4.1 Introduction

- Surface water hydrology deals with the movement of water along earth’s surface as a result of precipitation and snow melt.
- Knowledge of quantity and quality of stream flow is a request of municipal, industrial, agricultural and other water supply projects.
- The water flowing in stream is measured as discharge of water with a unit of volume (m$^3$/sec, cubic of feet per second – cfs).
Stream Measurements

1) Direct measurement of stream
   - Area-velocity methods
   - Dilution techniques
   - Electromagnetic methods
   - Ultrasonic method

2) Indirect measurement of stream
   - Hydraulic structure such as weir, flumes and gated structure
   - Slope area method
4.2 Measurement of Stage

- Direct measurement of discharge is a very time-consuming and costly procedure.

Two steps are followed:

1- The stage of the stream (elevation of water surface above a datum) is measured by many methods such as staff Gauge, wire gauge, automatic stage recorder.... etc. The results is stage hydrograph (Figure 4.7).

2- The discharge is related with the stage in well known stage-discharge relationship (rating curve)
Staff gauges (enamel painted)

Rating curve

Stream bank

Flow Q (cusec)

River bed

High water level

Staff reading (Gauge height, h)

2.5 m

5.0 m

7.5 m

Gauge height (h m)

Stage-discharge rating curve

Discharge 20 cusec

Staff gauge reading 0.7 m

Log-log paper

Stream discharge, Q (cusec)

1 2 3 4 5 6 7 8 9 10

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
4.4 Area-velocity method (direct method)

- Figure 4.14 and Example 4.1
- Velocity is measured at 0.6 of the depth
- For the first and last sections
  \[ \overline{W} = \left( \frac{W_1 + \frac{W_2}{2}}{2} \right)^2 \]
- For the rest of segment
  \[ \overline{W} = \left( \frac{W_2}{2} + \frac{W_3}{2} \right) \]
4.8 indirect method

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

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

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

$$Q=f(H)$$
4.8 indirect method
Slope-Area method

- The Manning equation

\[ Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}} \]

Where

\( Q \) = discharge (m\(^3\)/s)
\( n \) = Manning’s roughness coefficient (range between 0.01 and 0.75)
\( A \) = cross-section area (m\(^2\))
\( R \) = 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

\[ R = \frac{A}{P} \]

\( P \) = witted parameter
See Figure 4.21

Applying energy equation to section 1 and 2

\[ Z_1 + Y_1 + \frac{V_1^2}{2g} = Z_2 + Y_2 + \frac{V_2^2}{2g} + h_1 \]

\[ h_1 = Z_1 + Y_1 \]
\[ h_2 = Z_2 + Y_2 \]
\[ h_l \text{ (head losses)} = h_e + h_f \]
\[ h_e = \text{eddy loss} \]
\[ h_f = \text{frictional losses} \]
\[ h_1 + \frac{V_1^2}{2g} = h_2 + \frac{V_2^2}{2g} + h_e + h_f \]
\[ h_e = k_e \left| \frac{V_1^2}{2g} - \frac{V_2^2}{2g} \right| \]
\[ k_e = \text{eddy loss coefficient} \]
\[ h_f = (h_1 - h_2) + \left( \frac{V_1^2}{2g} - \frac{V_2^2}{2g} \right) - h_e \]
4.8 indirect method
Slope-Area method

For uniform coefficient

**L =** length of the section

**h/L = S =** 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/L = S = 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 (tries and errors)

1. Assumed $v_1 = v_2$
2. Calculate $Q$ by using $Q = k S^{0.5}$
3. Compute $v_1 = Q_1 A_1$ $v_2 = Q_2 A_2$
4. Refine the value of $h_2$ and then repeat step 2 until $Q$ or $h_f$ were very close

(see Example 4.3)
4.9 stage discharge relationship

- Measuring the discharge in direct method requires two steps:
  1. Measuring the stage (G) and discharge.
  2. Prepare a stage discharge (rating curve)

- For a gauging section of the channel, the measured values of discharge are plotted against the corresponding stages.

- The flow can be control by G-Q curve when:
  1. G-Q is constant with time (permanent)
  2. G-Q is vary with time (shifting control)
Permanent control

- Most of streams and rivers follow the permanent type and the G-Q curve can be represented by:
  \[ Q = C_r (G - a)^B \]

- \( Q \) = stream discharge
- \( G \) = gauge height
- \( a \) = a constant of stage at zero discharge
- \( C_r \) & \( B \) = rating constants
- See Figure 4.22 a and b
Permanent control

- Straight lines is drown in logarithmic plot for \((G-Q)\)
- Then \(C_r\) & \(B\) can be determined by the least square error method

\[
\log(Q) = B \log(G - \alpha) + \log(C_r) \Rightarrow y = Bx + b
\]

- For the best fit of N. observation, by regression analysis (use excel or other programs) or eq. 4.28 (a&b)
- \(r\) correlation coefficient is 1 for perfect fit
- \(0.6 - 1\) can be considered as good correlation
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 whether the data at $\log(Q)$ vs. $\log(G-a)$ indicate a straight line
- Trial and error find acceptable value of $(a)$
Stage for zero discharge (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) as
  \[
  \frac{Q_A}{Q_B} = \frac{Q_B}{Q_C}
  \]
- 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
Stage for zero discharge (a)

- Method 3 (eq. 4.30)

\[ a = \frac{G_1 G_3 - G_2^2}{(G_1 + G_3) - 2G_2} \]

- See example 4.4
**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
Backwater effect

The same stage will indicate different discharges

The backwater effect can be removed by

1. Secondary (auxiliary) gauge is installed in the downstream of the gauging section and the two readings is taken

\[ F_1 - F_2 = F \text{ (fall)} \quad Q = f(G,F) \]

\[ Q/Q_0 = (F/F_0)^m \]

\[ F_0 \text{ is normalized value (average)} \]

\[ Q_0 \text{ is normalized value (average)} \]

\[ F_0 \text{ and } Q_0 \text{ selected from observation} \]

See figure 4.24
Backwater effect

2. Draw constant fall curve
   - $Q_0$ vs. $G$ for constant $F_0$

3. Calculate $Q/Q_0$ and $F/F_0$ and plot (adjustment curve)

4. Both constant and adjustment curve can be refined by trial error (the best curve fit)

How to use them
   - For $G_1$ and $F_1$ use adjust curve to get $Q/Q_0$
   - For $G_1$ use constant fall curve to get $Q_0$ then actual discharge is $(Q_1/Q_0)kQ_0$

See figure 4.25
Unsteady flow effect

Due to flood waves in gauging section, the stage-discharge relationship for unsteady flow will not be a single valued relationship but it will be a looped curve as in figure 4.26.

\[
\frac{Q_m}{Q_n} = \sqrt{1 + \frac{1}{V_w S_0} \frac{dh}{dt}}
\]
Unsteady flow effect

- $Q_n$ = normal discharge at steady uniform flow
- $Q_m$ = actual measured for unsteady flow
- $S_0$ = channel slope
- $\frac{dh}{dt}$ = rate of change of stage (field data)
- $V_w = \text{velocity of flow wave} (= 1.4V)$ where $V$ is the average velocity estimated by manning formula
- $\frac{Q_m}{Q_n}$ is calculated based on the value of $\frac{dh}{dt}$