6. Streamflow Measurements

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.

$$Q = \frac{V}{t}$$

$$= v \times A$$

Where Q = discharge (L^3/T, m^3/s, liter/s,, cumec);

V = volume (L^3);

t = time (T);

v = velocity (L/T);

A = cross-sectional area (L^2).

It is hard and expensive to make a direct and continuous measurement of the stream flow rate. However, it is easier to obtain a continuous measurements of stream stage and then estimate the discharge from the relationship between the stage and discharge as $Q = f(s)$.

- ***Rating curve/Flow rating curve*** *is a graph shows the relationship between stage of a river channel, at a specific cross-section, and the corresponding discharge at that section,* Fig. 6.1.

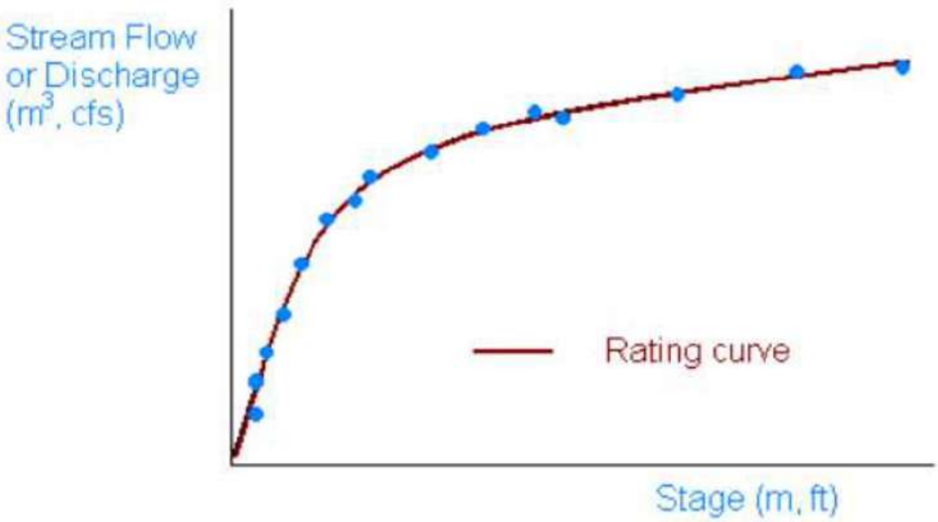


Fig. 6.1 Rating curve

6.1 Water Stage Measurements

***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.

6.1.1 Manual Gauges

The simples way to measure WL in the river is using staff gauge.

1. Staff Gauge

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.

Fig. 6.2 Staff gauge

(a) Simple vertical staff gauge

It is fixed rigidly to a structure, such as an abutment, pier, wall, etc. Fig. 6.3. The water level recorded from time to time. It is usually sued in the small river.

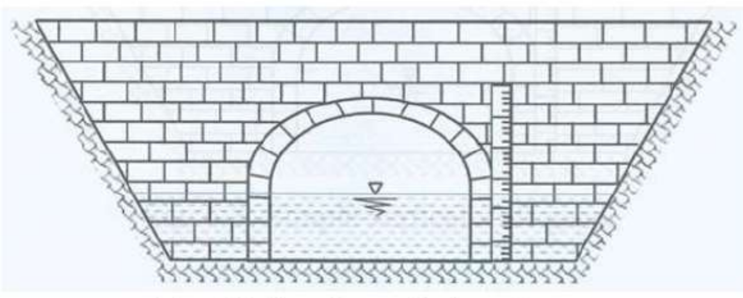


Fig. 6.3 Simple vertical staff gauge

b) Inclined staff gauge

Usually located on the concrete slope side of the lining channel and graduated so that the scale reads directly in vertical depth, Fig. 6.4.

$$H = L\ sin\theta + B.M.$$

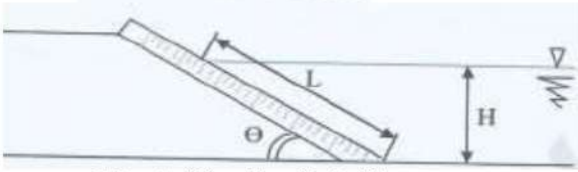


Fig. 6.4 Inclined staff gauge

(c) Section staff gauge

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. 6.5). 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.

