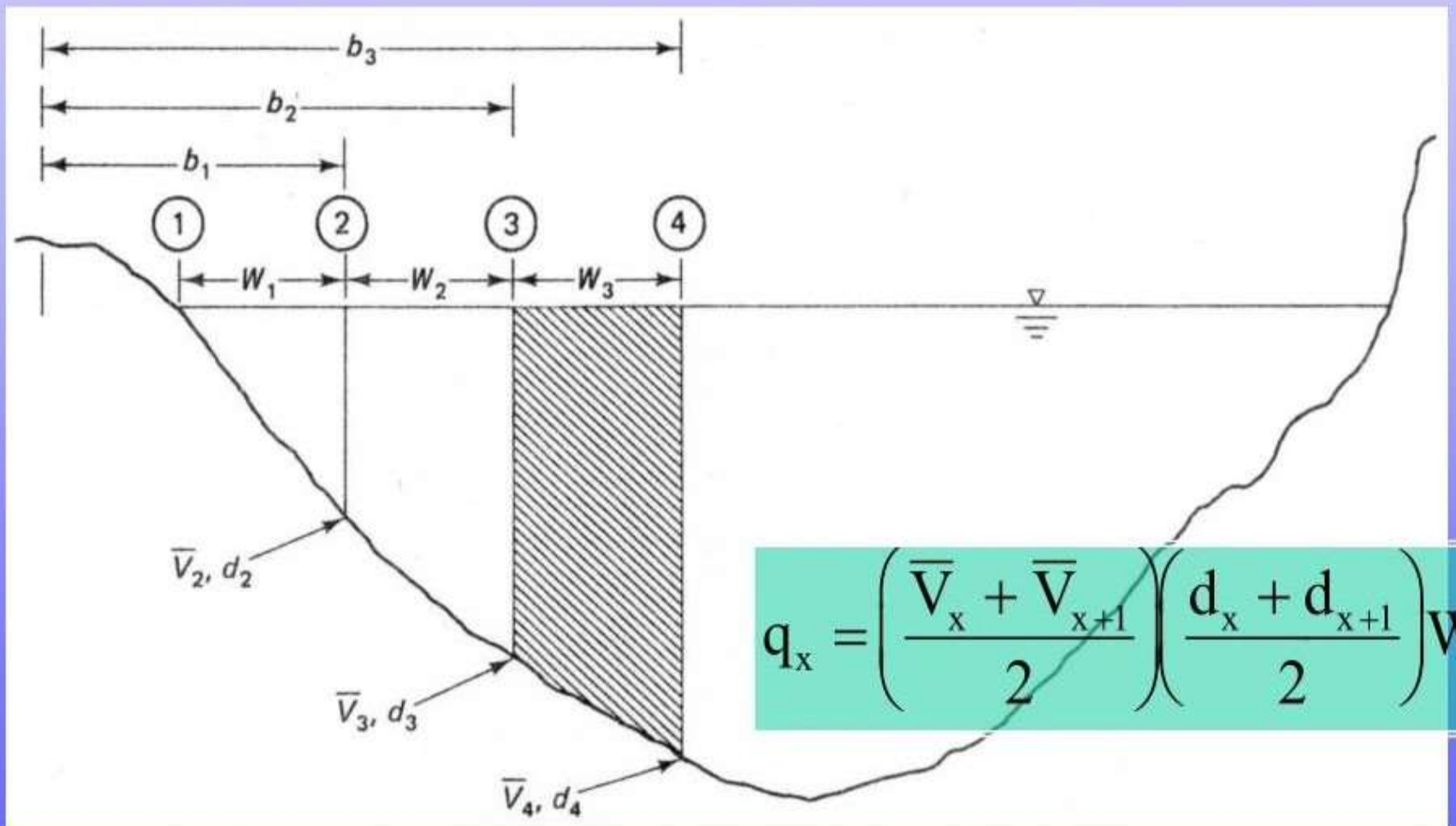
Mean-section Method



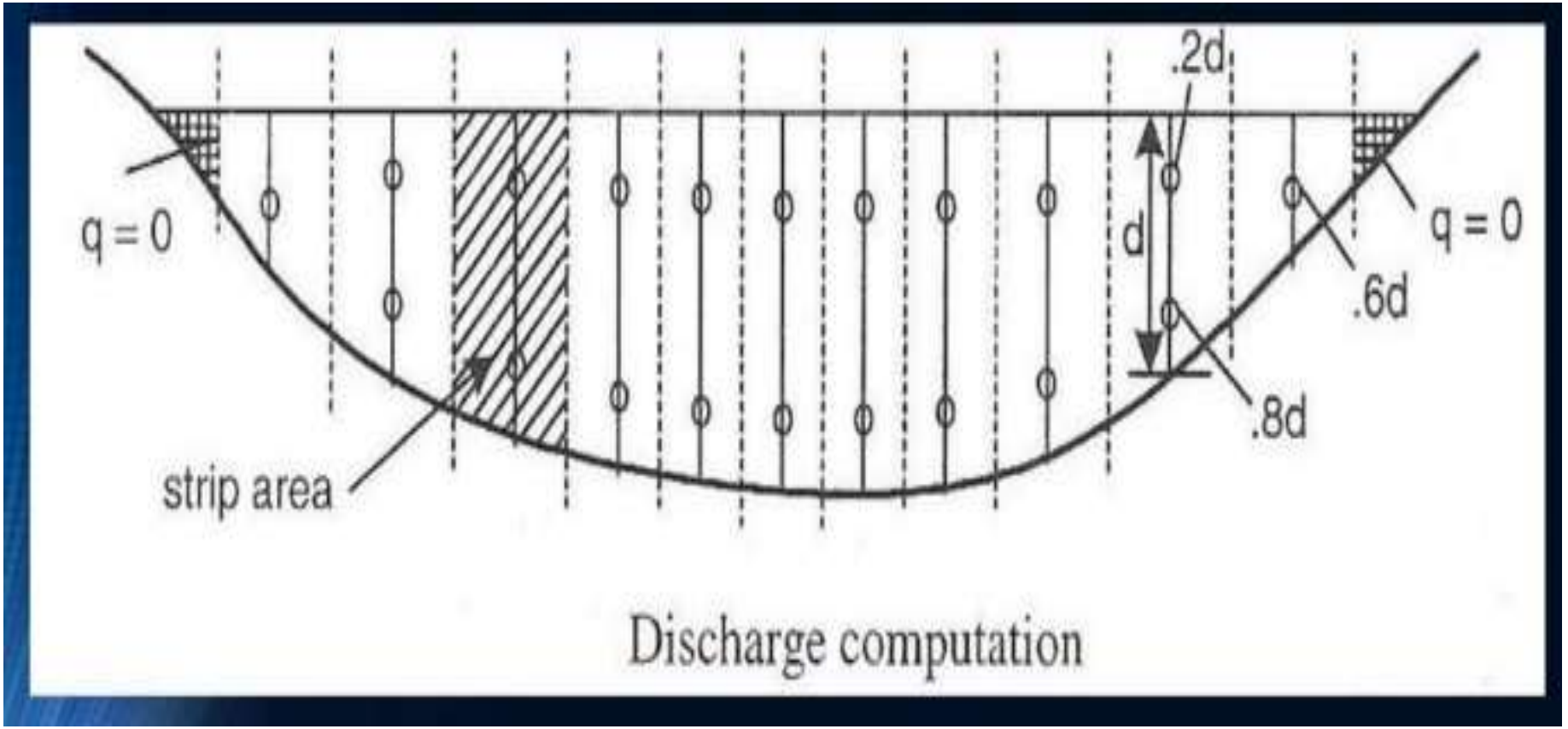
$$q_x = \left(\frac{\overline{V}_x + \overline{V}_{x+1}}{2}\right)\left(\frac{d_x + d_{x+1}}{2}\right)W_x$$

