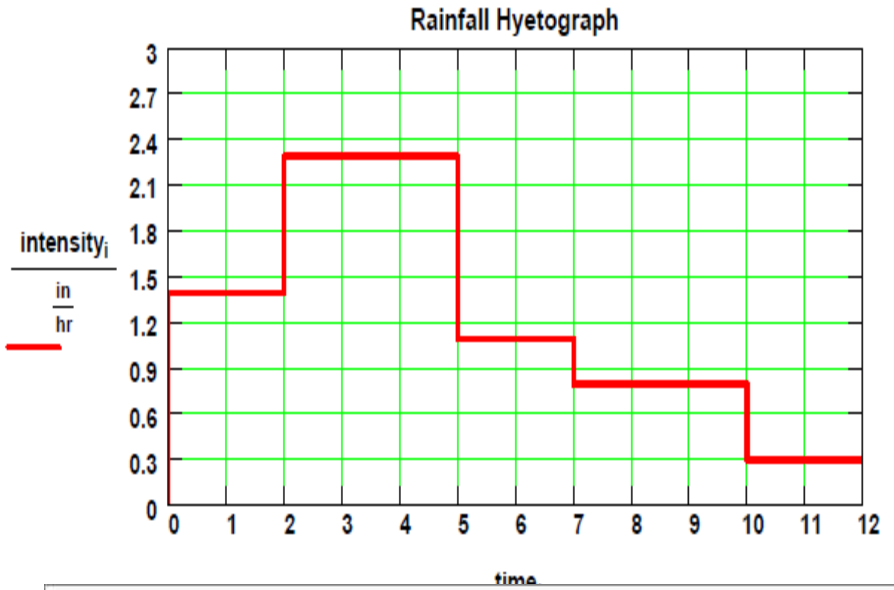
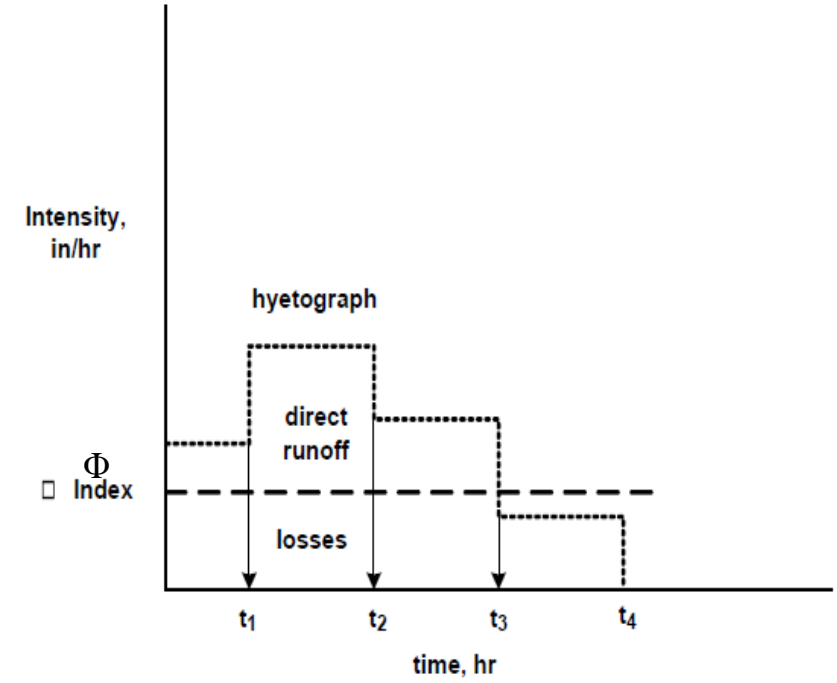
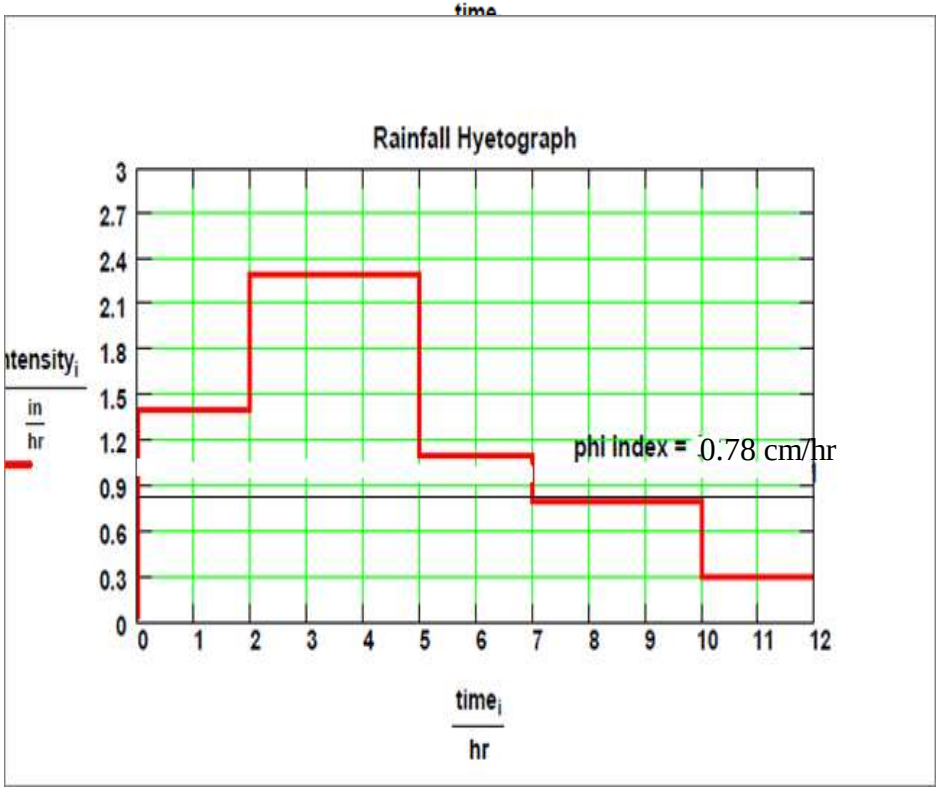


Fig. 3.2. ϕ index from hyetograph


$P = P_e + I_a + F_a$
Precipitation
P_e
I_a
F_a
Φ index
Time
t_p


Rainfall Hyetograph
intensity$_i$
in/hr
3
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
0 1 2 3 4 5 6 7 8 9 10 11 12
time


Intensity, in/hr
hyetograph
direct runoff
Φ Index
losses
t_1
t_2
t_3
t_4
time, hr


Rainfall Hyetograph
intensity$_i$
in/hr
3
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
0 1 2 3 4 5 6 7 8 9 10 11 12
phi index = 0.78 cm/hr
time$_i$
hr

Infiltration

Example

Calculate the Φ-index for the storm shown in figure if the total runoff from the catchment is 6.5 cm.

The total rainfall is 14.9 cm (2x1.4 + 3x2.3 + 2x1.1 + 3x0.8 + 2x0.3) in 12 hours.

$6.5 = 2\,(1.4 - \phi) + 3\,(2.3 - \phi) + 2\,(1.1 - \phi) + 3\,(0.8 - \phi) + 2\,(0.3 - \phi)$ or $\phi = 0.7$

With this value of ϕ, the last rainfall would have no infiltration as $i < 0.7$

Thus, the re-calculated ϕ is:

$6.5 = 2\,(1.4 - \phi) + 3\,(2.3 - \phi) + 2\,(1.1 - \phi) + 3\,(0.8 - \phi)$

Or $\phi = 0.78$ cm/hr

Note: the same amount of rainfall with different intensities would result in a different value of ϕ.

Hence, for a watershed a number of ϕ values are calculated for different hyetographs before selecting a single value of ϕ.

Streamflow

Stream flow, or *discharge*, is the volume of water moving past a cross-section of a stream over a set period of time. It is usually measured in cubic meters per second (m^3/sec or cumec).

Streamflow is important in hydrology for:

- Floodplain management (flood and drought management, land use planning, irrigation and water supply etc.)
- Design of water control structures – embankments, culverts, bridges, stormwater systems etc.
- Flood forecasting and analysis
- Reservoir operations (outflow and inflow)
- Navigation
- Low flows – water supply and quality concerns and aquatic life

Streamflow is important not only to human being, but also to aquatic habitat. Food sources, spawning areas and migration paths of fish and other wildlife are all affected and defined by stream flow and velocity.

Velocity and flow together determine the kinds of organisms that can live in the stream (some need fast-flowing areas; others need quiet, low-velocity pools). Different kinds of vegetation require different flows and velocities, too.

Streamflow

Stream flow is affected by both forces of nature and by humans.

In undeveloped watersheds, soil type, vegetation, and slope all play a role in how fast and how much water reaches a stream.

In developed watersheds (with high human involvement/development), water flow might be depleted by withdrawals for irrigation, domestic or industrial purposes or increased due to deforestation and land development.

Drastically altering landscapes in a watershed, such as with land development can also change flow regimes, causing faster runoff with storm events and higher peak flows due to increased areas of impervious surface. These altered flows can negatively affect an entire ecosystem by upsetting habitats and organisms dependent on the natural flow rates.

Dams and reservoirs used for electric power generation may affect flow, particularly during periods of peak need when stream flow is held back and later released in a surge.

Streamflow

Types of stream

Perennial stream flows all year around because the channel is in constant contact with the groundwater table. Most well developed streams are perennial.

Intermittent (seasonal) stream flow continuously only during certain seasons when the groundwater table is high and then dries out.

Ephemeral stream never intersects the water table and therefore flow only when it rains. These streams are common in the arid regions or deserts. These streams have flow only in direct response to effective precipitation.

Considering the contribution to or from the groundwater table, the streams are classified as:

Influent stream contributes water to the groundwater table. They are a type of losing stream because discharge decreases downstream as water percolates from the river.

Effluent stream receive water from the groundwater table. Perennial streams are generally effluent all year around whereas intermittent streams are influent or effluent on a seasonal basis.

A perennial river may become influent to effluent or vice versa along its length depending upon the geological formations it runs along.

Types of river considering planform.