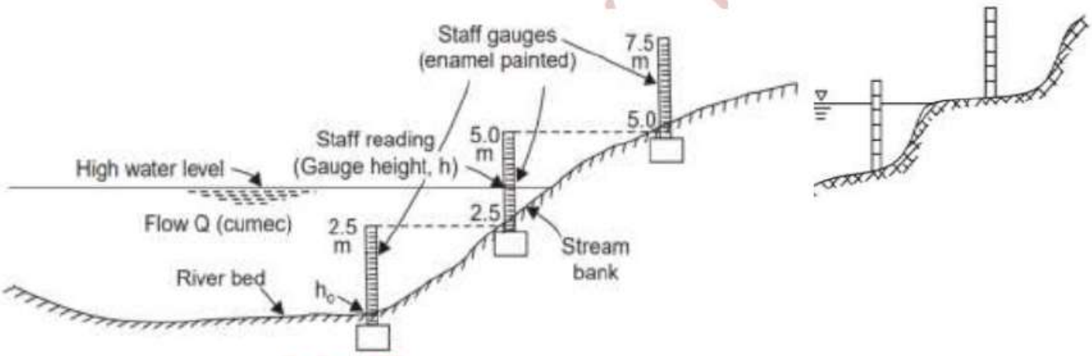


Fig. 6.5 Sectional staff gauge

2. Wire Gauge

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, Fig. 6.6.

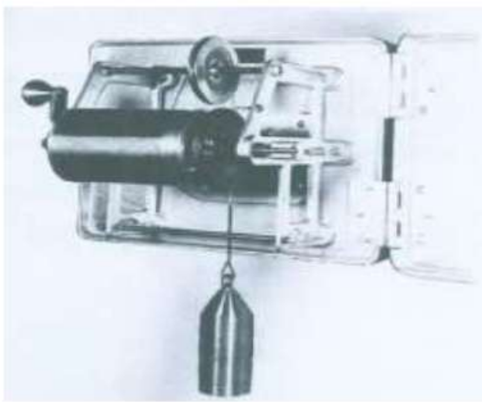


Fig. 6.6 Wire gauge

3. Automatic Stage Recorders

To overcome the difficulty of measuring the rapid change in the river stage, the motion of the float is recorded on a chart for 24 hrs, Fig. 6. 7. To protect the float from debris and to reduce the water surface wave effects on the recording, stilling wells are provided in all float-type stage recorder installations, Figure 6.8.