Example: Area-velocity method (Mean-section)

			Velocity (m/s)						
Distance	d	d_{avg}	0.6d	0.2d	0.8d	V	V_{avg}	w	qi
0	0					0			
2	0.5	0.25	0.108			0.108	0.05	2	0.025
4	2.6	1.55		0.250	0.233	0.242	0.175	2	0.543
6	4.0	3.30		0.288	0.268	0.278	0.260	2	1.716
8	7.2	5.60		0.229	0.203	0.216	0.247	2	2.766
10	4.3	5.75		0.208	0.184	0.196	0.206	2	2.369
12	3.2	3.75		0.200	0.172	0.186	0.191	2	1.432
14	0.5	1.85	0.100			0.100	0.143	2	0.529
15.5	0	0.25				0.000	0.05	1.5	0.018

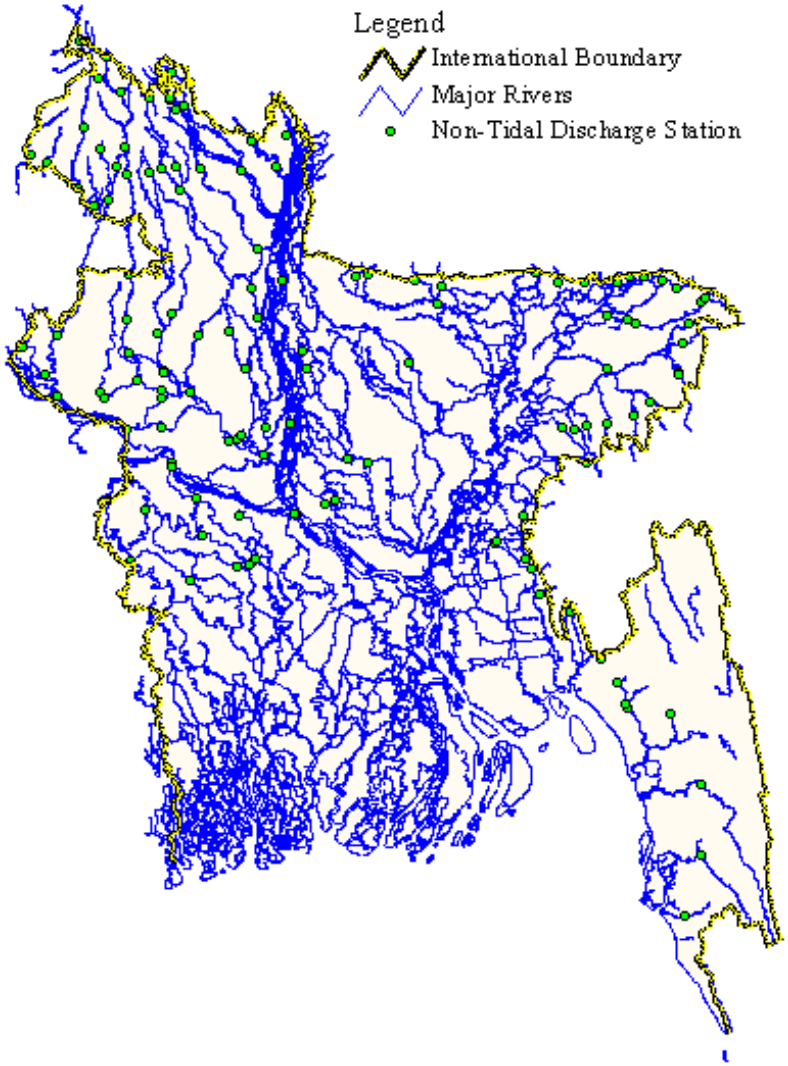
Q = 9.667 m^3/s

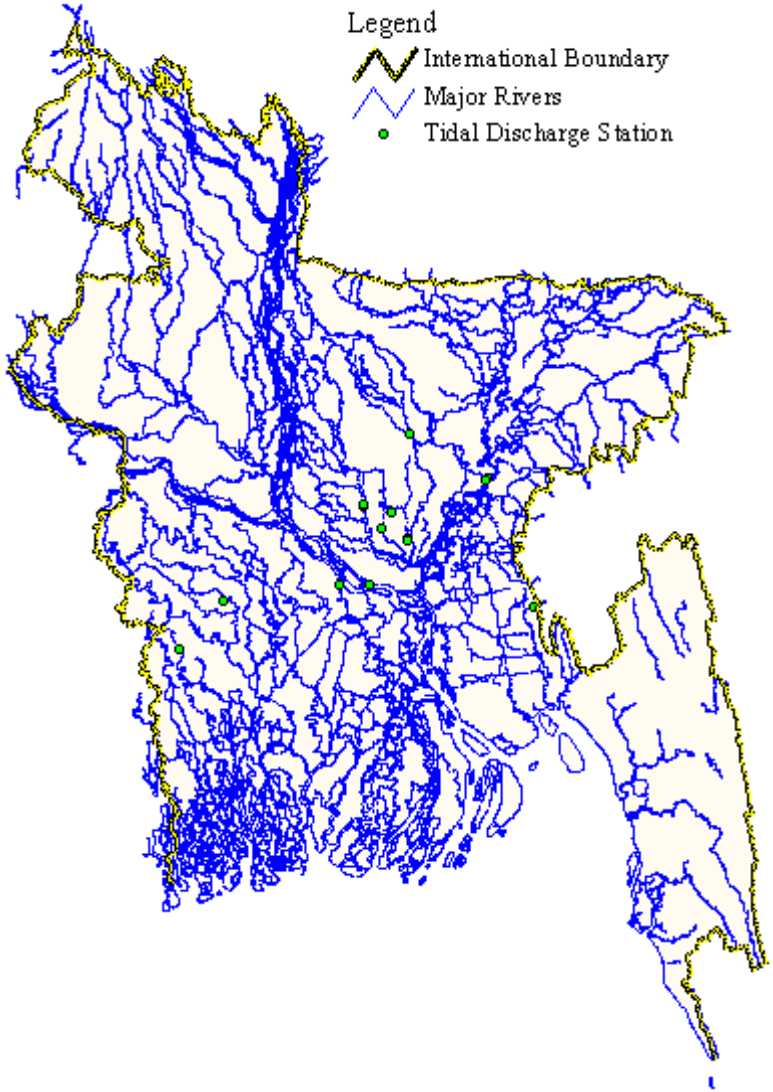
The disadvantage with Mid-section method is that the discharge at the ends are neglected. But for higher accuracy, the discharge at the end triangles can be measured by measuring the depth and velocity at the centroid of the triangle.



Discharge Measurement in Bangladesh

In Bangladesh discharge is measured at 112 stations (tidal and non-tidal). The discharge is measured by area-velocity method and there is a plan to introduce ADCP for discharge measurement in the next five years.