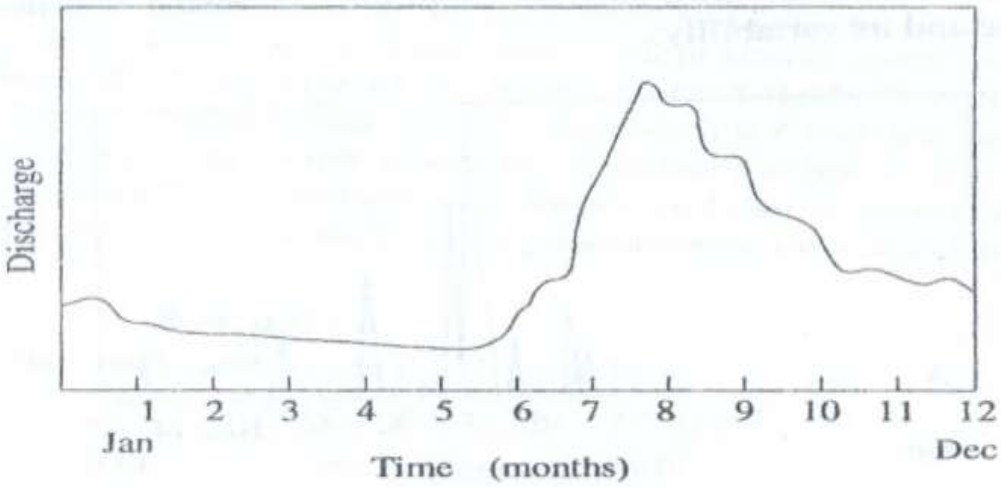


Fig. 5.2 Perennial stream



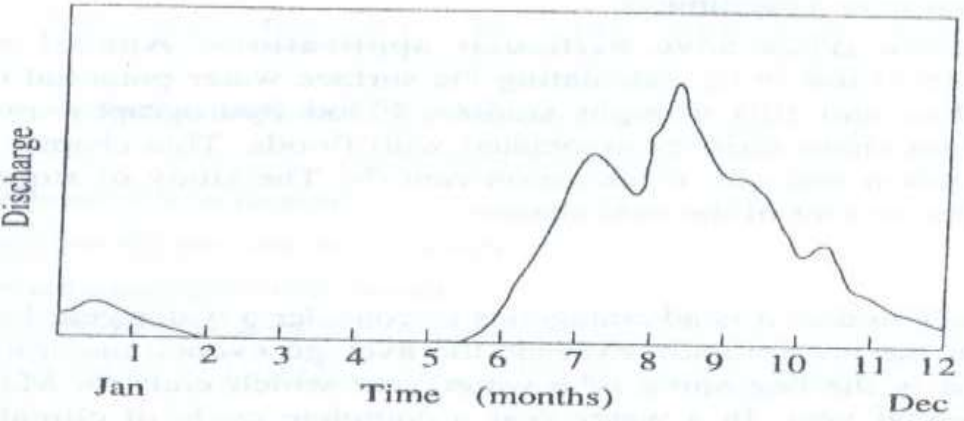
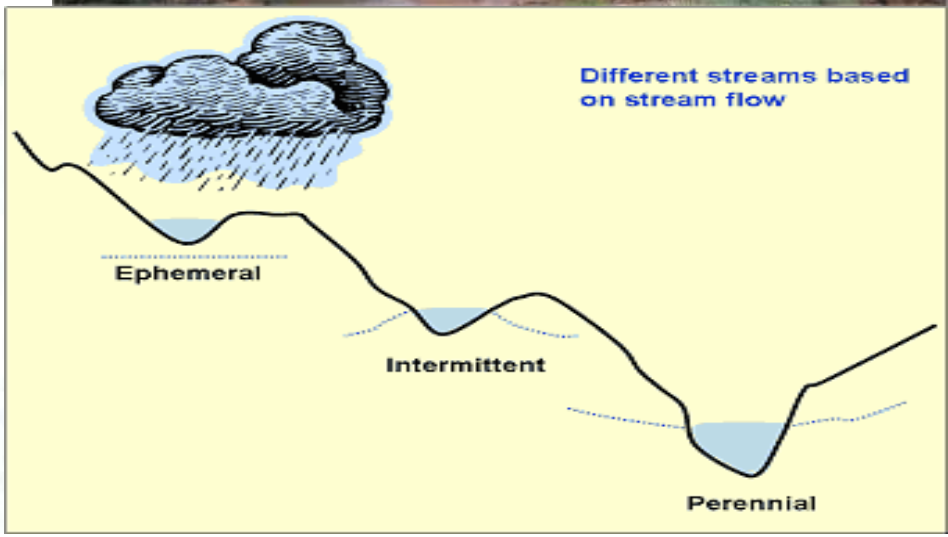


Fig. 5.3 Intermittent Stream



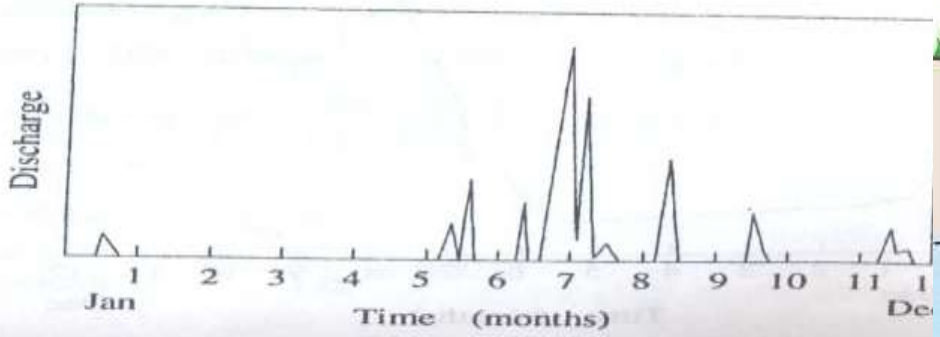
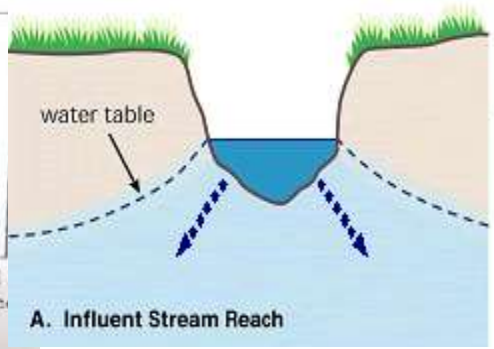
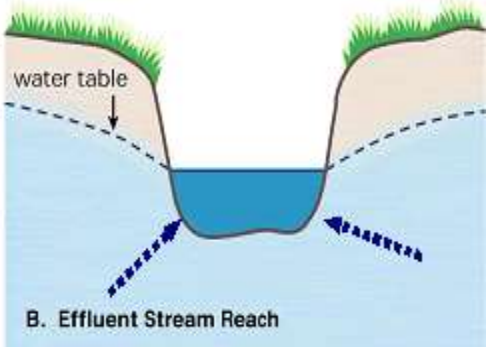


Fig. 5.4 Ephemeral stream





Three Types of River Considering Planform

Straight, Braided and Meandering River



Meandering



Braided



Straight

Streamflow

Streamflow measurement

Discharge or flow: $Q = V * A$

Where , Q = discharge (m^3 /sec)

V = average water velocity (m/sec)

A = cross-sectional area (m^2)

To find the area of a channel we need to know the width of channel (w) and the depth of channel (d) and Area, A = w x d

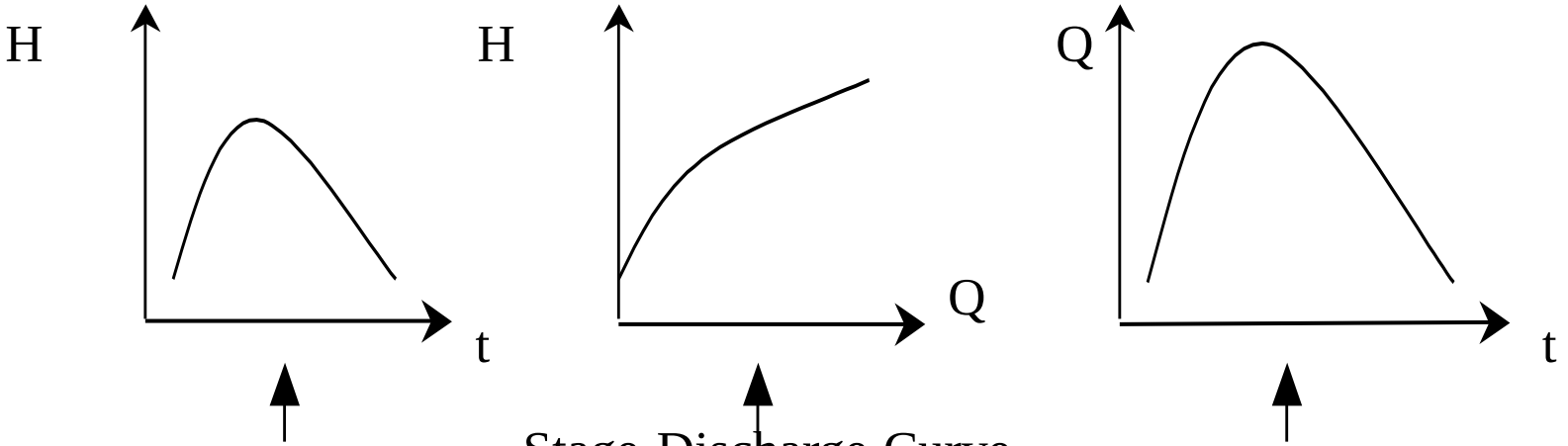
Streamflow measurements can be direct and indirect.

Direct measurement is expensive and also time consuming.

In Indirect Measurement, the discharge of a river is related to the water surface elevation or stage using a series of discharge measurements and a stage-discharge relationship called rating curve is developed. The water stage is routinely observed and the discharge is obtained from the rating curve.

The measurement of stage is easy and relatively inexpensive.

For indirect measurement, the river section has to be stable (non-eroding) and periodic discharge measurement is necessary to check the validity of the rating curve.

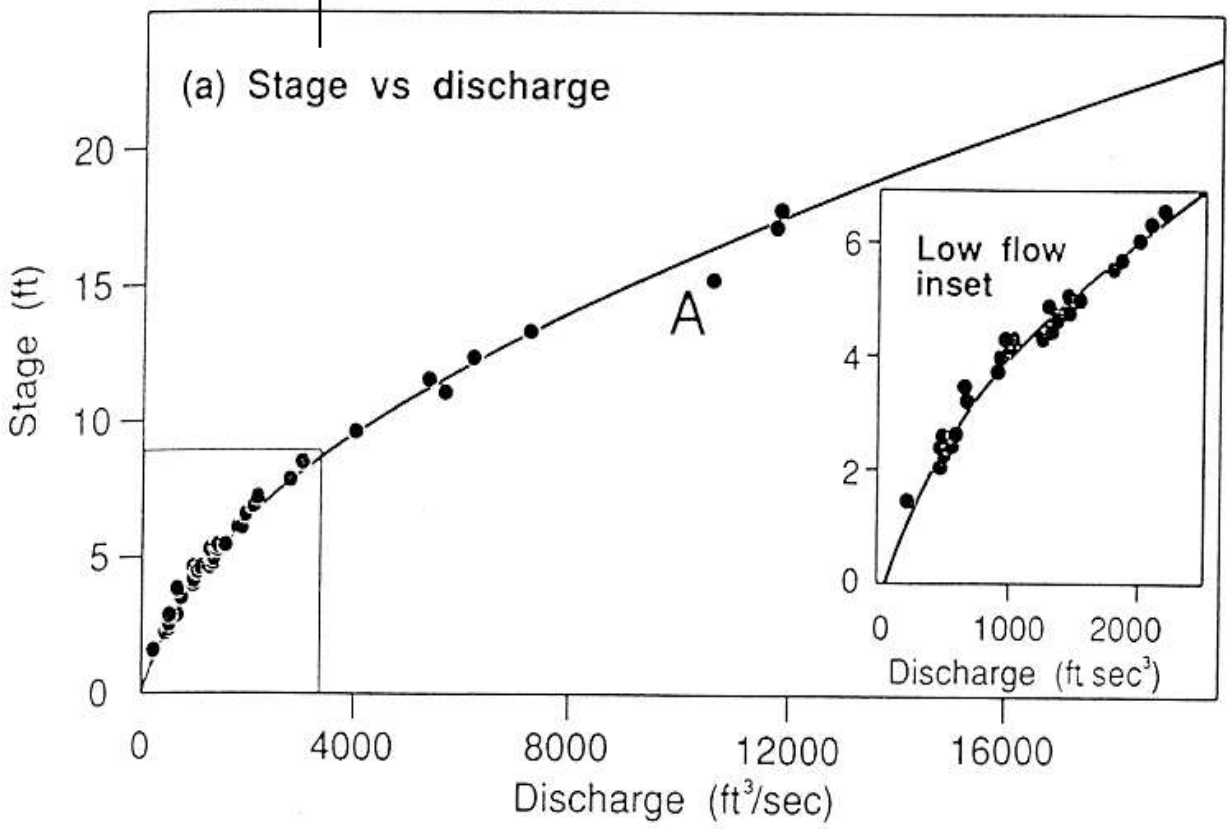


Stage Hydrograph

Stage-Discharge Curve or Rating Curve

Discharge Hydrograph

Stage and Discharge Hydrograph and Rating Curve



Streamflow

Hydrometry

Hydrometry is concerned with the measurements of all the variables in the hydrologic cycle and hydrological information is necessary for the practice of efficient water management.

Although hydrometery is concerned with all the variables of hydrologic cycle, it is generally referred to as only the measurement of flow in the streams.

Measurement of Stage

River stage is the elevation of the water surface with respect to a datum (usually the mean sea level, MSL).

Stage can be measured by gauges which can be either non-recording (no record and only water level) or recording (or automatic gauge).

