Streamflow Estimation: Hydraulic Structures

HYN – 102

Engineering Hydrology

Indirect method

Make use of the relation between the discharge and the flow discharge and the depths at specified locations.

1. Slope area methods
2. Flow measuring structures (weirs, flume…etc)

For flow measuring structures the discharge Q is a function of the water-surface elevation measured at specified location

$$Q=f(H)$$

Direct measurement

- can be used in small streams where it is possible to focus all flow into a collector

More "Permanent" installations can be made using:

- Dam (plate) with a v-notch (typically) that allows for controlled discharge through the notch.
- discharge can be related to the height of the back-water
- problems with sedimentation

Rectangular Weir

$Q = 3.33(L-0.2H)H^{3/2}$

90º V-notch

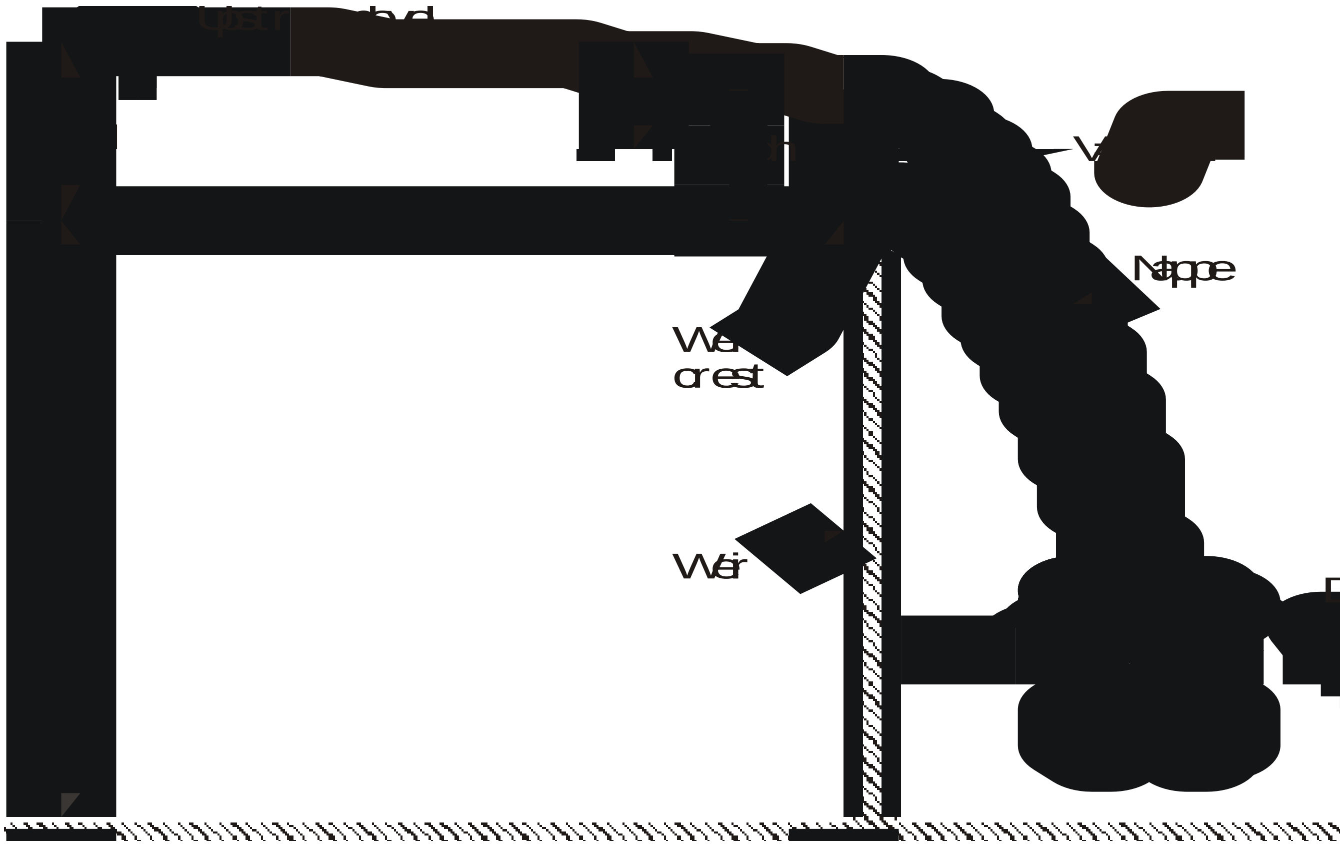
Where: Q is discharge (cfs)