Streamflow

Moving Boat Method

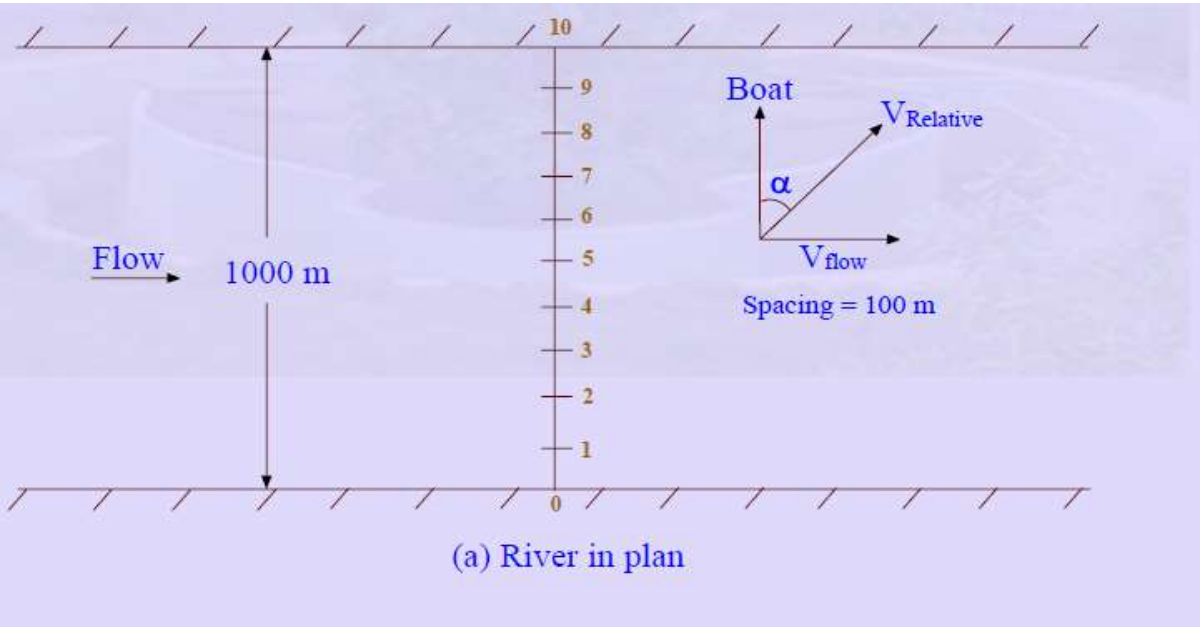
Discharge measurement in large rivers with the conventional area-velocity method is very difficult and time consuming. With high velocity it becomes impossible to keep the boat stationary at any vertical. Under such condition, the moving boat method is applied.

The moving boat method is accomplished by traversing a boat along the measuring section. An echo sounder records the stream bed profile, a continuously operating water current meter senses the combined velocity of stream and the boat i.e., the relative velocity V_R. The velocity of the boat V_b is the velocity at which the current meter is pushed through the water by the boat.

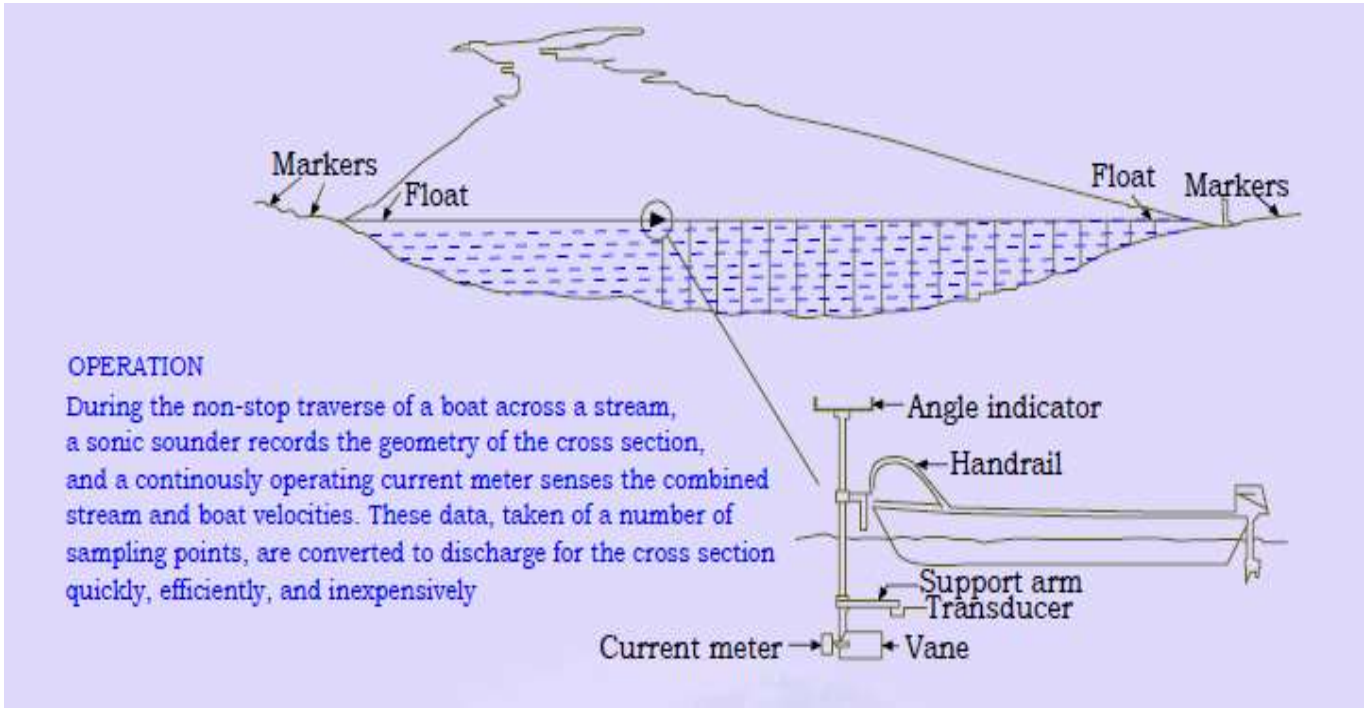
At the measuring point the angle represents the vertical angle the vane makes with the true course of the boat.

The velocity V_R is the vector sum of V_f the component of stream velocity perpendicular to the boat path and V_b the velocity of the boat with respect to the stream bed, along the measuring section.