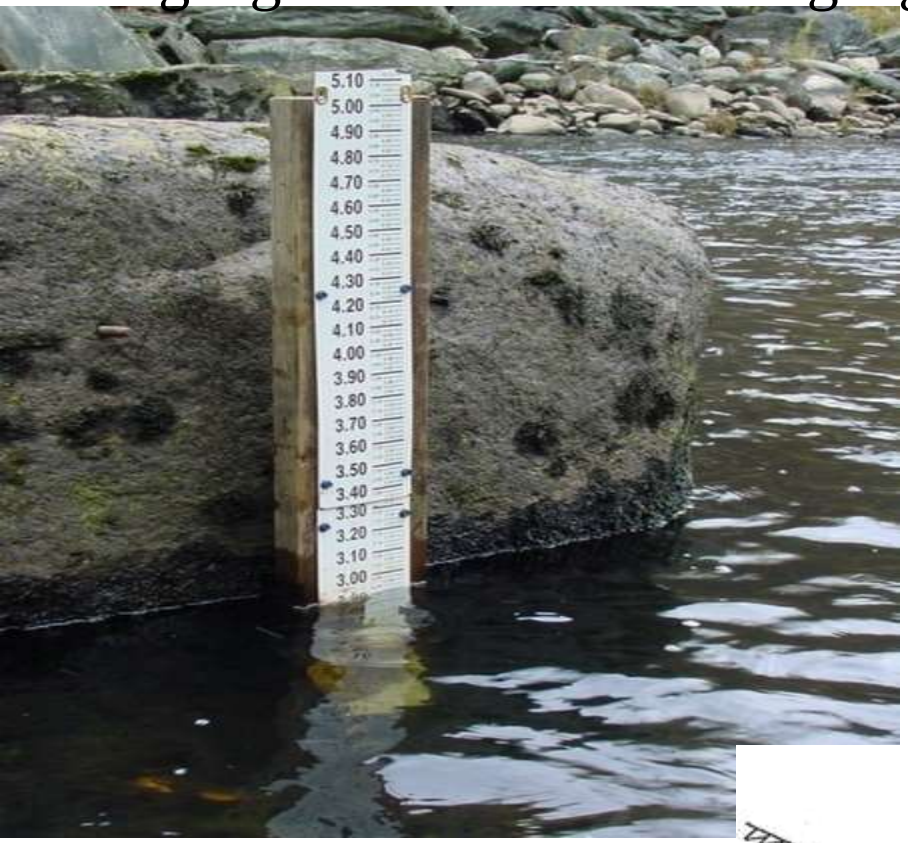
The most commonly used non-recording gauge is called the **staff gauge.**

A staff gauge is a long wooden vertical scale which is attached to bridge pier or abutment or fixed rigidly with the river bed. The gauge is painted in meter and hundredth so the smallest reading is 0.01m. The water level is normally observed everyday (at the same time).

If no suitable structure exists that is accessible at all stages or if the variations in water level is very high so that one gauge is not enough, then sectional staff gauge is used.

An alternative to sectional gauge is inclined staff gauge (graduated) placed on the slope of the river bank. But, such gauge requires stable (non-erodible) river bank.

Staff gauge and sectional staff gauge







Inclined staff

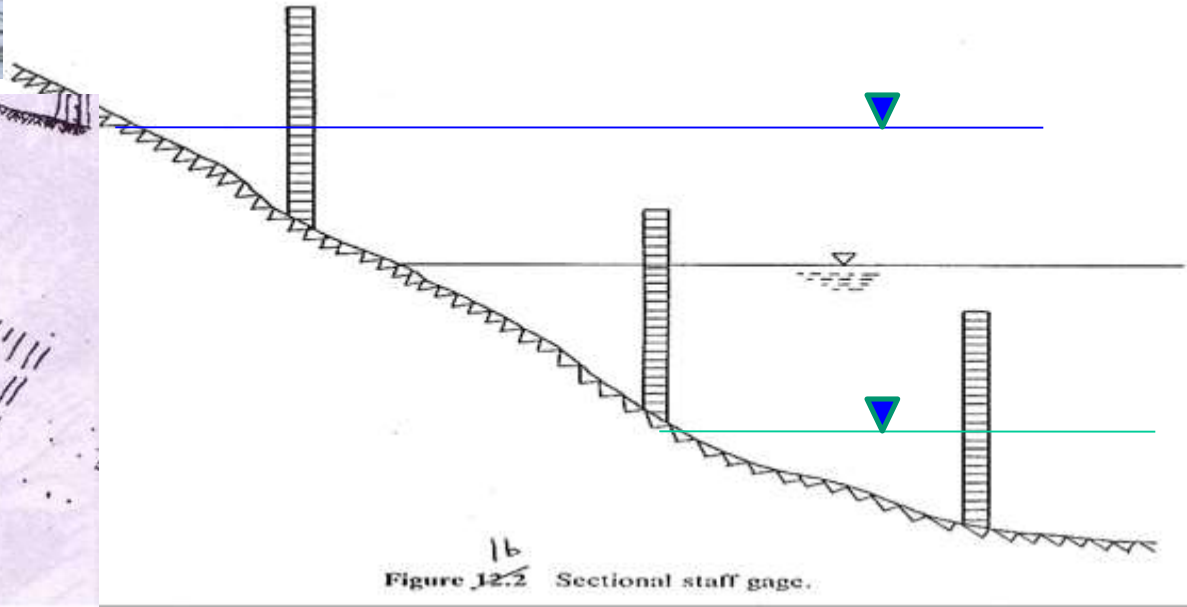


Figure 12.2 Sectional staff gage.

Streamflow

Recording gages: when large variations in water level occur within short time or when continuous water level data are needed, recording gauges (float type) are used.

Site selection

Installation of gauge depends upon the purpose for which the data would be needed. If the stage data is primarily for flood forecasting and navigation, then accessibility should be the main criterion.

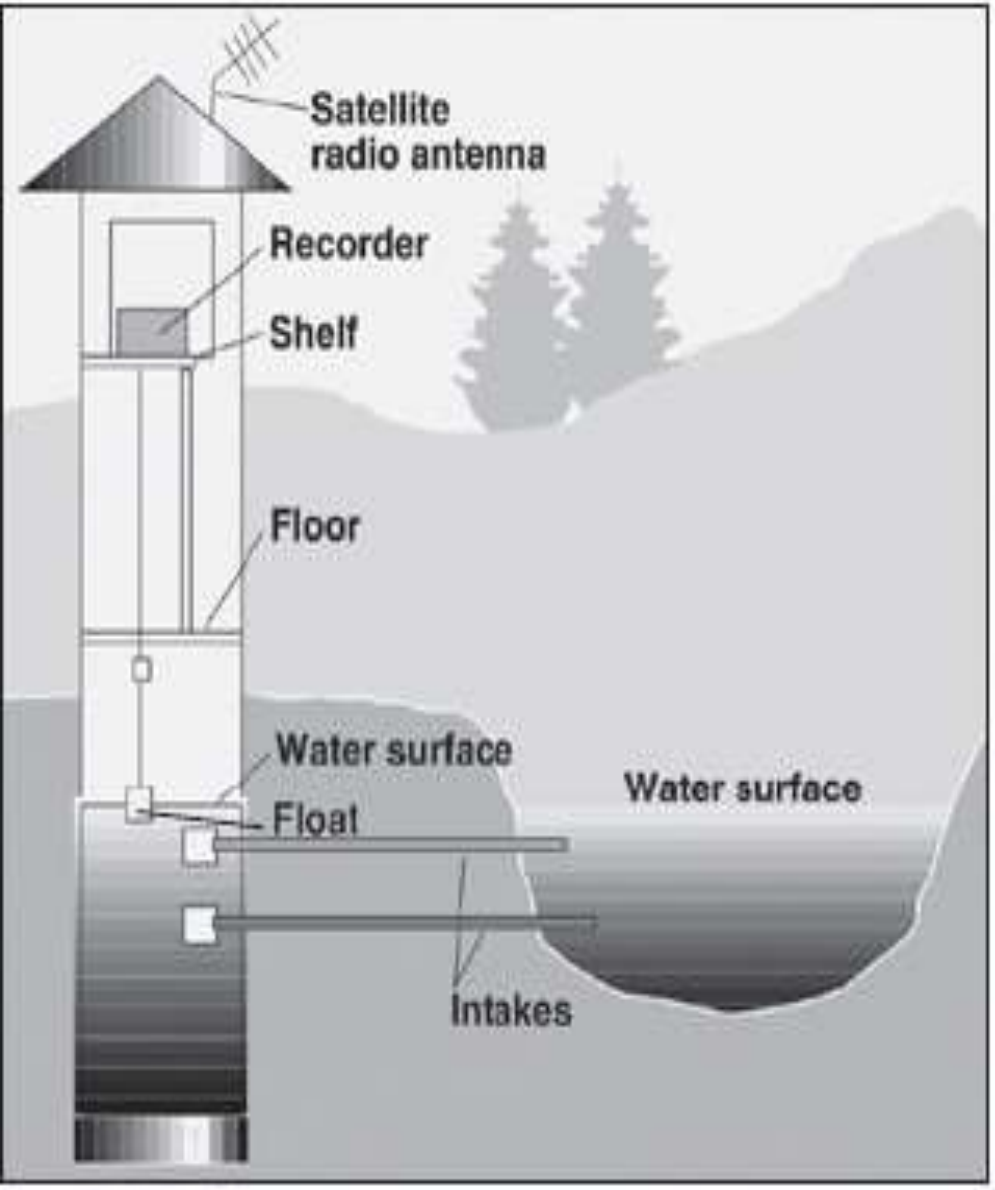
If the primary use of the stage data is for discharge measurement, then the following factors are considered:

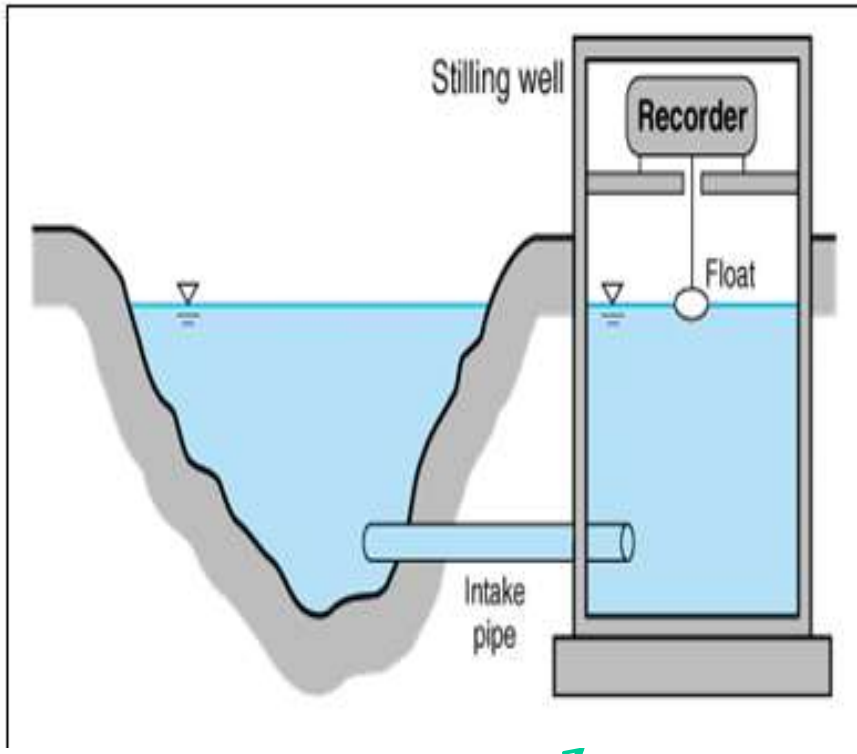
- The site is stable (non-eroding) – section control (control: a cross section in a stream that determines the relationship between the stage and discharge of the stream).
- If the site is unstable (discharge is controlled by the channel characteristics: slope, size and roughness –channel control) frequent discharge measurement would be necessary to take care of errors in stage readings (as the same stage can have different discharges).
- Select a straight reach avoiding the bends (for at least 50 m above and below the measuring station).
- Avoid sites with backwater effect: dams, confluence, tidal action etc.