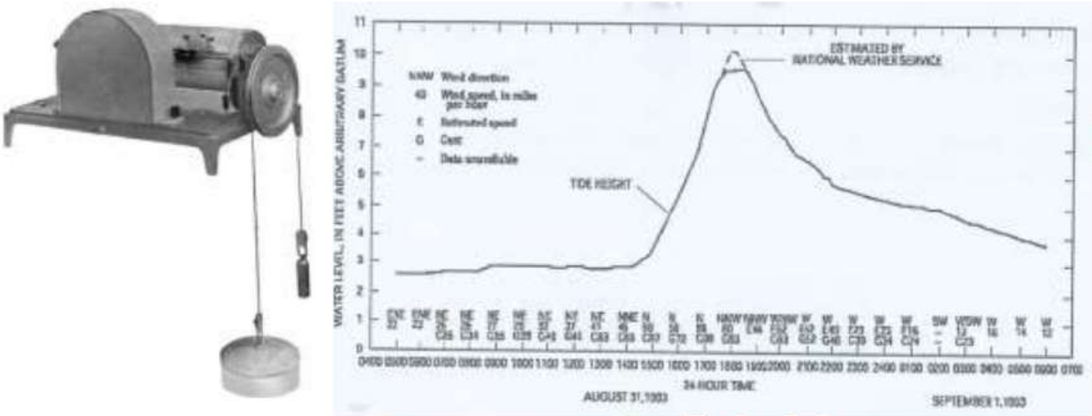


Fig. 6.7 Recording gauge

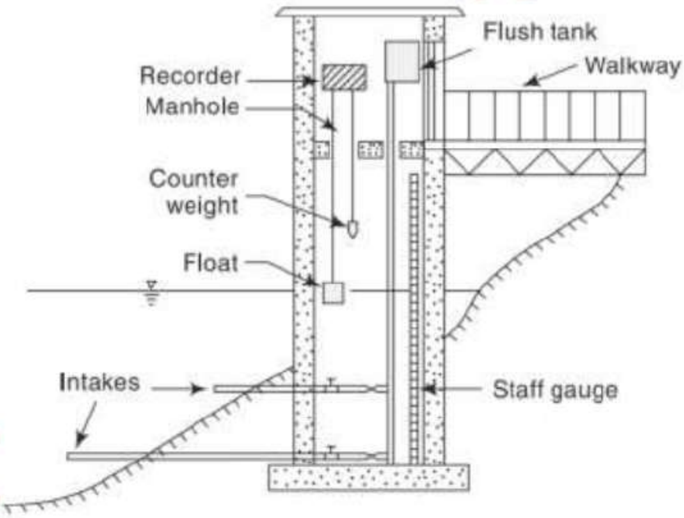


Fig. 6. 8 Stilling well installation

4 Crest-stage gages

They are used to record high water marks when peak events occur. Ground cork will float from the bottom cap as water levels rise, stick to the wooden rod and leave a mark.

6.2 Stream flow measurements

Can be broadly classified into two categories as

1. Direct determination of stream discharge:

(a) Area-velocity methods,

(b) Dilution techniques,

(c) Electromagnetic method, and

(d) Ultrasonic method.

2. Indirect determination of stream-flow:

(a) Hydraulic structures, such as weirs, flumes and gated structures, and

(b) Slope-area method

1. Direct determination of stream discharge:

$$Q = v \times A$$

(a) Area-velocity methods:

Is one of the methods that used to find the Q in the medium and small rivers where the flow velocity is calculated from the current meter device, Fig. 6.9.

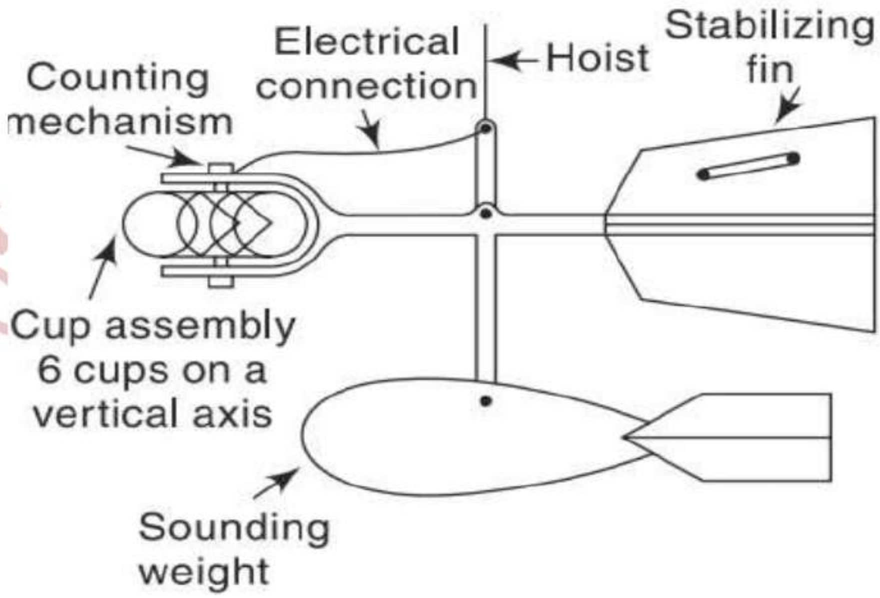


Fig. 6.9 Vertical-axis Current Meter

The counter records the number of revolution for specific time and the flow velocity estimated from:

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

where: a = constant represent the starting velocity or velocity to overcome mechanical fraction;

b = constant of proportionality;

N = number of revolution by time.

For purposes of discharge estimation:

(a) the cross section is divided into a large number of subsections by verticals (Fig. 4.10). The segment width should not be greater than 1/15 to 1/20 of the width of the river.

(b) Estimate the total depth for each section by the ruler or any survey method.