L is length of weir crest (ft)

H is head of backwater above crest (ft)

See text for metric equations

Principle



$$V(h) = \sqrt{2gh}$$

Principle

$$Q = \int_A V(h)\,dA = \sqrt{2g}\int_0^H b(h)\sqrt{h}\,dh$$

$$= kh^n$$

$$\log(Q) = \log(kh^n) = \underset{\uparrow\ \text{Slope}}{n}\log(h) + \underbrace{\log(k)}_{\text{Intercept}}$$

flumes

- artificial stream reaches that conduct flow through through a constricted cross section that has a fixed stage-discharge relation (rating curve)
- height measured in flume relates directly to discharge
- sedimentation problems minimal
-

-often useful to calibrate with stream gaging over a range of flows (both weirs and flumes). Rating curve

Slope- Area method

- The Manning equation

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S_f^{\frac{1}{2}}$$

Where

Q = discharge (m3/s)

n = Manning's roughness coefficient (range between 0.01 and 0.75)

A = cross-section area (m2)

R = the hydraulic radius, equal to the area divided by the wetted perimeter (m)

S = the head loss per unit length of the channel, approximated by the channel slope

R=A/P
P = wetted parameter

Slope- Area method

- Applying energy equation to section 1 and 2
- **$Z_1+Y_1+V_1^2/(2g)= Z_2+Y_2+V_2^2/(2g)+h_l$**
- $h_1 = Z_1+Y_1$
- $h_2 = Z_2+Y_2$
- h_l (head losses) = $h_e + h_f$
- he = eddy loss
- h_f = frictional losses
- $h_1+ V_1^2/(2g)= h_2+ V_2^2/(2g)+ h_e + h_f$
- $h_e = k_e|V_1^2/(2g)-V_2^2/(2g)|$
- k_e = eddy loss coefficient
- $h_f = (h_1- h_2)+(V_1^2/(2g)- V_2^2/(2g)-h_e$

Slope- Area method

For uniform coefficient

- L= length of the section
- $h_f/L = S_f$ = energy slope = Q^2/k^2
- k = conveyance of the channel = $1/n\ A\ R^{2/3}$
- where n is manning roughness coefficient
- $K = (K_1K_2)^{0.5}$ for different cross sections A_1 and A_2

For non-uniform flow

- an average conveyance is used for $h_f/L = S_f$ = energy slope = Q^2/k^2
- where previous equation and continuity equation can be used to estimate discharge Q (known value of h, cross-section properties and n)
- $Q=A_1V_1=A_2V_2$

Procedure (trial and error)

- Assumed v_1=v_2
- Calculate Q by using $Q = k\ S^{0.5}$
- Compute $v_1 = Q_1 A_1$ & $v_2 = Q_2 A_2$
- Refine the value of h_f and then repeat step 2 until Q or h_f were very close

(see Example 4.4)

Stage-Discharge Relationship

(also known as ***Rating curve*** **)**

- Aim of all current meter and other **direct-discharge measurements** is to prepare a stage-discharge relationship.
- Measurement of discharge by the direct method involves a two step procedure.

1. Development of stage-discharge(G-Q) relationship.
2. Measuring stage(G) and reading the discharge(Q) from the (G-Q) relationship.

- The measured value of discharge when plotted against the corresponding stage gives relationship that represents the integrated effect of a wide range of channel and flow parameters. The combined effect of these parameters is termed ***control.***
- **Permanent Control:** If the (G-Q) relationship for a gauging section is constant and does not change with time.
- **Shifting Control:** If the (G-Q) relationship changes with time.