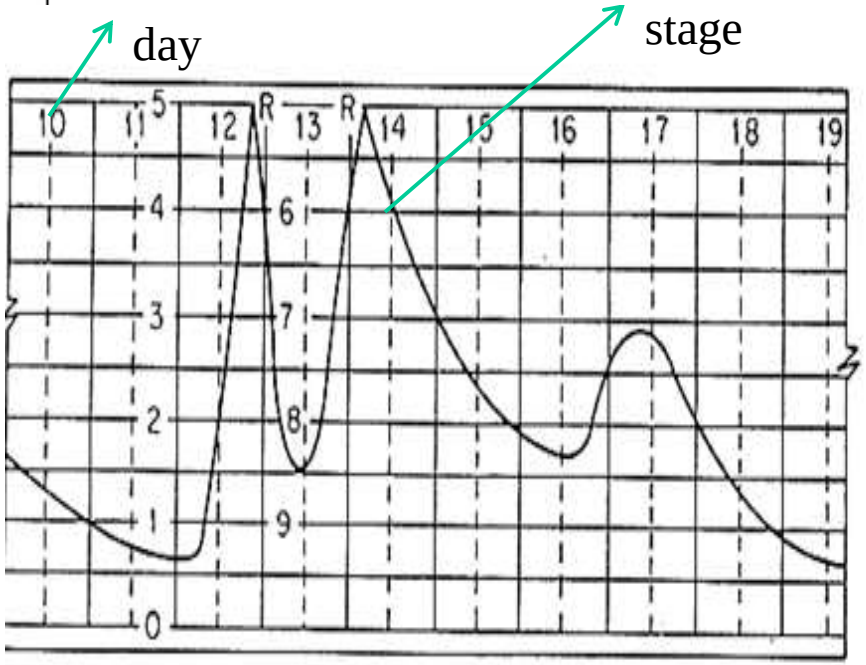
Stage data

The stage data is presented in a plot of stage against time which is known as stage hydrograph. Such long term data are essential for the analysis and flood level, land development, navigation, flood forecasting, damage assessment and evacuation etc.

Float type recording gauge

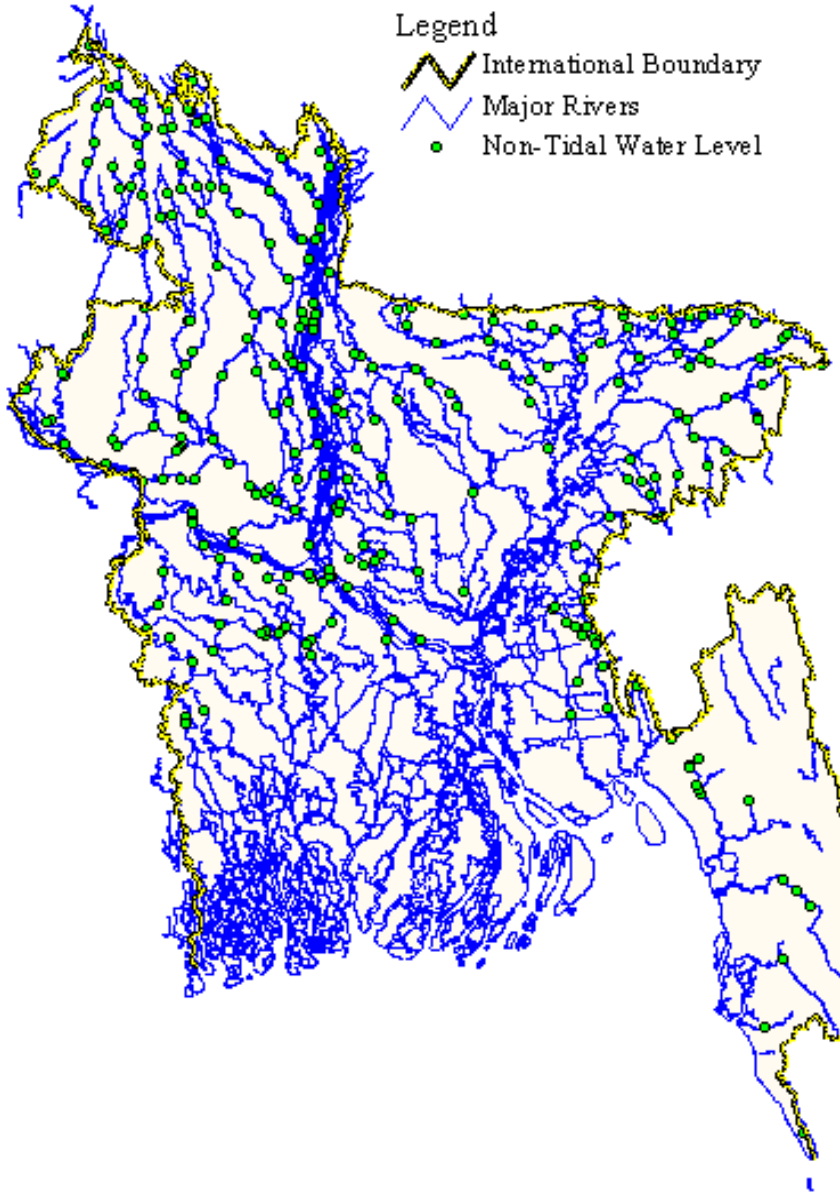


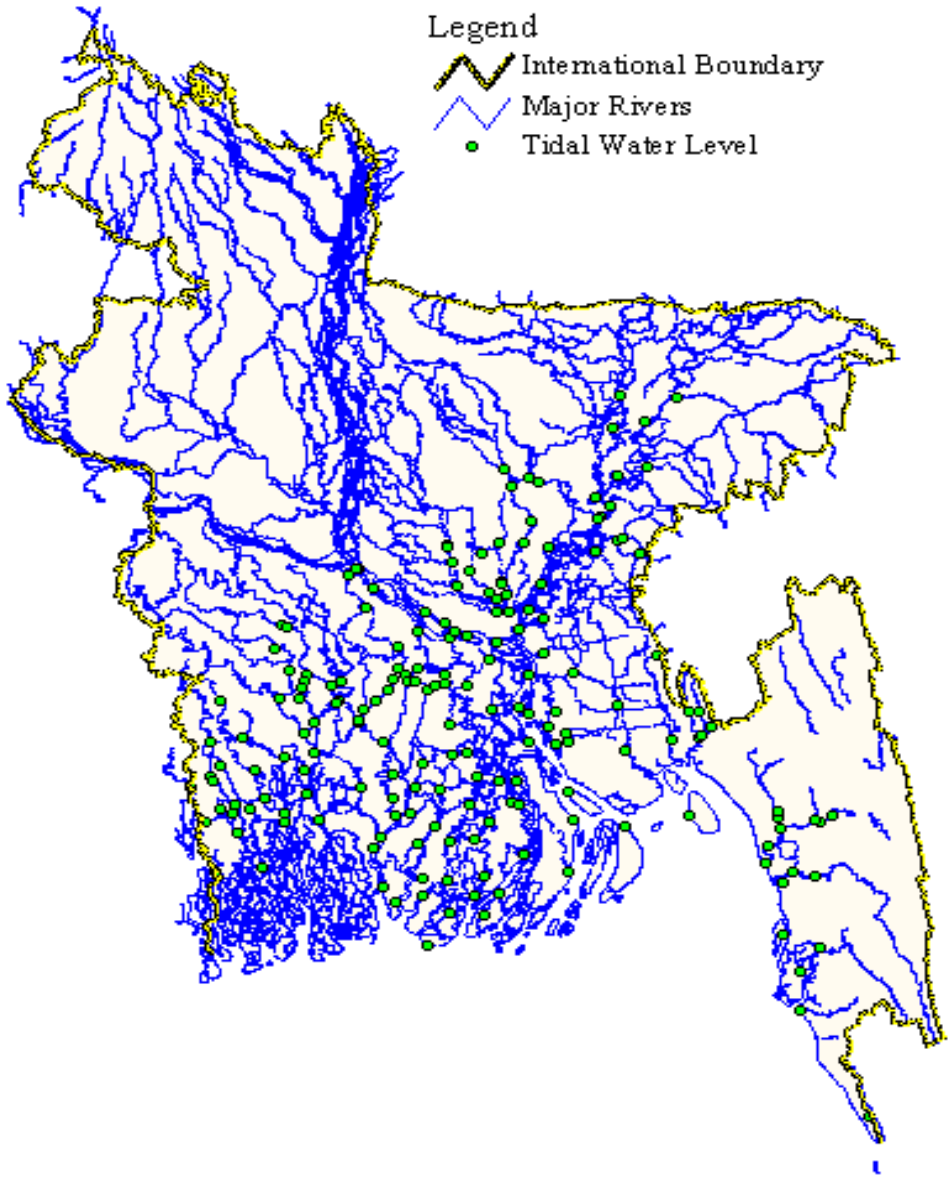




Water level measurement in Bangladesh

In Bangladesh water level (stage) is measured at 343 stations (both non-tidal and tidal).





FLOOD FORECASTING AND WARNING CENTER, BWDB

RIVER SITUATION AS ON 01-09-2022 AT 09:00 HOURS

SL	RIVER	STATION NAME	DISTRICT	UPAZILLA	RHWL	D.L.	31-08-2022	1/9/2022	Rise(+) Fall(-)	Above(+) Below(-) D.L.
					m PWD	m PWD	m PWD	m PWD	in cm	in cm
	BRAHMAPUTRA BASIN									
1	DUDHKUMAR	PATESWARI	KURIGRAM	BHURUNGAMARI	31.43	30.05	28.71	28.52	-19	-153
2	DHARLA	KURIGRAM	KURIGRAM	KURIGRAM S.	27.84	26.50	25.39	25.25	-14	-125
3	TEESTA	DALIA	NILPHAMARI	DIMLA	53.30	52.60	52.35	52.27	-8	-33
4	TEESTA	KAUNIA	LALMONIRHAT	LALMONIRHAT S.	30.52	29.20	28.77	28.63	-14	-57
5	JAMUNESWARI	BADARGANJ	RANGPUR	TARAGANJ	33.61	32.15	28.91	29.58	+67	-257
6	GHAGOT	GAIBANDHA	GAIBANDHA	GAIBANDHA S.	22.81	21.70	18.37	18.77	+40	-293
7	KARATOA	CHAK RAHIMPUR	BOGRA	BOGRA S.	21.41	20.15	16.12	16.51	+39	-364
8	KARATOA	BOGURA	BOGRA	SHAJAHANPUR	17.45	16.30	11.71	11.7	-1	-460
9	BANGALI	SHIMUBARI	BOGRA	SONATOLA	19.22	18.23	14.3	14.47	+17	-376
10	BRAHMAPUTRA	NOONKHAWA	KURIGRAM	NAGESHWARI	28.10	26.50	23.56	23.68	+12	-282
11	BRAHMAPUTRA	HATIA	KURIGRAM	ULIPUR	26.30	24.75	22.55	22.62	+7	-213
12	BRAHMAPUTRA	CHILMARI	KURIGRAM	CHILMARI	25.07	23.70	21.37	21.44	+7	-226
13	JAMUNA	*FULCHARI	GAIBANDHA	FULCHARI	20.69	19.35	16.7	16.86	+16	-249
14	JAMUNA	SAGHATA	GAIBANDHA	SAGHATA	21.20	19.20	15.87	16	+13	-320
15	JAMUNA	*BAHADURABAD	JAMALPUR	ISLAMPUR	20.63	19.05	16.34	16.49	+15	-256
16	JAMUNA	SARIAKANDI	BOGRA	SARIAKANDI	19.07	16.70	13.87	14.17	+30	-253
17	JAMUNA	KAZIPUR	SIRAJGANJ	KAZIPUR	17.47	15.25	12.68	13	+32	-225
18	JAMUNA	SERAJGANJ	SIRAJGANJ	SIRAJGANJ S.	15.12	13.35	10.76	11.08	+32	-227
19	JAMUNA	*PORABARI	TANGAIL	NAGARPUR	12.84	11.90	9.28	9.53	+25	-237
20	JAMUNA	MATHURA	PABNA	BERA	11.90	10.06	8.02	8.23	+21	-183
21	JAMUNA	*ARICHA	MANIKGANJ	SHIBALAYA	10.30	8.95	6.93	7.07	+14	-188
22	GUR	SINGRA	NATORE	SINGRA	13.76	12.65	10.69	10.91	+22	-174
23	ATRAI	BAGHABARI	SIRAJGANJ	SHAHJADPUR	12.45	10.40	8.52	8.68	+16	-172
24	DHALESWARI	*ELASIN	TANGAIL	TANGAIL S.	12.34	10.95	6.76	7.1	+34	-385
25	OLD BRAHMAPUTRA	*JAMALPUR	JAMALPUR	JAMALPUR S.	17.08	16.10	9.76	9.73	-3	-637
26	OLD BRAHMAPUTRA	*MYMENSINGH	MYMENSINGH	GAURIPUR	13.25	12.05	4.19	4.29	+10	-776
27	LAKHYA	*LAKHPUR	GAZIPUR	KAPASIA	8.24	5.35	2.89	2.93	+4	-242
28	BURIGANGA	*DHAKA	DHAKA	KERANIGANJ	7.12	5.55	2.8	2.77	-3	-278
29	BURIGANGA	*HARIHARPARA	MUNSHIGANJ	LOHAJANG	6.67	5.35	2.7	2.68	-2	-267
30	BALU	*DEMRA	DHAKA	DEMRA THANA	6.67	5.30	2.84	2.84	0	-246
31	LAKHYA	*NARAYANGANJ	NARAYANGANJ	NARAYANGANJ S.	6.47	5.05	2.92	2.96	+4	-209
32	TURAG	*KALIAKOIR	GAZIPUR	KALIAKAIR	9.82	7.95	5.75	5.73	-2	-222
33	TURAG	*MIRPUR	DHAKA	MIRPUR THANA	7.89	5.50	2.96	2.89	-7	-261
34	TONGI KHAL	*TONGI	GAZIPUR	GAZIPUR S.	7.38	5.65	2.93	2.94	+1	-271
35	KALIGANGA	*TARAGHAT	MANIKGANJ	MANIKGANJ S.	9.95	7.95	3.7	3.85	+15	-410
36	DHALESWARI	*JAGIR	MANIKGANJ	MANIKGANJ S.	9.50	7.80	3.64	3.75	+11	-405
37	DHALESWARI	*REKABI BAZAR	NARAYANGANJ	NARAYANGANJ S.	7.20	4.75	2.79	3	+21	-175