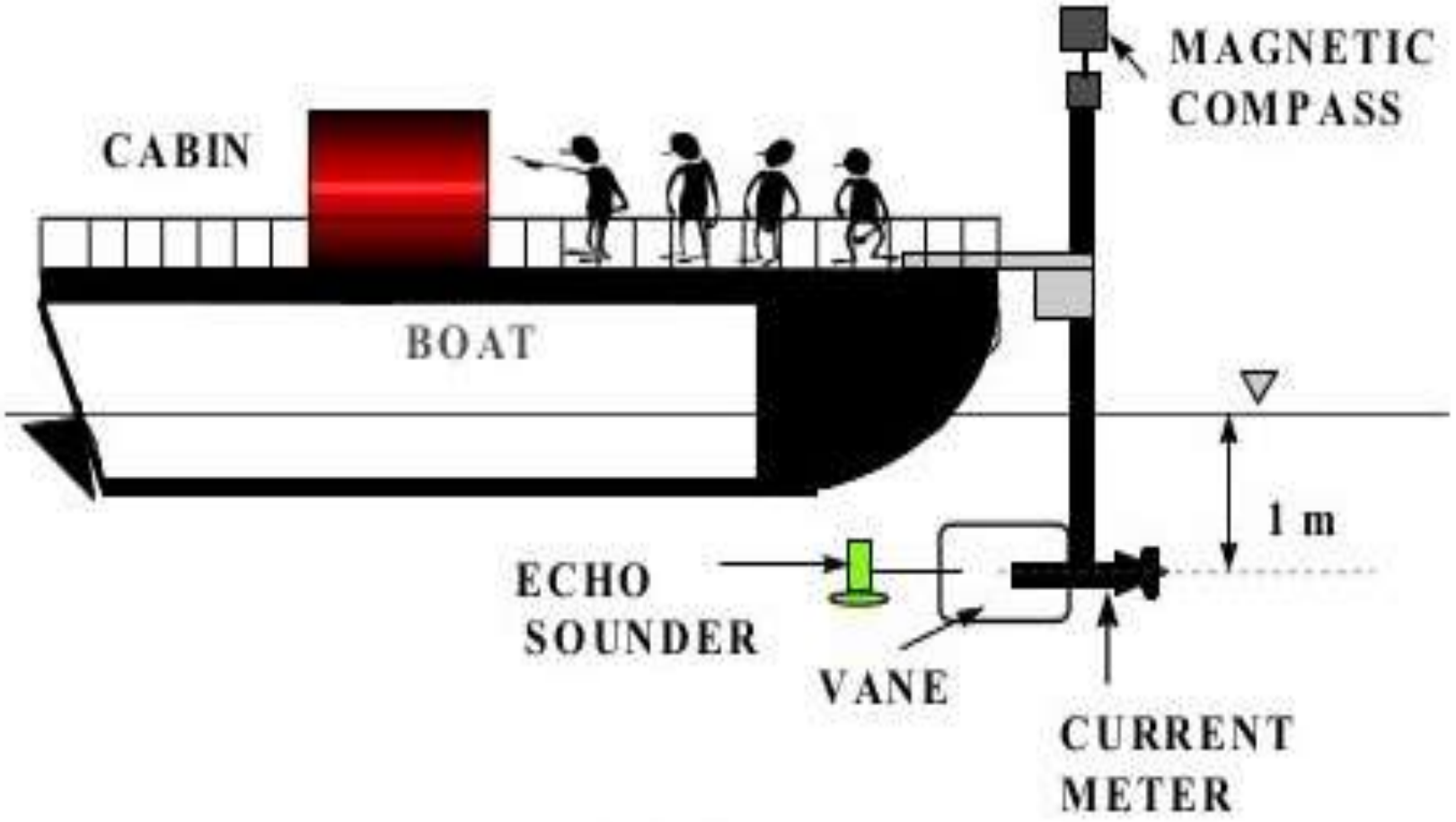
Moving Boat Method of Streamflow Measurement



(a) River in plan



MOVING BOAT EQUIPMENT



Streamflow

If a boat with current meter moves with a velocity v_b at right angle to the direction of river flow v_f, then the resultant velocity (as shown by the current meter) is v_R, making an angle of α with the direction of the boat. Thus;

$$v_b = v_R \cos \alpha \quad \text{and} \quad v_f = v_R \sin \alpha$$

If the time required to travel between two verticals (1 and 2) is Δt, then the length of the vertical w is: $w = v_b \Delta t$

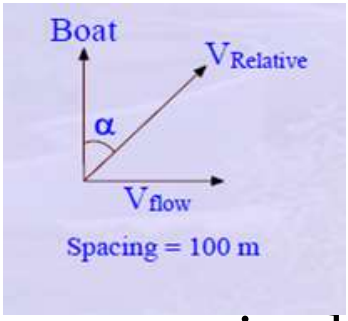
The area of the subsection is: $wd = v_b \Delta t (d_1 + d_2)/2$

The flow ΔQ through the subsection is: $\Delta Q = wdv_f = v_f v_b \Delta t (d_1 + d_2)/2$

Or $\Delta Q = v_R \sin \alpha \, v_R \cos \alpha \, \Delta t (d_1 + d_2)/2$

Or $\Delta Q = v^2_R \sin \alpha \cos \alpha \, \Delta t (d_1 + d_2)/2$

The discharge Q is the summation of the ΔQ.



In this method, during field measurement the current meter is placed at a depth of 0.5 – 1 m from the surface to measure the surface velocities and the inclination angle α is measured by compass.

The surface velocities are converted to average velocities by multiplying with a coefficient.

Example

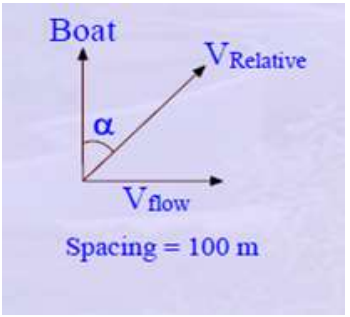
In the moving boat method of discharge measurement the magnitude (V_R) and direction (□) of the velocity of the stream relative to the moving boat are measured. The depth of the stream is also simultaneously recorded. Estimate the discharge in a river that gives the following moving - boat data. Assume the mean velocity in a vertical to be 0.95 times the surface velocity measured by instrument.

DATA TABLE

Section	V_R (m/s)	¯ (degrees)	Depth (m)	Remark
0	-	-	-	Right bank
1	1.75	55	1.8	Θ is the angle made by V_R with the boat direction and Channel Width 75 m.
2	1.84	57	2.5	
3	2.00	60	3.5	
4	2.28	64	3.8	
5	2.30	65	40	
6	2.20	63	3.8	
7	2.00	60	3.0	
8	1.84	57	2.5	
9	1.70	54	2.0	
10	-	-	-	Left bank

For section: 1 $\Delta Q = v^2{}_R \sin\alpha \cos\alpha \, \Delta t \, (d_1)/2$

But, $v_R \cos\alpha \, \Delta t = w = 75$ m (given)



So, $\Delta Q = (1.75) \sin 55^0 \times 75 \times (d_1)/2$

$= (1.75) \times 0.819 \times 75 \times (1.8)/2$

$= 96.76 \text{ m}^3/\text{sec}$

Note: If W is not given then the time (Δt) must be given. In that case:

$$\Delta Q = v^2{}_R \sin\alpha \cos\alpha \, \Delta t \, (d_1)/2$$

For section -1

$\Delta t = 75 / v_R \cos e = 75/ (1.75 \cos 55) = 74.72$ secs

$Q_1 = [(0+1.8)2][\ 1.75^2 \sin 55 \cos 55]\ 74.2 = 96.76\ m^3/s$

For section -2

$\Delta t = 75 / v_R \cos e = 75/ (2.5 \cos 57) = 74.84$ secs

$Q_2 = [(1.84+2.5)2][\ 1.75^2 \sin 57 \cos 57]\ 74.84 = 248.83\ m^3/s$

and so on-

Solution(contd.)