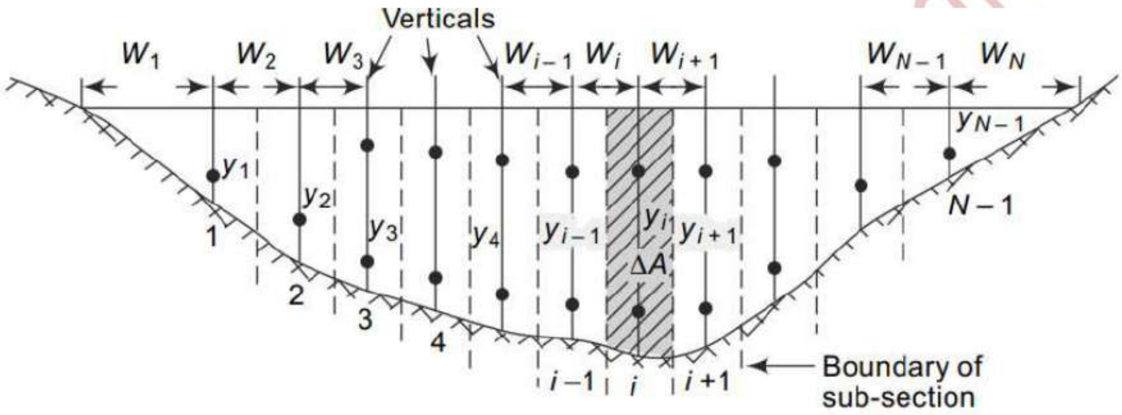


Fig. 6.10 Stream Section for Area-velocity Method

(c) The flow velocity each subsection is measured at a depth (0.8 D) and (0.2 D) or (0.6 D) of the total water depth at the section. The average velocity in the subsection:

(d) Multiply the average velocity for each section by the area from the mid-distance between every two records position to be the next record position, Fig. 6.11.

$$\Delta Q = (b \times d) \times v_{0.6d} \qquad \textit{in shaloow strips}$$

$$\Delta Q = (b \times d) \times \frac{v_{0.2d} + v_{0.8d}}{2} \quad \textit{in deep water strips}$$

$$\textit{stream discharge} \quad Q = \sum \Delta Q$$

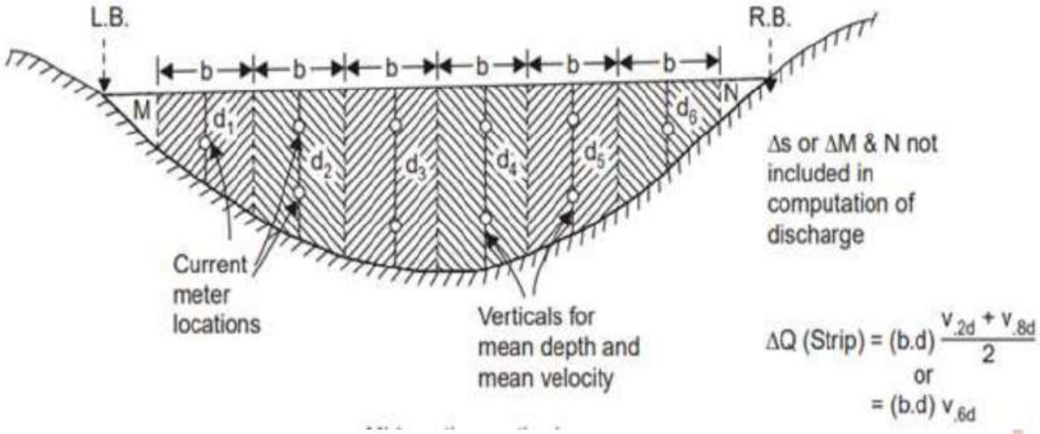


Fig. 6.11 Mid-section Method

Example1 : For the stream flow cross-section in Fig. 6. 12, estimate the discharge (m^3/s).