Streamflow

Direct streamflow measurement requires the measurement of both the area and velocity.

Measurement of Velocity

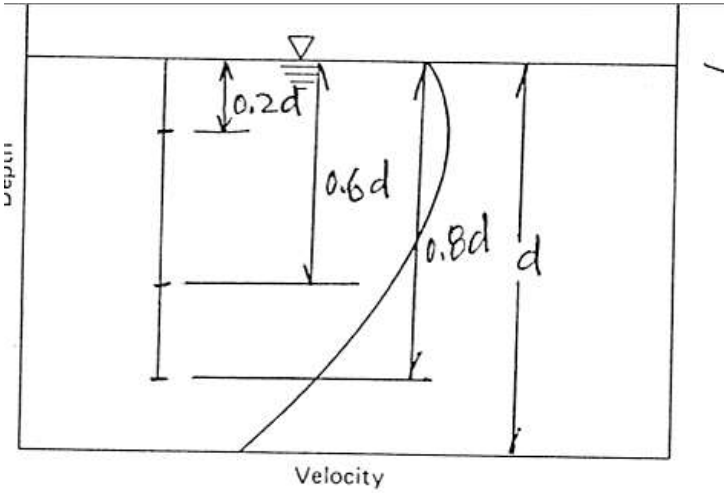
The velocity distribution in a channel is not uniform over width and depth of the channel. The velocity is maximum just under the water surface and the minimum value occurs along the channel boundary.

The velocity is not the maximum at the surface mainly because of resistance from air and secondary currents.

The velocity distribution along the vertical section of a channel is approximately logarithmic.

It has been determined empirically and from many years of experience by the USGS that for most channels the velocity at six-tenths of the total depth below the surface (0.6d) is a close approximation to the mean velocity at that vertical line. However, the average of the velocities at two-tenths (0.2d) and eight-tenths depth (0.8d) below the surface on the same vertical line provides a more accurate value of mean velocity at that vertical line.

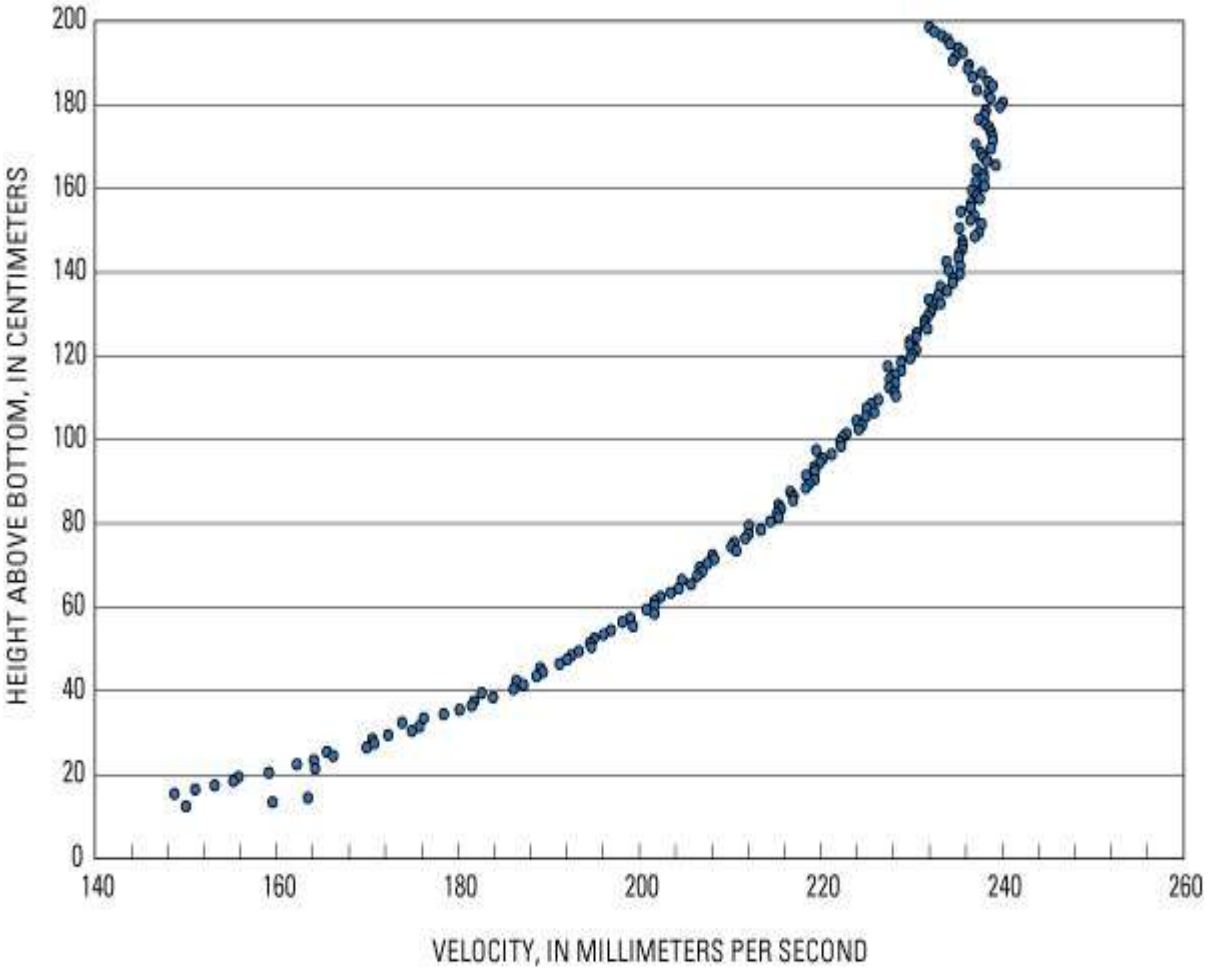
The velocity at different depths is as follows:



Ratio of observation depth to depth of water	Ratio of point velocity to mean velocity in the vertical
0.05	1.160
.1	1.160
.2	1.149
.3	1.130
.4	1.108
.5	1.067
.6	1.020
.7	.953
.8	.871
.9	.746
.95	.648

Velocity Distribution in a River

Velocity distribution in a river is approximately logarithmic – velocity of a flow at a certain depth is proportional to the logarithm of the distance from that river bed.



Streamflow

Measurement of velocity

For streams where the depth is less than 0.6m, the velocity is usually measured at the 60% depth (0.6 method) and this measurement is taken to be the average velocity in the individual section. Shallow depth does not allow accurate measurements at two depths.

For depths greater than 0.6m and up to 2m, measurements are taken at the 80% and 20% depths and the two measurements are averaged.

For depths greater than 2m, velocities can be measured at all three depths (20, 60, and 80%) and then averaged (with 0.6d added twice). But, normally the velocity is measured at 0.2d and 0.8d.

Deph < 0.6m $\quad \bar{V} = V_{0.6d}$; 0.6 water depth from the water surface

$0.6\text{m} \leq \text{Depth} \leq 2\text{m} \quad \bar{V} = \dfrac{V_{0.2d} + V_{0.8d}}{2}$

Depth ≥ 2m $\quad \bar{V} = \dfrac{V_{0.2d} + 2V_{0.6d} + V_{0.8d}}{4}$

Streamflow

Measurement of Velocity

The velocity in a stream can be measured by the following methods:

1. Current Meters: Propeller type (horizontal axis meters)

   Cup type (vertical axis meters)

2. Surface Floats

3. Dilution (Tracer or Chemical) Gauging

4. Acoustic Doppler Current Profiler (ADCP)

Current Meters

The most commonly used method for velocity measurement is by current meters.

For velocity measurement in rivers, cup type (vertical axis) meters are generally used.

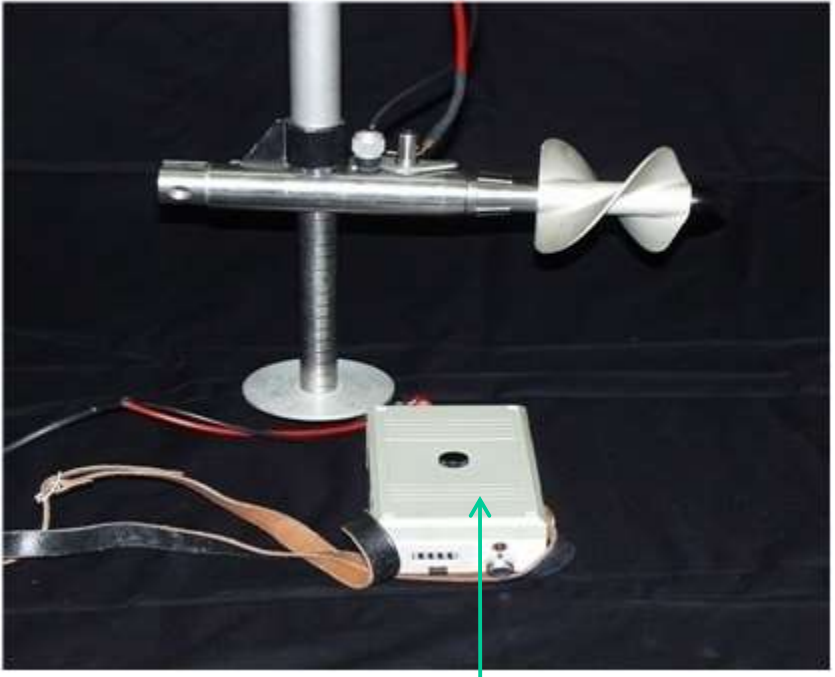
The advantage of cup type meters is that it gives better reading even if the direction of velocity is not perpendicular to the axis of the meter.