Calculation Table

Section	v_R (m/s)	Θ (degrees)	Depth (m)	$\Delta t = W / v_R \cos \theta$ (sec)	$Q_i = [(y_i + y_{i+1})/2][v^2_R \sin \theta \cos \theta] * \Delta t$ (m^3/s)
0	-	-	-		0.0
1	1.75	55	1.8	74.72	96.76
2	1.84	57	2.5	74.84	248.83
3	2.00	60	3.5	75.00	389.71
4	2.28	64	3.8	75.04	560.99
5	2.30	65	4.0	77.16	609.73
6	2.20	63	3.8	75.09	573.35
7	2.00	60	3.0	75.00	441.67
8	1.84	57	2.5	74.84	318.27
9	1.70	54	2.0	75.06	232.09
10	-	-	-		3471.4

Calculation of time is not necessary as width is given.

So, $Q = \sum \Delta Q = 3471.4 \times 0.95 = 3297.8\ m^3/sec$

Note: <u>The velocity correction factor may not be given!</u>

Limitations of Moving Boat Method

LIMITATIONS

- **RIVER WIDTH SHOULD BE > 300 m**
- **RIVER DEPTH SHOULD BE > 2 m**
- **MINIMUM SEGMENTS ARE 25**
- **VELOCITY RECORDED IS 1 m BELOW WATER SURFACE**
- **NOT SUITABLE WHEN UNDER WATER CURRENTS ARE PRESENT**

- The velocity correction factor is not a constant

Streamflow

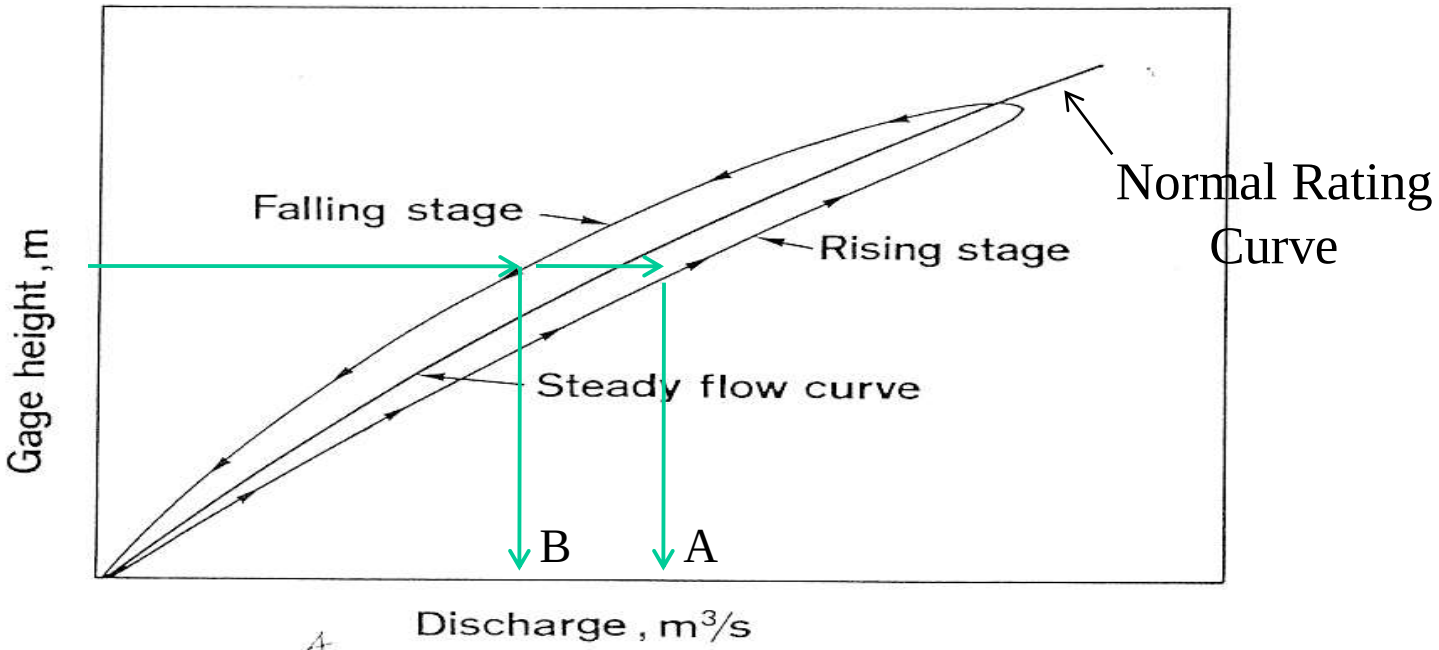
Stage-discharge Curve (Rating Curve)

A relationship between discharge and stage is determined over time by taking periodic measures of discharge over a wide range of flows. The relationship (known as stage-discharge curve or **rating curve**) is then used to translate the continuous measurements of stage into discharge values.

Loop Rating Curve – during the flood the velocities in alluvial rivers are higher than the normal velocities and results in erosion of the river bed (rising stage). Thus, at the same stage, the discharge is higher than the normal discharge (A). During the recession (falling stage), the velocity decreases and also there is deposition in the river bed. Thus, the same stage has lower discharge (B). The resulting curve is known as:

loop rating curve.

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RATING CURVE

- Relates stage to discharge
- Constructed by plotting measured discharge agains stage
- Typically non-linear curves