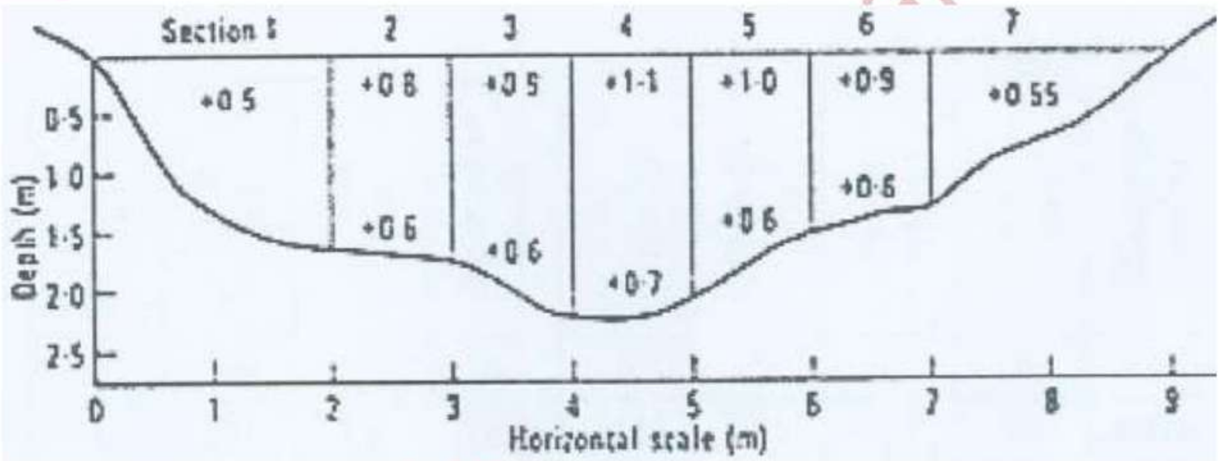


Fig. 6.12 Stream cross-section dimensions

Solution:

Section no.	Flow velocity (m/s)			Water depth (m)	Width (m)	Area (m^2)	Flow (m^3/s)
	0.2 D	0.8 D	mean				
1	-	-	0.5	1.3	2	1.3 × 2 = 2.6	0.5 × 2.6 = 1.3
2	0.8	0.6	0.7	1.7	1	1.7 × 1 = 1.7	0.7 × 1.7 = 1.19
3	0.9	0.6	0.75	2.0	1	2 × 1 = 2.0	0.75 × 2 = 1.5
4	1.1	0.7	0.9	2.2	1	2.2 × 1 = 2.2	0.9 × 2.2 = 1.98
5	1.0	0.6	0.8	1.8	1	1.8 × 1 = 1.8	0.8 × 1.8 = 1.44
6	0.9	0.6	0.75	1.4	1	1.4 × 1 = 1.4	0.75 × 1.4 = 1.05
7	-	-	0.55	0.7	2	0.7 × 2 = 1.4	0.55 ×1.4 = 0.77
							Q = 9.23

Example 2: Estimate the discharge in the stream based on the data given in table below. The current meter with (a = 0.01 and b = 2.4)

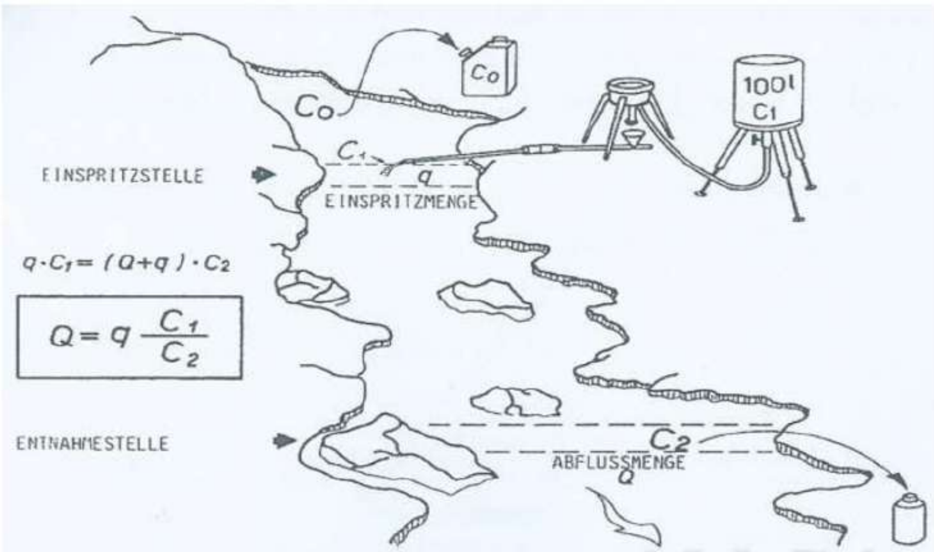
Distance (m)	1	4	7	10		13		15		16	17
Depth (m)	0.95	1.2	2	2.1		2.3		2		1.5	0
Observation depth	0	0.6	0.6	0.2	0.8	0.2	0.8	0.2	0.8	0.6	0
Revolution	0	5	7	15	10	20	10	15	10	15	0
Time (s)	0	40	43	50	50	52	40	55	54	40	0