The rotational speed of the meter is related to the velocity (V) as:

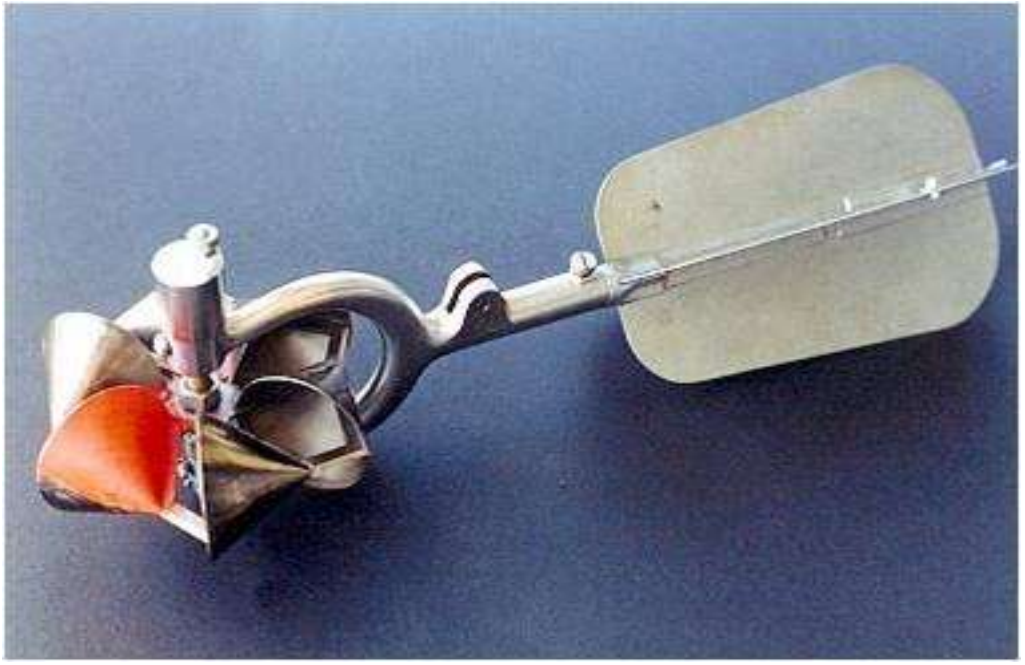
$$V = a + b \times N$$

where a = starting velocity to overcome the mechanical friction; b = equipment calibration constant; N = revolutions/sec.

The values of a and b are provided by the manufacturer but the meter has to be calibrated from time to time to maintain the accuracy of the measurements.



Counter



Current Meters

Weight



Exercise

Given V = 0.3N + 0.05 (m/s). Determine stream discharge using velocity-area method.

Distance from Datum (m)	Stream depth (m)	Current meter reading					
		0.6D		0.2D		0.8D	
		Rotation	Duration (s)	Rotation	Duration (s)	Rotation	Duration (s)
3	0.5	10	60				
6	3.0			35	62	20	65
9	5.7			42	65	28	62
12	8.5			50	68	25	64
15	4.6			57	65	30	68
18	3.8			40	60	32	60
21	2.5			34	62	25	65
24	0.5	15	60				

Velocity is determined in each section depending on the depth of flow.

Streamflow

Surface Floats

Avery crude method of estimation.

The time (t) taken by a float (wooden discs) to travel a certain distance (L) is noted and the mean velocity (V) is noted as:

$$V = 0.85 (L/t)$$ (note: the coefficient is 0.85)

Dilution (Tracer or Chemical) Gauging

Applicable only for small streams.

Dye, radioactive material or salt is injected into the stream and from the measured concentrations, the discharge is calculated.

With constant rate of injection: $Q_1C_1 = Q_2C_2$

A tracer with a known concentration (C_1) at a known flow rate (Q_1) is injected into the stream. The stream concentration (C_2) after complete mixing is then measured. The discharge (Q_2) is then calculated as:

$$Q_2 = (Q_1C_1)/C_2$$

Float Method

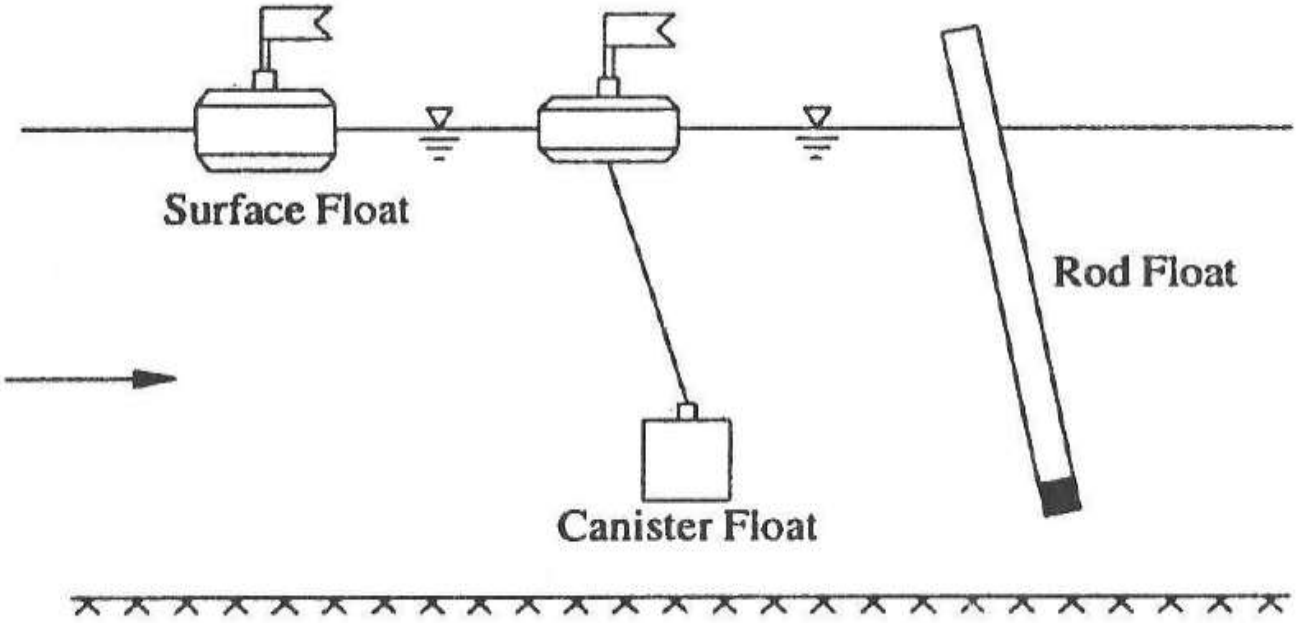
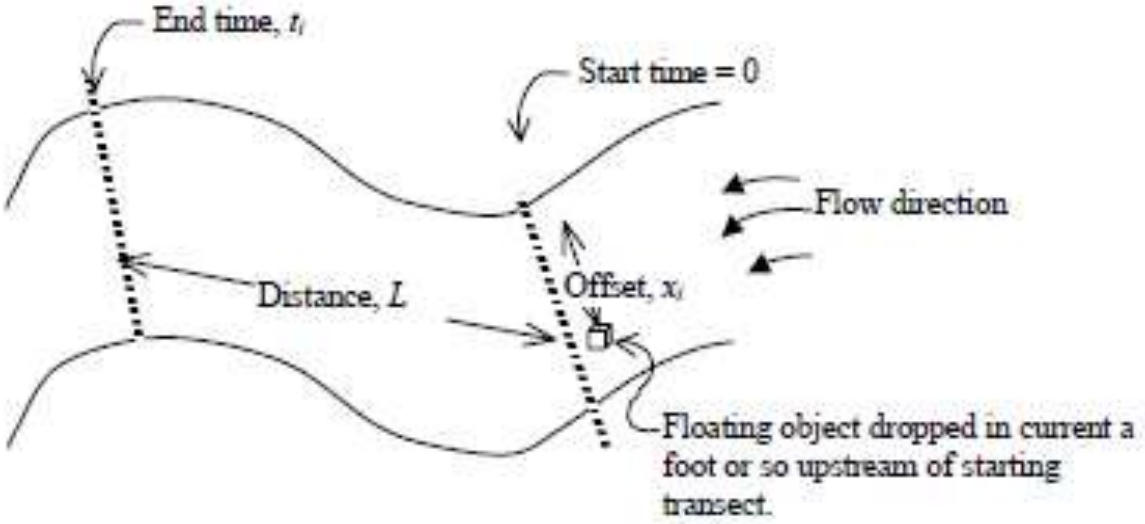
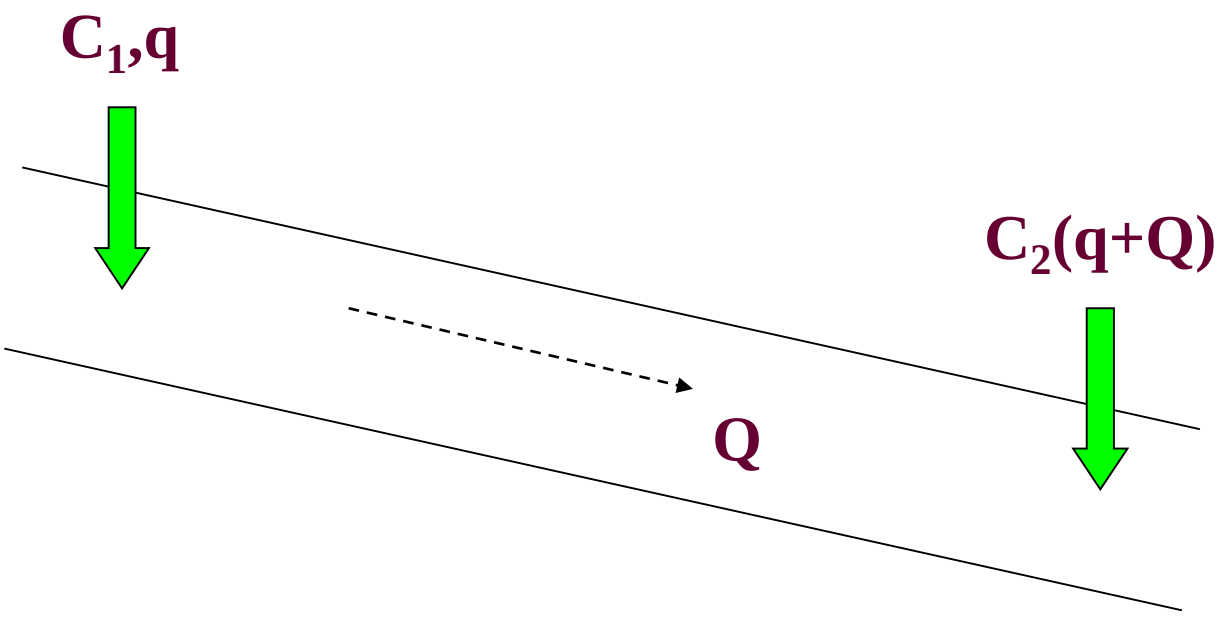
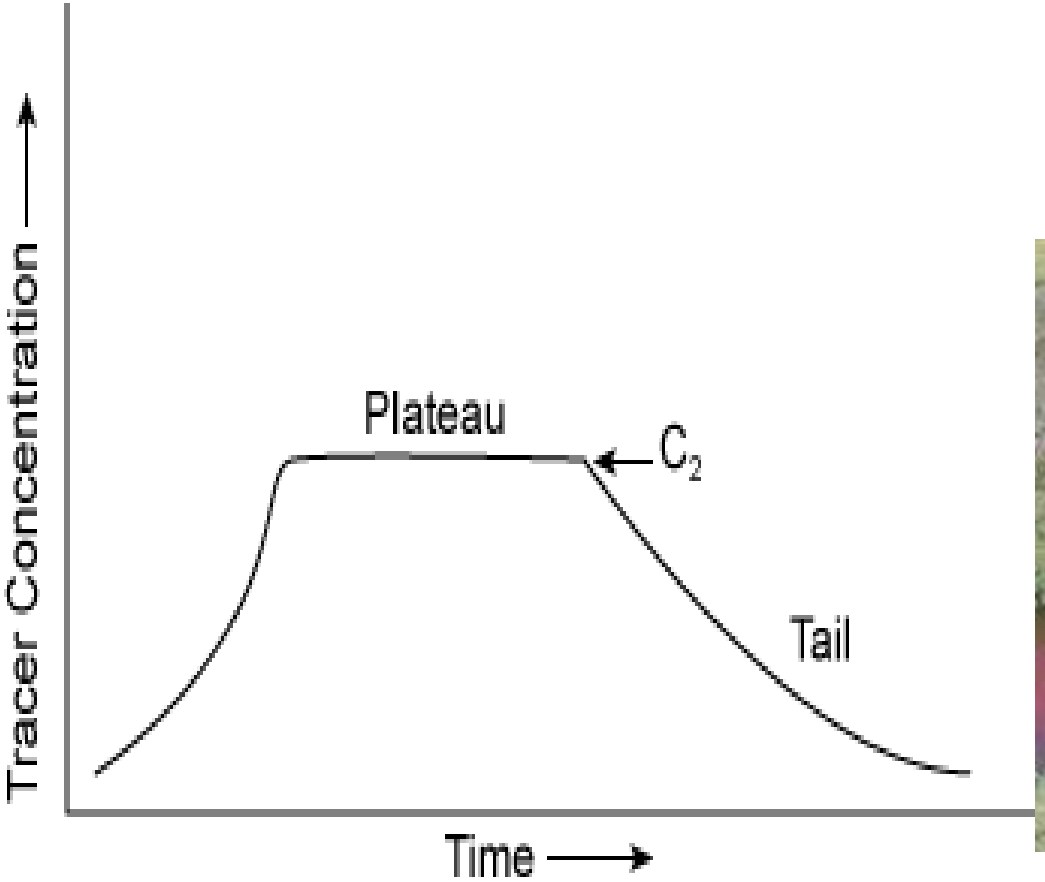