Shifting controls

Change of stage discharge with time due to:

1. the changing characteristics of channel
2. aggradations or degradation of alluvial channel
3. variable backwater effect (the gauging section)
4. unsteady flow effects (rapidly change stage)

For 1 & 2 it is recommended to update rating curves frequently

For 3 & 4 shifting control is recommended

- **Permanent Control**
- Majority of streams and rivers, especially nonalluvial rivers exhibit permanent control.
- The relationship between the stage and the discharge is a single valued relation which is expressed as:

$$Q = C_r (G - a)^{\beta}$$

Q = stream discharge, G = stage, a = a constant which represent the stage corresponding to zero discharge, C_r and β are rating curve constants.

- The (G-Q) relationship can be expressed graphically by plotting the observed relative stage(G-a) against the corresponding discharge values in an arithmetic or logarithmic plot.
- Logarithmic plotting is advantageous. Straight line can be drawn to best represent the data plotted as Q *vs* (G-a).
- The best values of C_r and β for a given range of stage are obtained by the least-square method.

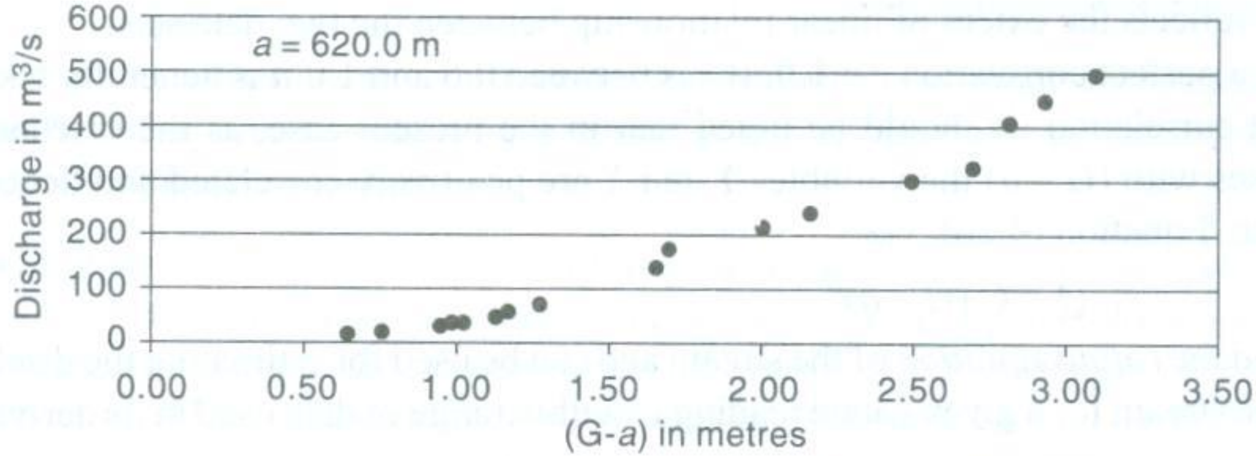


Fig. 4.22(a) Stage-Discharge Curve: Arithmetic Plot

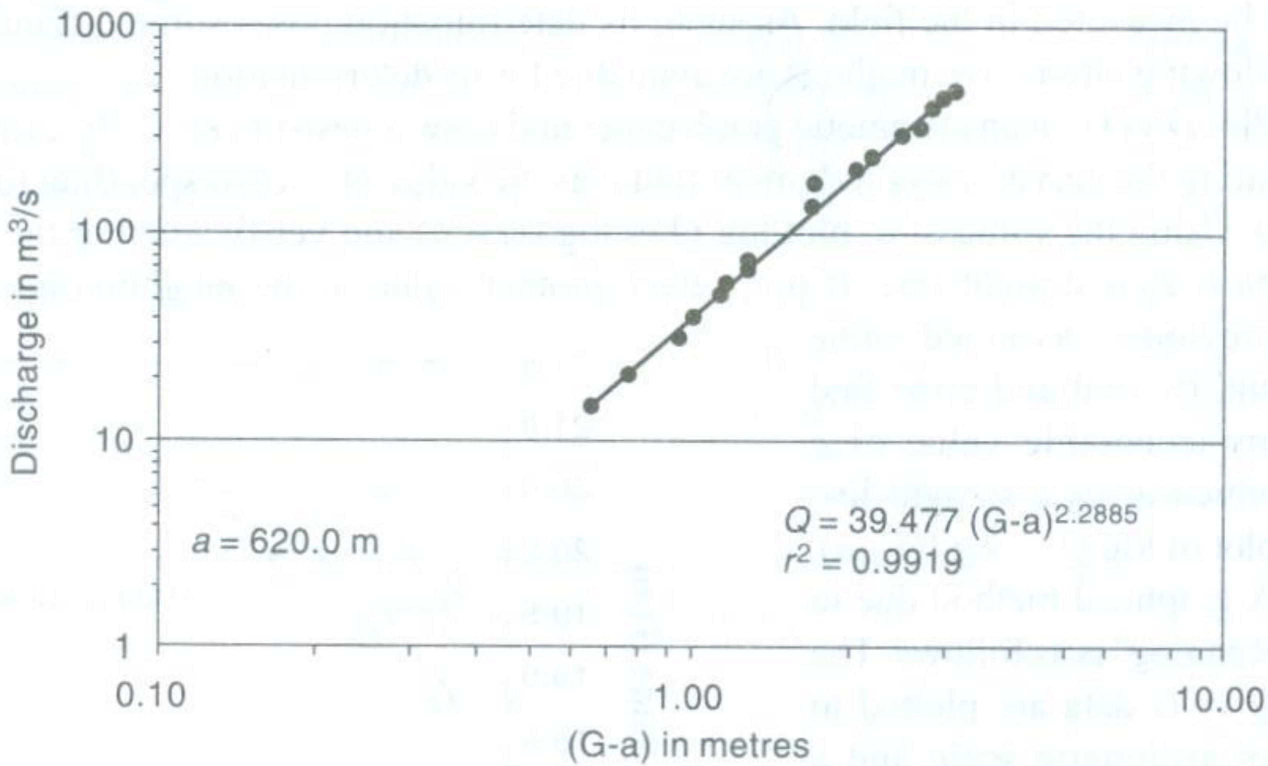


Fig. 4.22(b) Stage-Discharge Curve: Logarithmic Plot

$$Q = C_r (G - a)^{\beta}$$

- By taking logarithms,

$$\log Q = \beta \log (G - a) + \log C_r$$
$$Y = \beta X + b$$

$$\beta = \frac{N(\Sigma XY) - (\Sigma X)(\Sigma Y)}{N(\Sigma X^2) - (\Sigma X)^2}$$

and $$b = \frac{\Sigma Y - \beta(\Sigma X)}{N}$$

Pearson product moment correlation coefficient

$$r = \frac{N(\Sigma XY) - (\Sigma X)(\Sigma Y)}{\sqrt{[N(\Sigma X^2) - (\Sigma X)^2][N(\Sigma Y^2) - (\Sigma Y)^2]}}$$

Stage for zero discharge (*a*)

- It is hypothetical parameter and can't be measured

Method 1

- Plot Q vs. G on arithmetic scale
- Draw the best fit curve
- Select the value of (a) where Q = 0
- Use (**a**) value and verify weather the data at log(Q) vs. log(G-a) indicate a straight line
- Trial and error find acceptable value of (a)

Method 2 (Running's Method)

- Plot Q&G on arithmetic scale and select the best fit curve
- Select three points (A,B and C)
- Draw vertical lines from (A,B and C) and horizontal lines from (B and C)
- Two straight lines ED and BA intersect at F