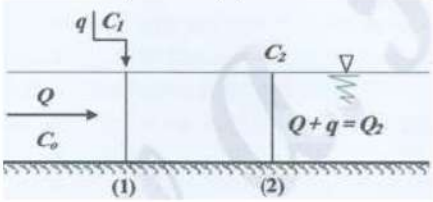
Solution:

Distance (m)	Depth (m)	Observation depth	Rev.	Time (s)	N (rev./s)	V (m/s)	$V_{ave.}$	Area (m^2)	Q (m^3/s)
1	0.95	0	0	0	0	0	0	0	0
4	1.2	0.6	5	40	0.125	0.31	0.31	3.6	1.12
7	2	0.6	7	43	0.163	0.4	0.4	6	2.40
10	2.1	0.2	15	50	0.3	0.73	0.61	6.3	3.84
		0.8	10	50	0.2	0.49			
13	2.3	0.2	20	52	0.385	0.93	0.77	5.75	4.43
		0.8	10	40	0.25	0.61			
15	2	0.2	15	55	0.27	0.67	0.56	3.0	1.68
		0.8	10	54	0.19	0.45			
16	1.5	0.6	15	40	0.38	0.91	0.91	1.5	1.37
17	0	0	0	0	0	0	0	0	0
									Q_{total} = 14.83 m^3/s

(b) Dilution/chemical Technique

It depends upon the continuity principle applied to a tracer which is allowed to mix completely with the flow.





$$Q \times C_o + q \times C_1 = (Q + q) \times C_2$$

$$Q \times C_o + q \times C_1 = Q \times C_2 + q \times C_2$$

$$Q \times (C_2 - C_o) = q \times (C_1 - C_2)$$

$$\therefore Q = \frac{q \times (C_1 - C_2)}{C_2 - C_o}$$

If $C_o = zero$ $\therefore Q = \frac{q \times (C_1 - C_2)}{C_2}$ $\therefore Q = q \times (\frac{C_1}{C_2} - 1)$

If $C_o = zero$ & $Q \gg q$ $\therefore Q = q \times (\frac{C_1}{C_2})$

where: Q = discharge (L^3/T);

C_o = background concentration (m/g) or (*ppm*);

Q = rate of injection (L^3/T);

C_1 = concentration of injection substance at point 1;

C_1 = concentration of injection substance at point 2;

Example 3: *200000 mg/l* of tracer is injected into flowing stream at a concentration rate of *1 l/s*. Downstream from the injection point when the tracer is completely mixed, the recorded concentration is *5 mg/l*. Estimate the discharge of the stream, if the stream has no background concentration of that particular tracer.

Solution:

$$Q = q \times (\frac{C_1}{C_2})$$

$$Q = 1 \times (\frac{200000}{5}) = 40000\, l/s = 40\, m^3/s$$

Tracers should not be

1. Absorbed by the sediment, channel boundary and vegetation.
2. Non-toxic.
3. Capable of being detected in a distinctive manner in small concentrations.
4. Very expensive.

The tracers used are of three main types:

1. Chemicals (common salt and sodium dichromate are typical)
2. Fluorescent dyes;
3. Radioactive materials.

Extension of Stage-Discharge Rating Curve

When it is necessary to estimate a discharge that is larger than the maximum discharge estimated in the rating curve, then it would important to extend the rating curve by creating the equation of the curve. The common equation is:

$$Q = k\,(h - a)^b$$

where h = stage (L);

a, b, and k = station's constant.

To estimate the values of (a, b, and k):

1. Plot the (Q) versus (h) on graph paper and draw smooth accurate curve;
2. Chose three Q (Q_1, Q_2, & Q_3) so that $\left[\frac{Q_1}{Q_2} = \frac{Q_2}{Q_3}\right]$ or $Q_2 = \sqrt{Q_1 \times Q_3}$;
3. Find the value of corresponding ((h_1, h_2, & h_3) from the curve and the equation:

$$\left[\frac{h_1 - a}{h_2 - a} = \frac{h_2 - a}{h_3 - a}\right]$$

$$(h_1 - a) \times (h_3 - a) = (h_2 - a)^2$$

$$h_1h_3 - h_1a - h_3a + a^2 = {h_2}^2 - 2\,h_2a + a^2$$

$$h_1h_3 - {h_2}^2 = a\,(h_1 + h_3 - 2\,h_2)$$

$$\therefore\ a = \frac{h_1h_3 - {h_2}^2}{h_1 + h_3 - 2\,h_2}$$

Use least square error method to estimate (k and b) constants by taking the logarithm for both sides of the eq.:

$$\log Q = \log k + b \log (h\text{-}a)$$

$$Y = A + b\,X$$

$$\log Q = \log k + b \log (h - a)$$

$$A = \frac{\sum Y \sum X^2 - \sum X \sum XY}{n \sum X^2 - (\sum X)^2}$$

$$b = \frac{n \sum XY - \sum X \sum Y}{n \sum X^2 - (\sum X)^2}$$

$$k = 10^A$$

The other methods used to extending the rating curve depending on Manning or Chezy equations:

$$Q = A\,C\sqrt{R\,S}$$

If $C\sqrt{S}$

is assumed to be constant = k and R $\frac{A}{P}$ is mean depth (D) for shallow water.

$$\therefore Q = k\,A\sqrt{D}$$

By plotting the discharge (Q) versus $(A\sqrt{D})$, the shape of the relation will be resulted that is very close to a straight line and can be extended. The values of $(A\sqrt{D})$, for the stages, which is larger than the available values in the rating curve can be calculated in the field and then applied on the extension of the rating curve.

Example 4: For extension of rating curve, by the least square error method, the following discharges and the corresponding stages reading were obtained from measurement. Find the best eq. for the curve.

(h-a) (m)	10	20	30	50	80
Q (l/s)	100	300	600	1000	2400

Solution:

$$log\,Q = log\,k + b\,log\,(h\text{-}a)$$

$$Y = A + b\,X$$

(h - a) (m)	Q (l/s)	Log (h –a) X	Log Q Y	$(\text{Log}(h-a))^2$ X^2	$(\text{Log } Q)^2$ XY
10	100	1.00	2.00	1.00	2.00
20	300	1.30	2.48	1.69	3.22
30	600	1.48	2.78	2.18	4.10
50	1000	1.70	3.00	2.89	5.10
80	2400	1.90	3.38	3.62	6.43
		$\sum X = 7.38$	$\sum Y = 13.64$	$\sum X^2 = 11.38$	$\sum XY = 20.86$

$$A = \frac{\sum Y \sum X^2 - \sum X \sum XY}{n \sum X^2 - (\sum X)^2} = \frac{13.64\times11.38-7.38\times20.86}{5\times11.38\times(7.38)^2} = 0.53$$

$A = \log k$, $K = 10^A = 10^{0.53} = 3.36$

$$b = \frac{n\sum XY - \sum X \sum Y}{n \sum X^2 - (\sum X)^2} = \frac{n\times20.86-7.38\times13.64}{5\times11.38\times(7.38)^2} = 1.49$$

$$Q = 3.36\,(h-a)^{1.49}$$

Example 5: The stage-discharge data at a river are given below. *Determine*: (a) The relationships between the stage and the discharge by a rating curve. (b) The discharge corresponding to a stage of 23 m. (c) The stage corresponding to a discharge of 1400 m^3/s.

Stage (m)	20.52	21.30	21.72	22.48	22.95	23.31	23.72	24.04
Q (m^3/s)	50	180	250	430	580	710	900	1100

Solution:

(a) Draw the rating curve: $Q = k\,(h - a)^b$

- To estimate the values of (a, b, and k):

1. Plot the (Q) versus (h) on graph paper and draw smooth accurate curve;

2. Choose 3 Q (Q_1, Q_2, & Q_3) so that $\left[\frac{Q_1}{Q_2} = \frac{Q_2}{Q_3}\right]$ or $Q_2 = \sqrt{Q_1 \times Q_3}$;