Fig. 4.13 Floats



Tracer Method







Streamflow

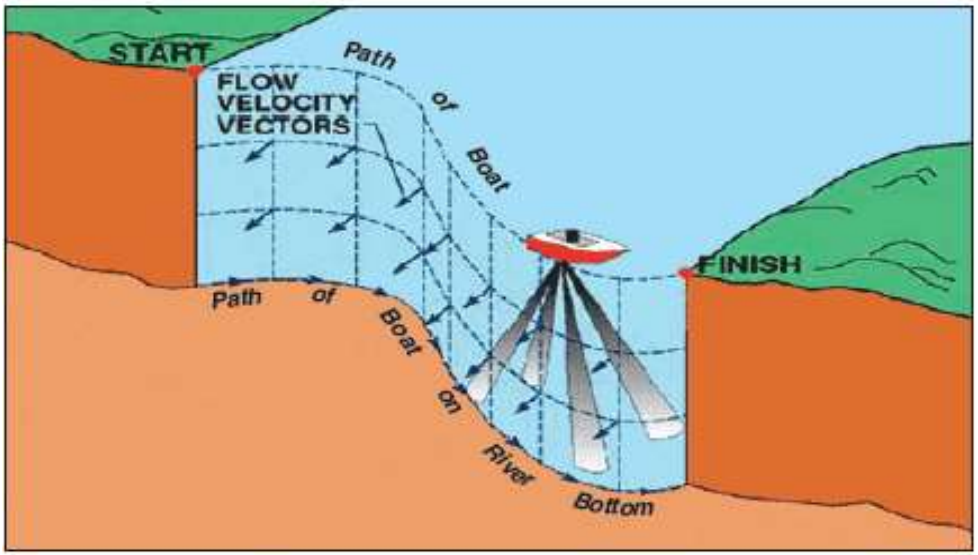
Acoustic Doppler current profilers (ADCP)

With modern computers and electronics, it is now possible to hook up a computer to a device that constantly measures depth and velocity across the stream using sound waves.

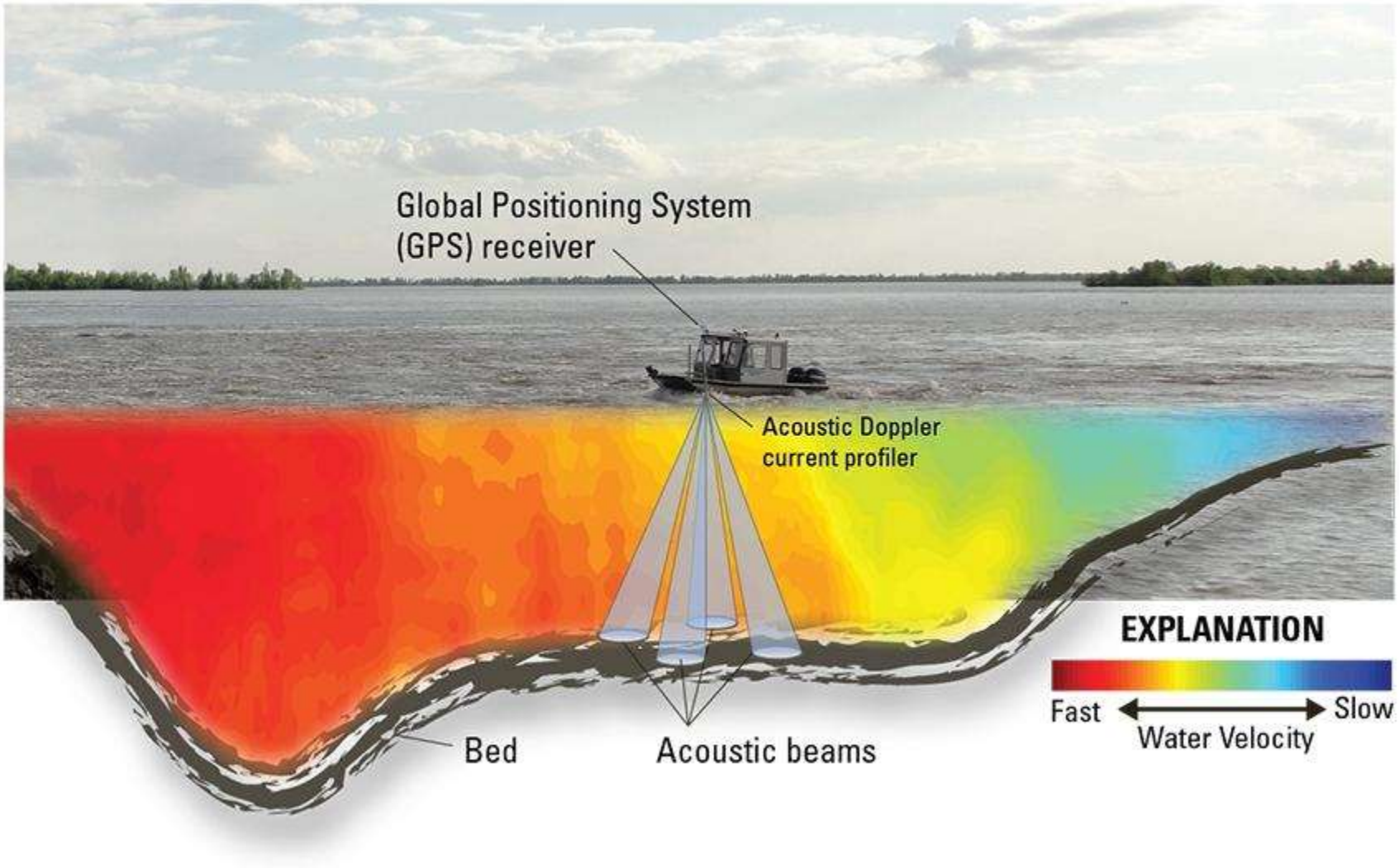
Acoustic Doppler Current Profiler (ADCP) transmit sound into the water and receive reflected sound (echoes) from particles suspended in the water (generally sediment) and from the streambed.

As an ADCP can measure water velocities, depth, and platform path simultaneously, it can compute discharge. Computing discharge using these methods is easier, faster, more accurate, and produces a much more detailed analysis of streamflow characteristics.

The measuring device can be attached to a boat, pulled across the stream from shore, or be attached to a small, remote-controlled float that looks like a small speedboat.

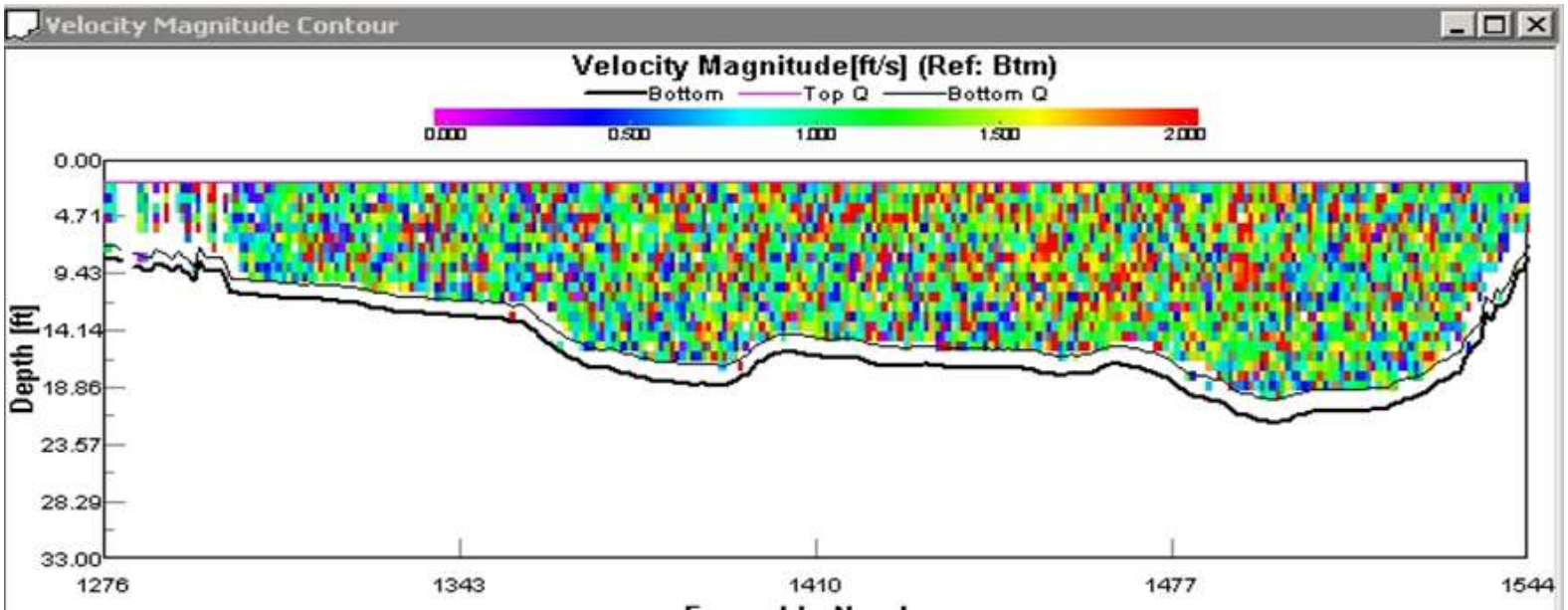


ADCP in operation ----



Velocity (discharge) measurement using ADCP





Streamflow

Measurement of Discharge by Current Meters

If the velocity and the depth of water are known, the discharge can be computed by Area-Velocity method (which is a direct method).

Area-Velocity Method

This is the most common method for the measurement of river discharge.

For the purpose of measurement a straight reach of the river is selected.

The width of the stream is measured from bank to bank at right angles to the direction of flow.