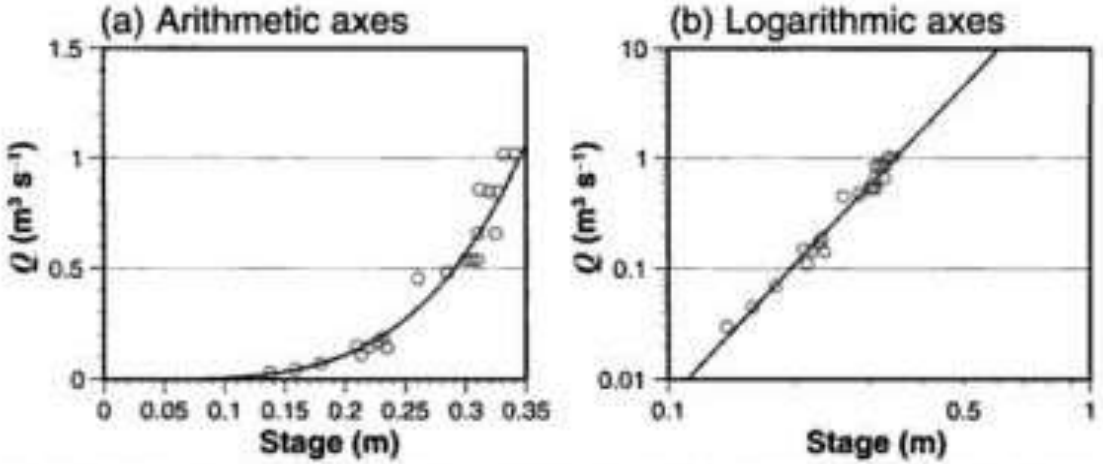
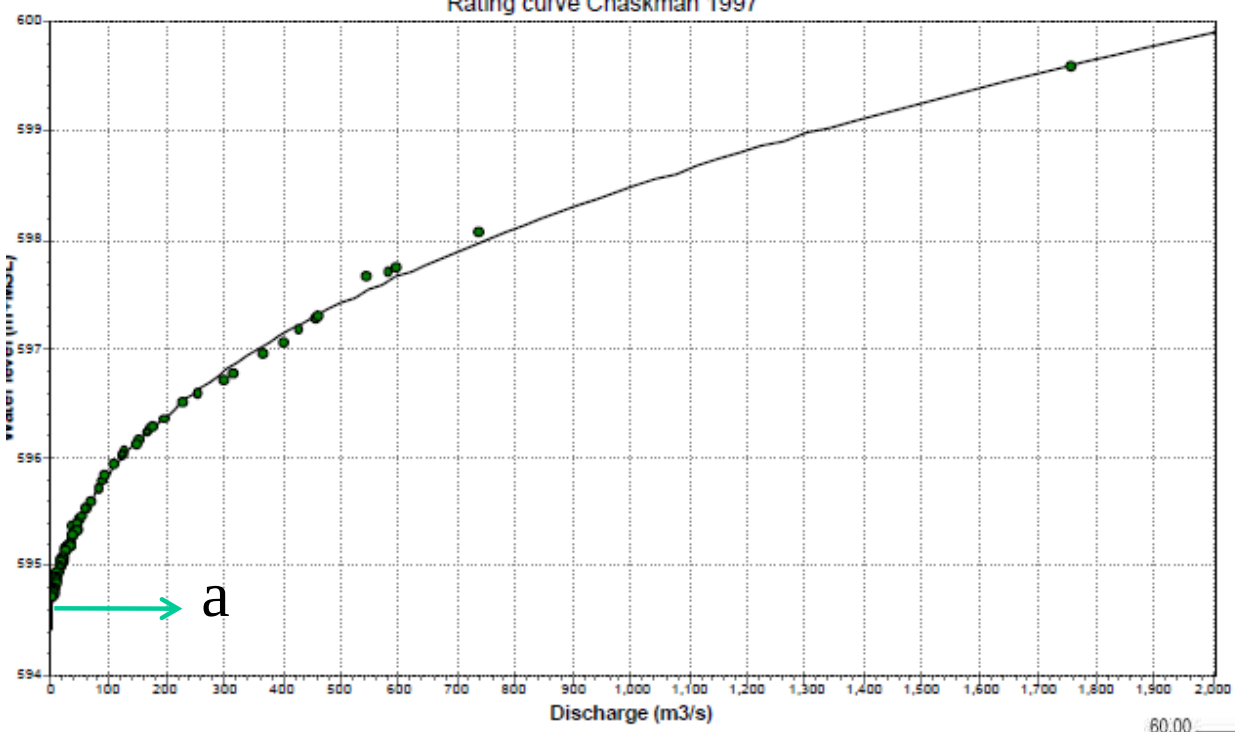


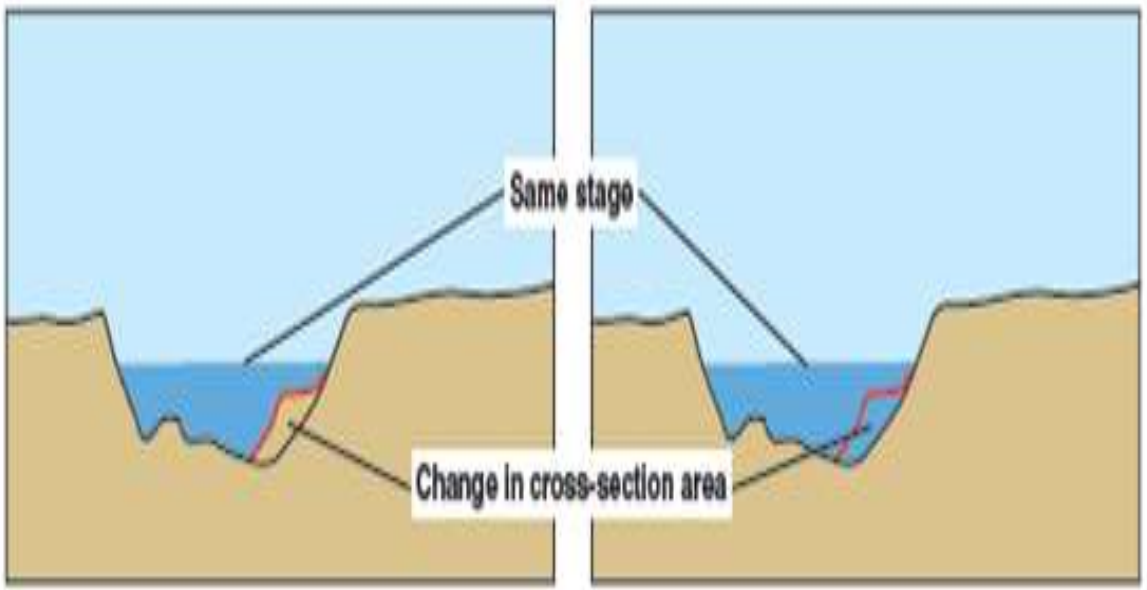
Figure 5.3 Rating curve (stage-discharge curve) for the Snake River above Montezuma, Colorado. The equation for the lines is $Q = 76.5(\text{stage})^{4.1}$. Data from Boyer (1994).

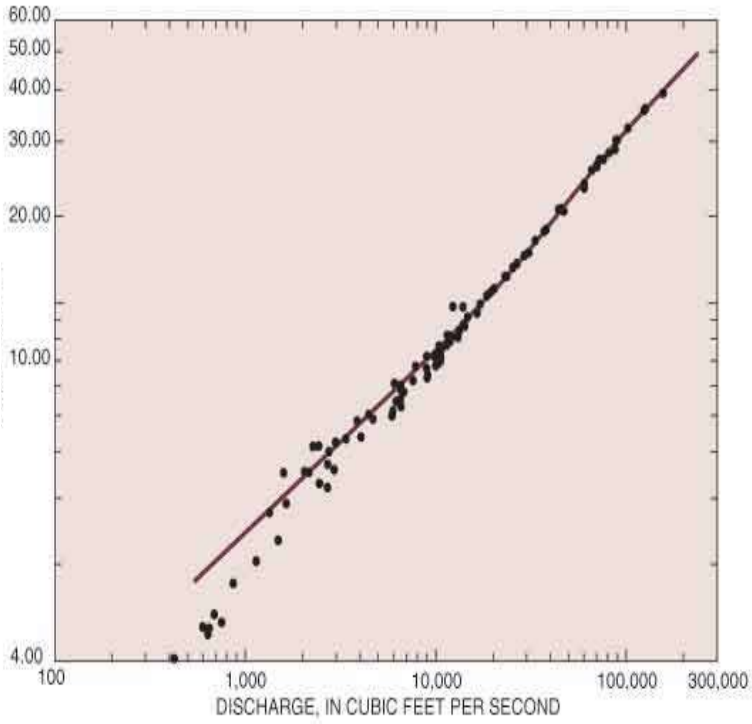
- Rating Curves can be extrapolated



Rating curve in normal paper

Rating curve in log-log paper





Streamflow

Stage-Discharge Relationship

In a natural channel of irregular shape, the stage discharge relationship can be developed via Manning's equation.

$Q = (AR^{2/3}S^{1/2})/n$

where Q is the flow rate, A is the cross sectional area of flow, n is the roughness coefficient, R is the wetted perimeter, and S is the streambed slope.