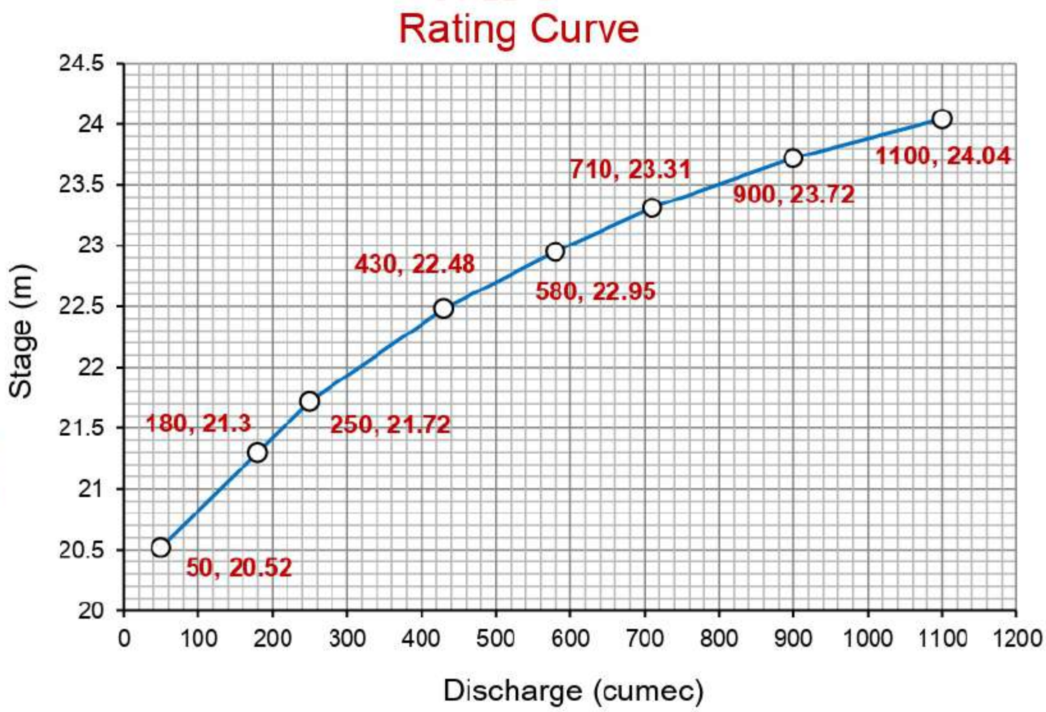
Choose Q_1 =180 m^3/s, Q_3 =580 m^3/s for the graph.

Then $Q_2 = \sqrt{180 \times 580}$ = 323 m^3/s h_2 = 22 m from graph

$$a = \frac{h_1 \times h_3 - {h_2}^2}{h_1 + h_3 - 2h_2} = \frac{21.3 \times 22.95 - 22^2}{21.3 + 22.95 - 2 \times 22} = 19.34\ m$$

$log\ Q = log\ k + b\ log\ (h\text{-}a)$

$Y = A + b\,X$



Stage (m)	Q (m^3/s)	H - a	Log Q	Log (H – a)	$(\text{Log Q})^2$	Log Q × Log (H – a)
		Y	X	Y	X^2	X×Y
20.52	50	1.18	0.07	1.70	0.01	0.12
21.3	180	1.96	0.29	2.26	0.09	0.66
21.72	250	2.38	0.38	2.40	0.14	0.90
22.48	430	3.14	0.50	2.63	0.25	1.31
22.95	580	3.61	0.56	2.76	0.31	1.54
23.31	710	3.97	0.60	2.85	0.36	1.71
23.72	900	4.38	0.64	2.95	0.41	1.90
24.04	1100	4.7	0.67	3.04	0.45	2.04
			$\sum X = 3.71$	$\sum Y = 20.60$	$\sum X^2 = 2.01$	$\sum XY = 10.18$

$$A = \frac{\sum Y \sum X^2 - \sum X \sum XY}{n \sum X^2 - (\sum X)^2} = \frac{20.60 \times 2.01 - 3.71 \times 10.18}{8 \times 2.01 \times (3.71)^2} = 1.57$$

$$A = \log k,$$

$$K = 10^A = 10^{1.57}$$

$$= 37.361$$

$$b = \frac{n \sum XY - \sum X \sum Y}{n \sum X^2 - (\sum X)^2} = \frac{8 \times 10.18 - 3.71 \times 20.60}{8 \times 2.01 \times (3.71)^2} = 2.16$$

$$Q = 37.36\,(h - 19.34)^{2.16}$$

$$Q = 37.36\,(23 - 19.34)^{2.16} = 617.75 \text{ cumec}$$

$$Q = 37.36\,(h - 19.34)^{2.16}$$

$$1400 = 37.36\,(h - 19.34)^{2.16}$$

$$h = 24.96 \text{ m}$$