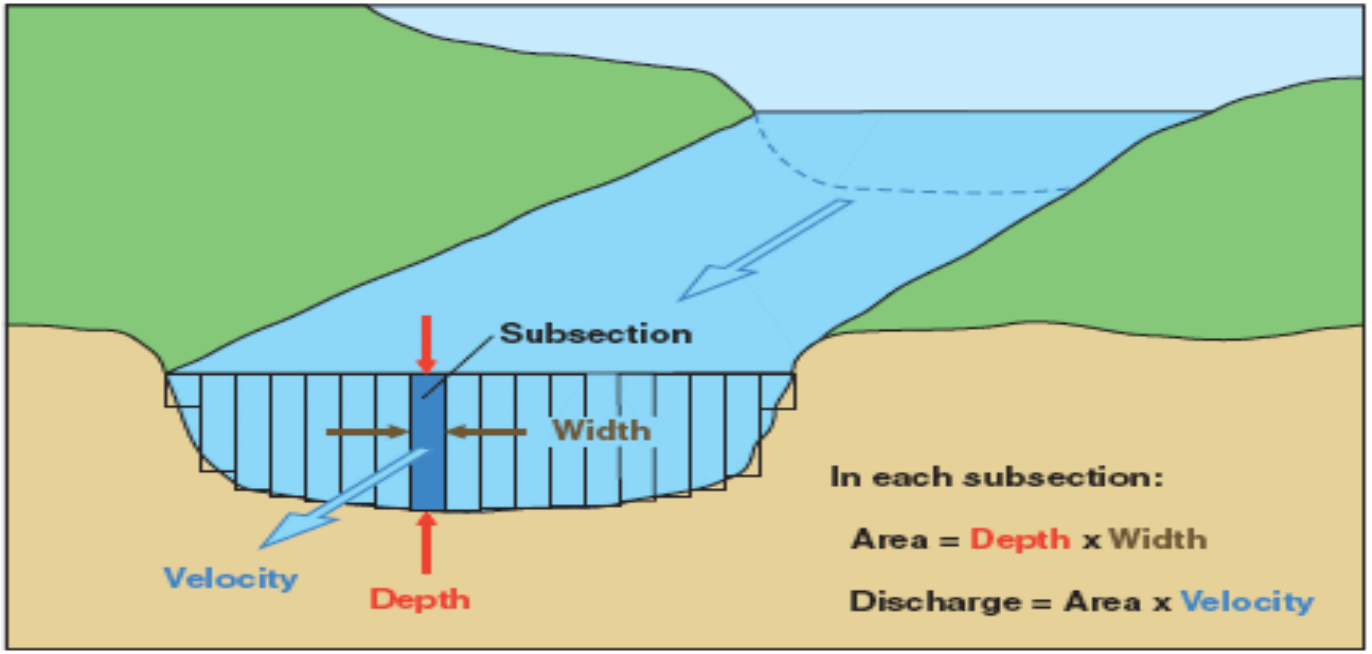
Next, the spacing or the width of the verticals is determined.

The verticals are spaced so that no subsection has more than 10 percent of the total discharge (usually a subsection has 3-4% of the total flow).

The preferred number of verticals is 20 to 30 depending upon the width of the river.

For each of the verticals, the depth of water (d) and the velocity are measured. The velocity should be measured at 0.6d if the d is <= 0.6m and 0.2d and 0.8d if the d is > 0.6m.

The velocity can also be measured at the middle of the subsection extending halfway to the adjacent vertical (mid-section method).


Subsection
Width
Velocity
Depth
In each subsection:
Area = Depth x Width
Discharge = Area x Velocity

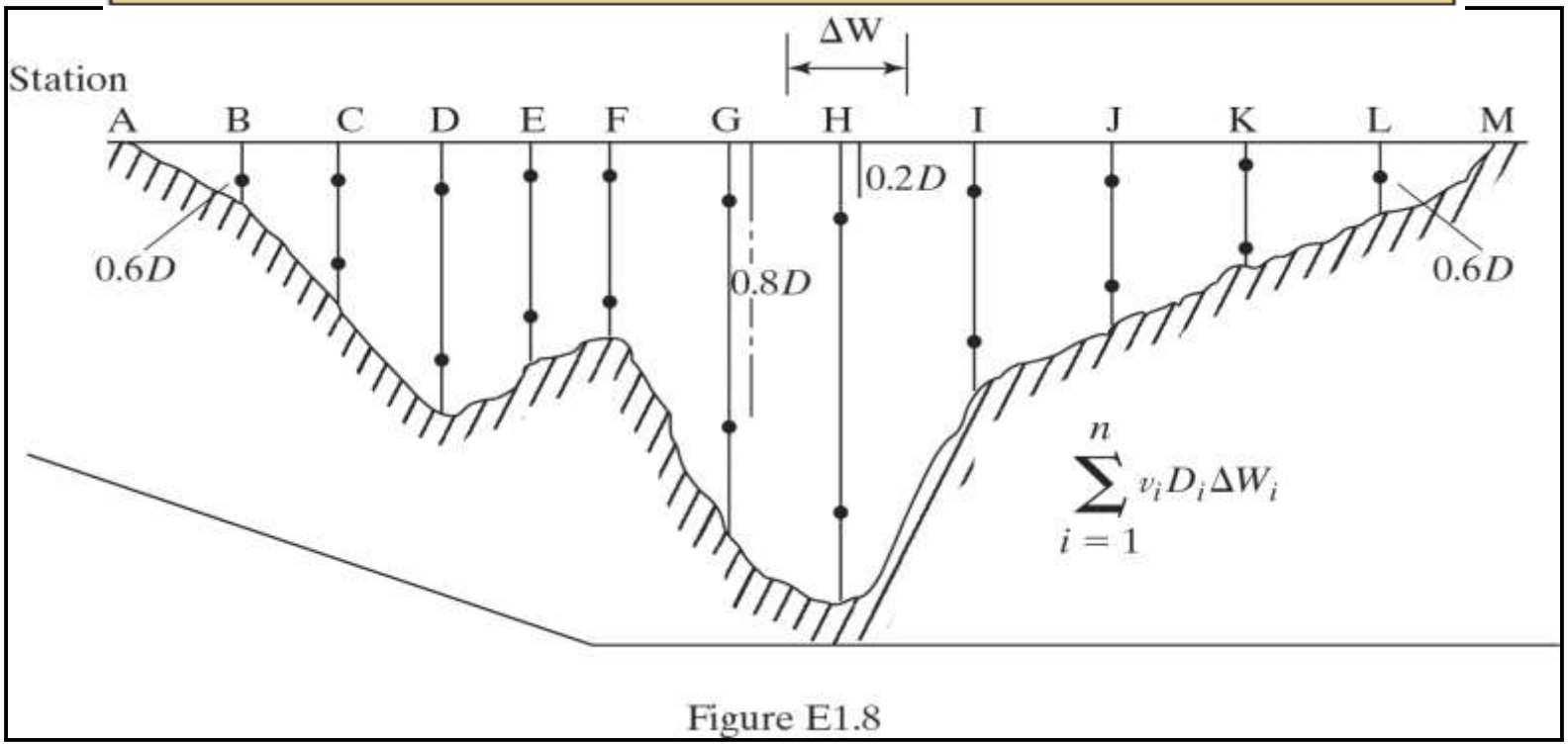
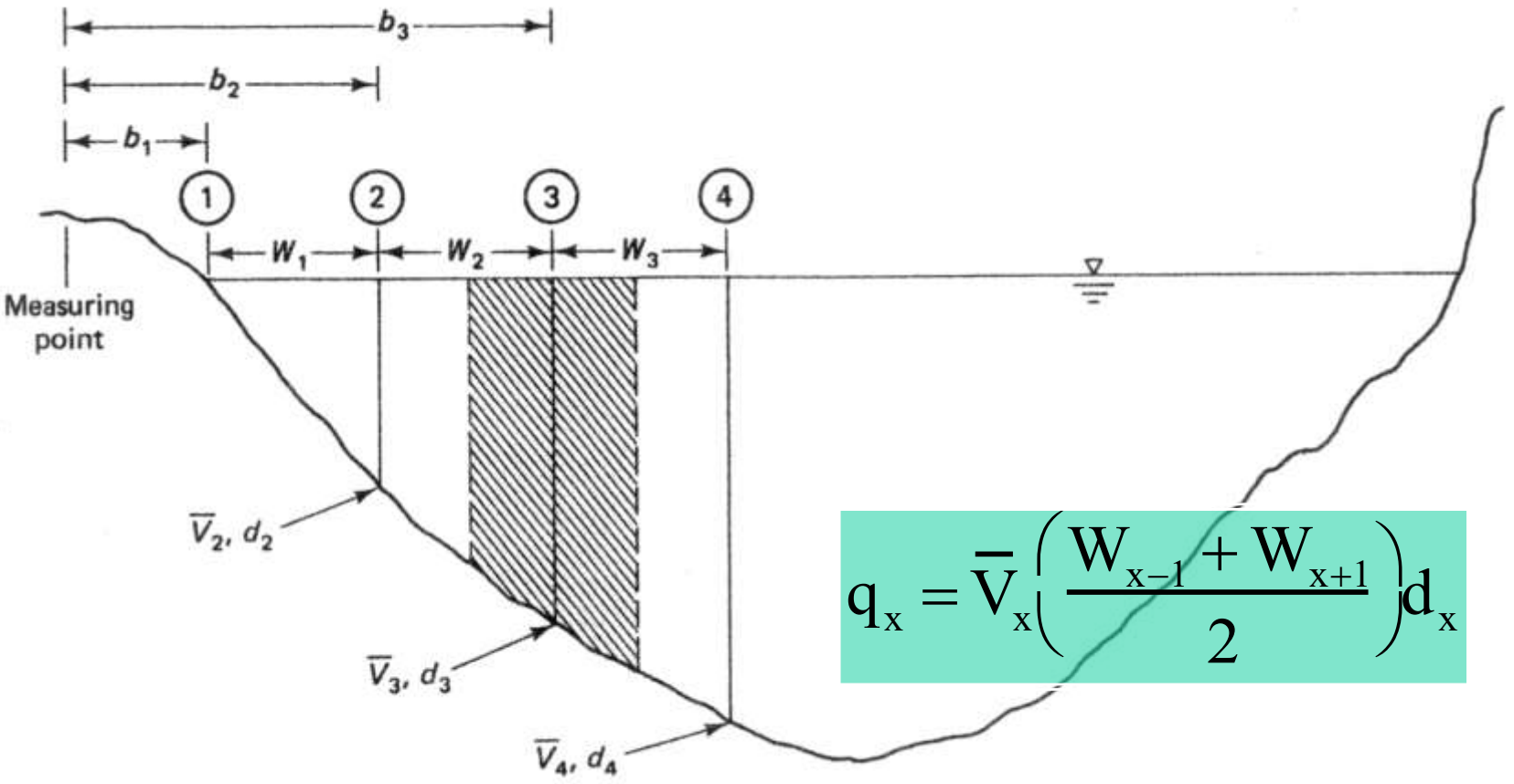

Station
ΔW
A
B
C
D
E
F
G
H
I
J
K
L
M
0.2D
0.6D
0.8D
0.6D
$\sum_{i=1}^{n} v_i D_i \Delta W_i$

Figure E1.8

Mid-section Method



$$q_x = \overline{V}_x \left(\frac{W_{x-1} + W_{x+1}}{2} \right) d_x$$

The discharge Q_i of the subsection is computed by multiplying the average velocity of the vertical with the area of the subsection.
The total discharge Q is computed by summing the Q_i of subsections

Example Calculation:

Distance from edge, b (m)	Depth, d (m)	Rev/min		
		0.6d	0.2d	0.8d
0	0			
2	0.5	14		
4	2.6		48	44
6	4.0		57	52
8	7.2		43	37
10	4.3		38	32
12	3.2		36	29
14	0.5	12		
15.5	0			

Example: Area-velocity method

		Velocity (m/s)					
Distance	d	0.6d	0.2d	0.8d	V_{avg}	$(b_{i+1}/2 + b_i/2) = w$	qi
0	0				0		
2	0.5	0.108			0.108	2	0.108
4	2.6		0.250	0.233	0.242	2	1.26
6	4.0		0.288	0.268	0.278	2	2.224
8	7.2		0.229	0.203	0.216	2	3.11
10	4.3		0.208	0.184	0.196	2	1.686
12	3.2		0.200	0.172	0.186	2	1.19
14	0.5	0.100			0.100	1.75	0.088
15.5	0				0.000		

$Q = 9.67\ m^3/s$