However, the following assumptions are necessary in developing the stage discharge relationship:

- n is constant and the energy/bed slope (S) is also constant
- the cross sectional area is approximately equal to the depth (d) multiplied by the width (W), the hydraulic radius, R, is equal to d, and W is constant

Replacing $(S^{1/2})/n$ and W with a constant C, and R by d, Manning's equation becomes,

- $Q = dWd^{2/3}\ S^{1/2}/n$ simplifies to: $Q = C(d - a)^{1.67}$

The exponent b, varies between 1.3 and 1.8 (1.5 if Chezy's equation is used).

The d is replaced by (d – a), where d is the gage height or stage and a is the stage of effective zero flow.

Streamflow

Stage-Discharge Relationship

The relationship between stage or river depth (d) and discharge (Q) is expressed as:

$$Q = c\,(d - a)^b$$

Where b and c are constants and a is also a constant but represents the stage (water level) corresponding to zero discharge. (what is a = ? in perennial river)

The relationship can be expressed graphically by plotting the stage and the discharge in normal paper or log-log paper.

Logarithmic plotting has the advantage that it would be a straight line.

Extension of Rating Curve

For knowing discharges beyond the measured values it is easier to extend the logarithmic curve.

Taking log both sides:

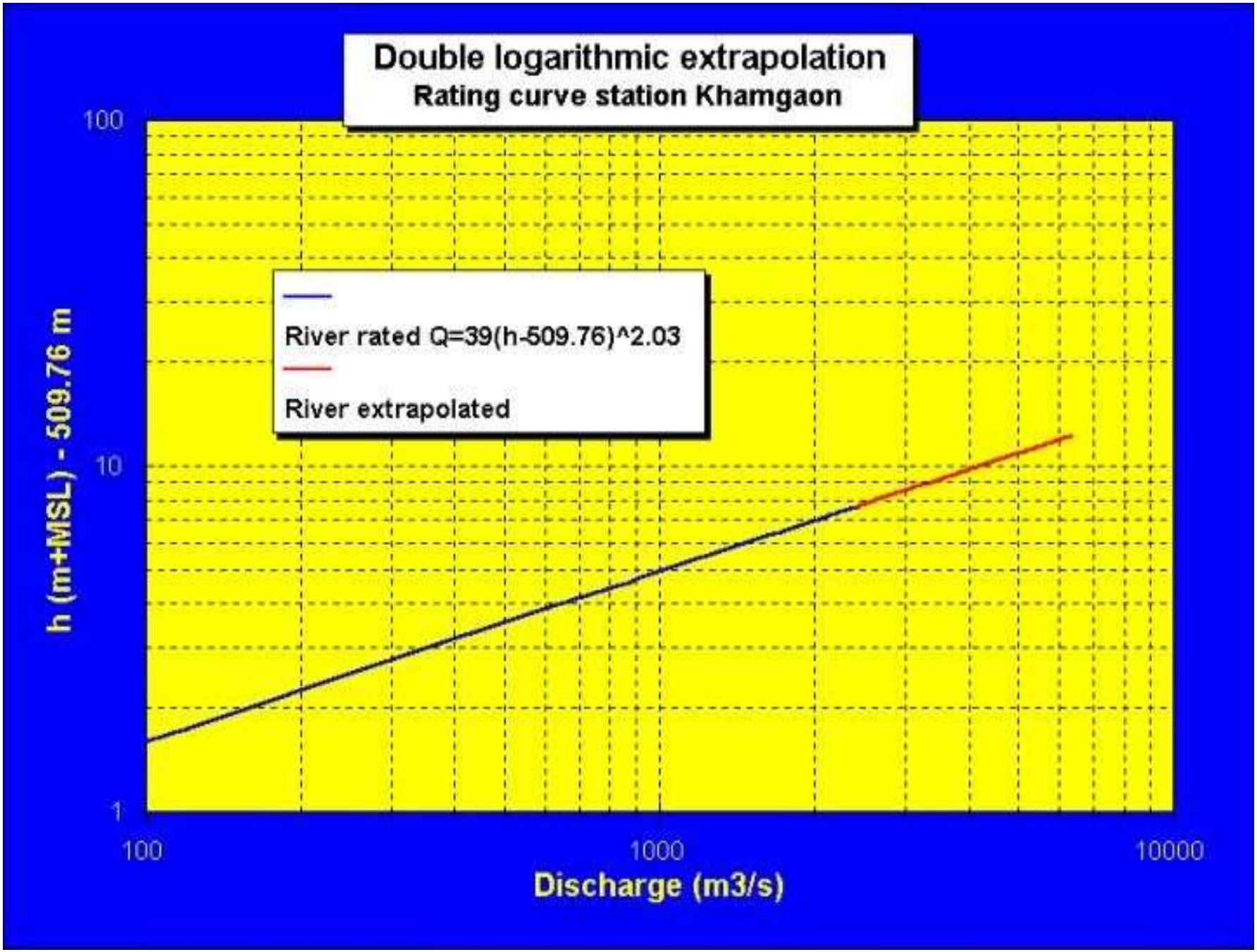
$$\log Q = \log c + b \log (d - a)$$

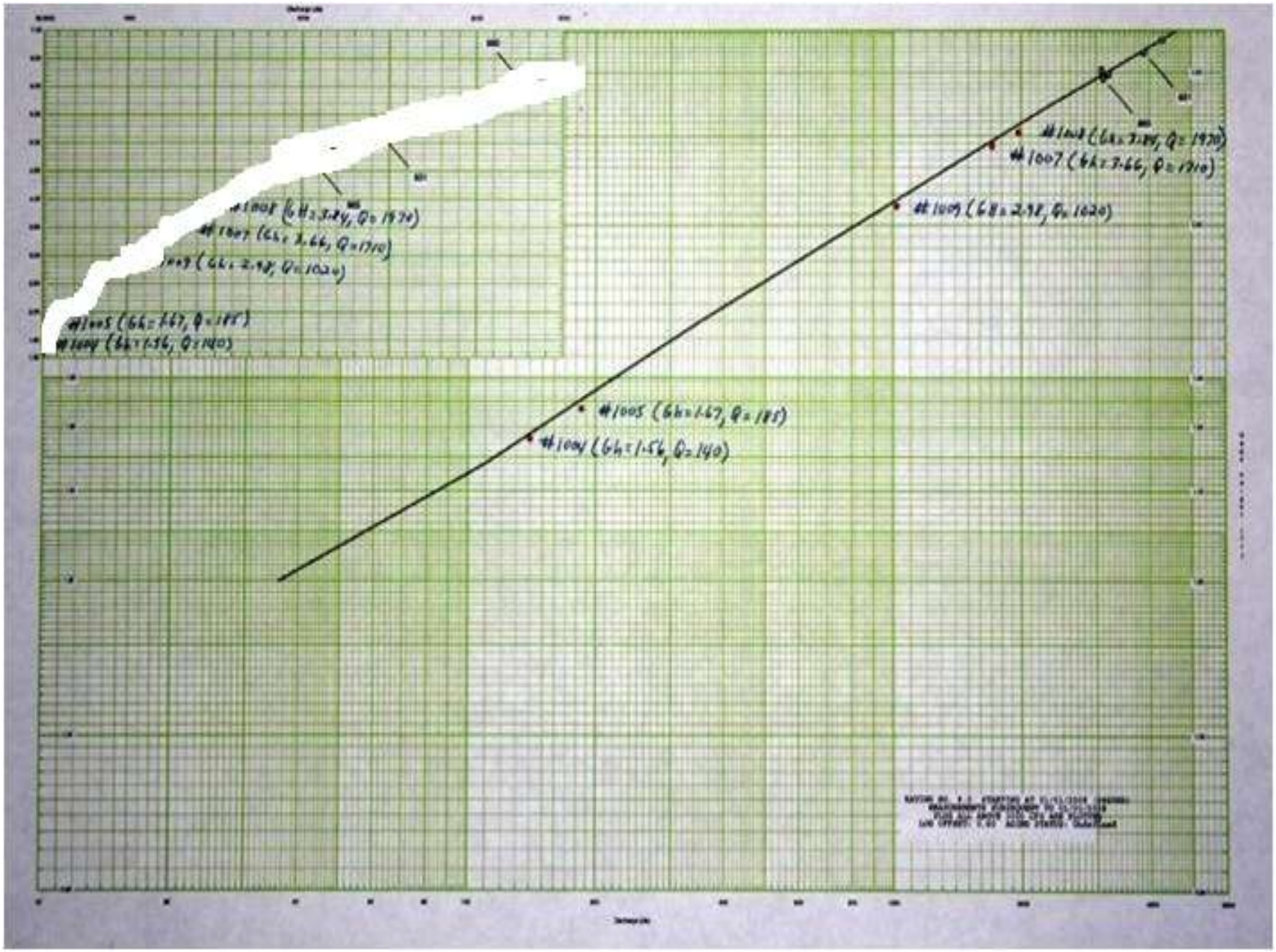
This is the same as: $y = mx + c$

A plot of Q and (d – a) in log-log paper would provide the value of b and c.