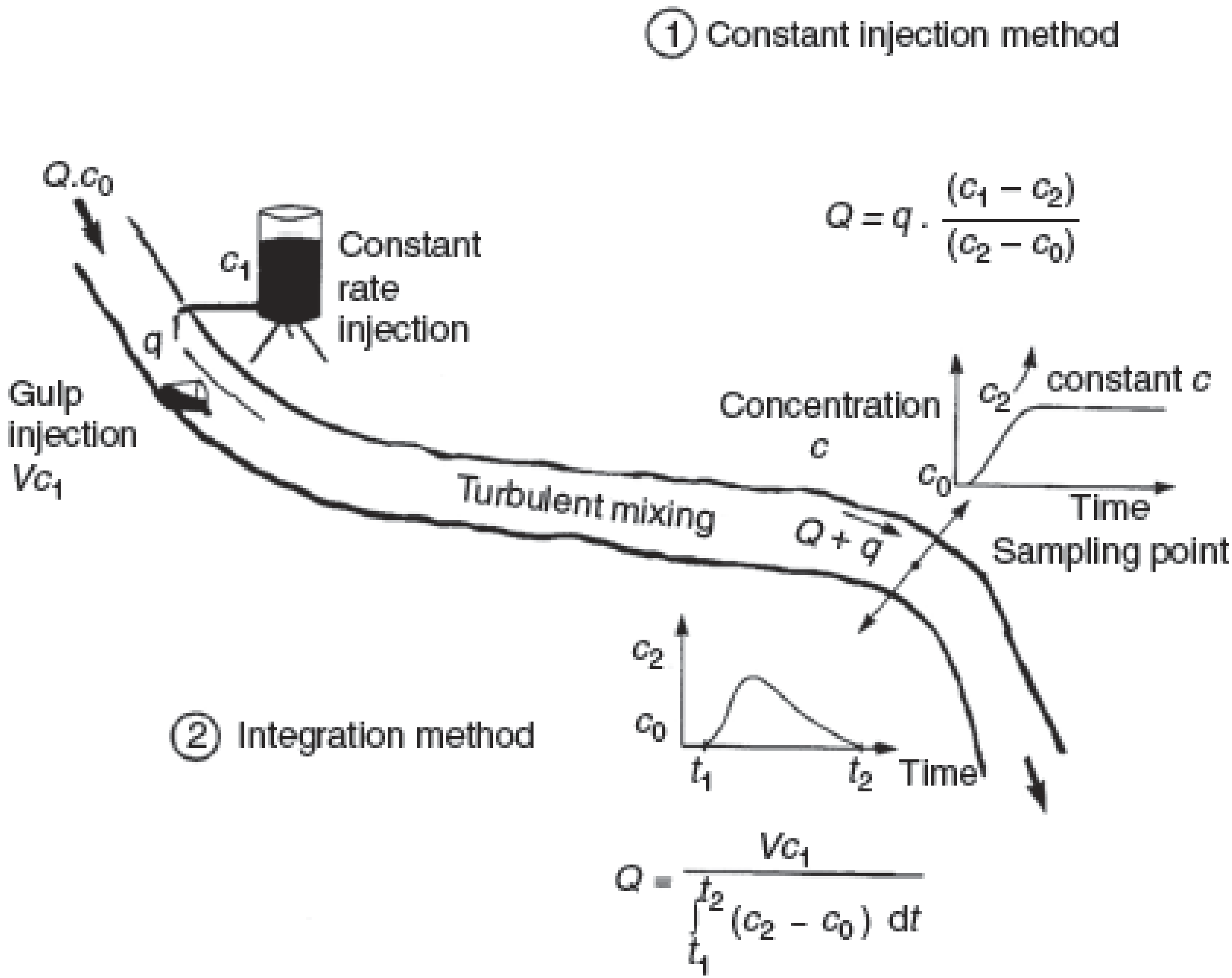
See figure 4.23

- **<u>Method 3</u>** (eq. 4.30)

$$\alpha = \frac{G_1 G_3 - G_2^2}{(G_1 + G_3) - 2G_2}$$

Salt Dilution Method

- A 25 g/l solution of a fluorescent tracer was discharged into a stream at a constant rate of 10 cm^3/s. The background concentration of the dye in the stream water was found to be zero. At a downstream section sufficiently far away, the dye was found to reach an equilibrium concentration of 5 parts per billion. Estimate the stream discharge.



1 Constant injection method
$Q.c_0$
c_1
Constant rate injection
$Q = q \cdot \frac{(c_1 - c_2)}{(c_2 - c_0)}$
q
Gulp injection Vc_1
Concentration c
c_2
constant c
c_0
Time
Turbulent mixing
$Q + q$
Sampling point
c_2
c_0
t_1
t_2
Time
2 Integration method
$Q = \frac{Vc_1}{\int_{t_1}^{t_2} (c_2 - c_0)\, dt}$