The value of a is generally determined from the rating curve in normal paper by putting Q = 0.

A plot of log Q and log (d – a) in normal paper would provide the value of b and c.


Double logarithmic extrapolation
Rating curve station Khamgaon
River rated Q=39(h-509.76)^2.03
River extrapolated
h (m+MSL) - 509.76 m
100
10
1
100
1000
10000
Discharge (m3/s)


#1008 (Δh=3.84, Q=1970)
#1007 (Δh=3.66, Q=1910)
#1009 (Δh=2.98, Q=1020)
#1005 (Δh=1.67, Q=185)
#1004 (Δh=1.56, Q=140)

Streamflow

Example

For the stage-discharge data given below compute the stage-discharge relation if the stage at Q = 0 is 0.2 m. What would be the discharge if the stage rises to 4.42m?

Q (Cumec)	h (m)	h –a (m)	Ln (h – a)
28.9	0.524	0.324	-1.12701
40.7	0.592	0.392	-0.93649
76.4	0.762	0.562	-0.57625
138.7	1.058	0.856	-0.15548
186.8	1.225	1.025	0.024693
217.9	1.298	1.098	0.09349
267.4	1.548	1.348	0.298622
282	1.605	1.405	0.340037
302.8	1.71	1.51	0.41211
370.7	1.823	1.623	0.484276
427.3	2.042	1.842	0.610852
455.6	2.081	1.881	0.631804
537.7	2.377	2.177	0.777948
582	2.667	2.467	0.903003
651.5	2.72	2.51	0.920283
707.5	2.807	2.607	0.9582
772.6	3.018	2.818	1.036027

$\ln Q = \ln a + c \ln(H+b)$

⇓

With $b = -0.2$, $\ln Q \sim \ln(H-0.2)$ is close to a straight line.

⇓

By Minitab (or Least square)

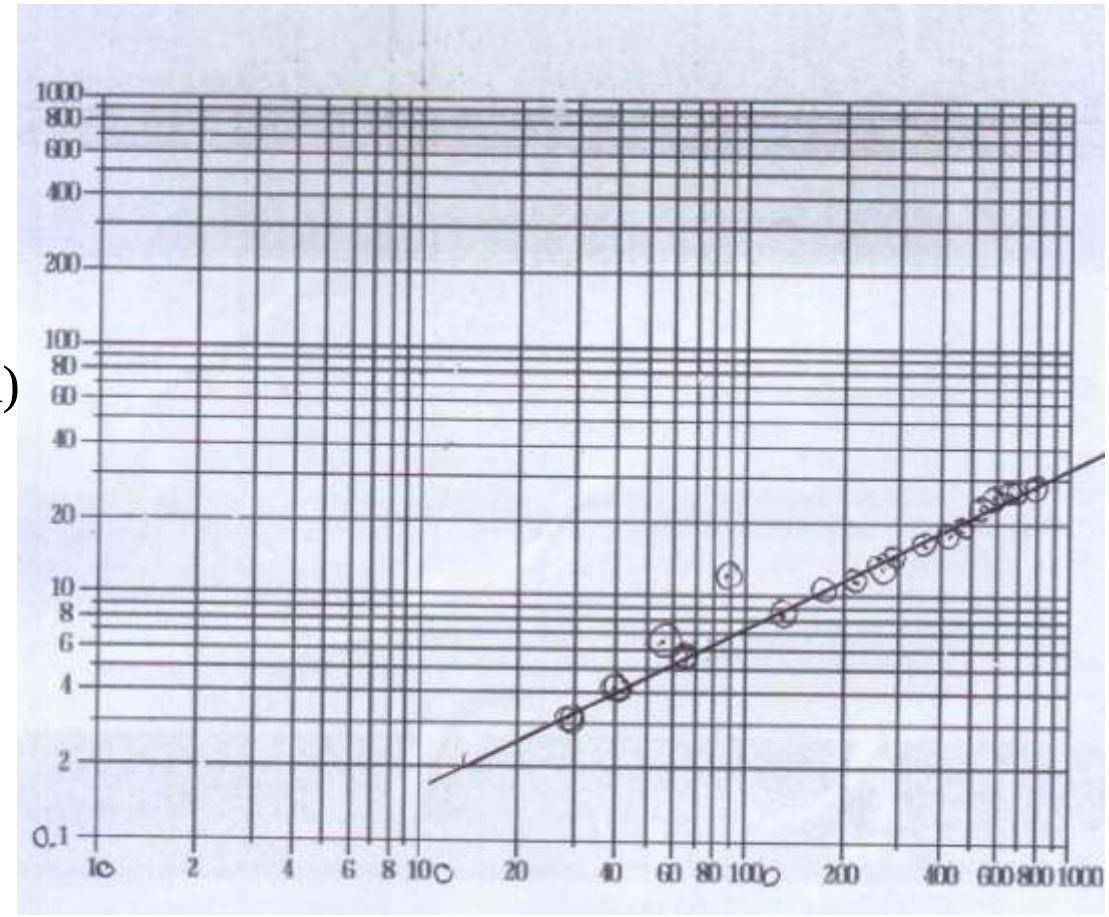
$\widehat{\ln a} = 5.14 \Rightarrow \hat{a} = 170.72$

$\hat{c} = 1.50$

⇓

At $H = 4.42^m$, $Q = 170.72(4.42-0.2)^{1.5}$

$= 1480 cm^3$



H (m)

Q (Cumec)