CH-5

STREAM FLOW

Introduction

Stream Flow is a flow rate or discharge of water along natural channel.

Stream Flow is the component of the hydrological cycle which transfers water, originally falling as rain or snow onto a watershed, from land surface to the oceans/Water body/

Stream Flow is generated by a combination of

- ***Base flow :- return flow from ground water***
- ***Inter flow :- rapid subsurface flow through pipes, pores, and*** seepage zones in the soil
- ***Saturated overland flow :- the part of the water that flows*** on the earth surface and create a channel or stream

- Stream: is the natural flow channel in which water from a basin is collected and drained to large water bodies
- Basin: is the area bounded by the highest contour called ridge line from where precipitated water is collected by surface and subsurface flows and drained out through the natural river.

(Catchment, Watershed, drainage area, drainage basin)

- Overland flow : is the part of rain water which flows over the land surface in the form of a sheet of water to join the nearest stream.
- Stream flow: the total runoff that consisting of surface runoff, subsurface runoff, base flow and the precipitation falling on the stream.

Surface Runoff : part of the precipitation and other drainage water of a basin which moves over earth surface and then through a network of channels (rivers). Thus draining out water from the basin is called surface runoff.

Subsurface Runoff: also know as interflow or subsurface flow is that part of precipitation which infiltrates into the ground and moves laterally or horizontally in the soil and meets the nearest stream

Direct Runoff: is the part of stream flow occurring promptly as precipitation starts and contributes for an acceptable period after the storm ceases

Base flow: the part of the stream flow available mainly from ground water reservoir and delayed subsurface flow appearing during dry period.

Hydrological year: is the period of one year starting with time when the ground and surface water storage of the basin is usually minimum

STREAM FLOW MEASURMENT

- Continuous stream flow records are necessary in

design of water supply systems,

in designing hydraulic structures,

in the operation of water management systems,

and in estimating sediment or chemical loads of streams

FACTORS AFFECTING RUNOFF

- **Climatic Factors :**
  - Intensity, duration, and areal distribution of precipitation
  - Evapotranspiration
- **Basin Characteristics**
  - The size (Area (A), Length (L), width)
  - Shape (Form factor, shape factor)
    - **Bs = Shape Factor**
    - **Ff = Form factor**
    - **Cc = Compactness Coefficient**

$$B_s = \frac{L^2}{A} > 1$$

$$F_f = \frac{A}{L^2} = \frac{W_b}{L_b} < 1$$

$$C_c = \frac{P}{\sqrt{4\Pi A}} = 0.281\frac{P}{A^{0.5}} \geq 1$$

  - Slope

$$S = \frac{h}{L}$$

h= Elevation difference between two points

L= Horizontal difference between two pints

  - drainage density or stream density of the basin
    - **Drainage Density (m/km^2)**
    - **D_s = Stream Density (No/km^2)**
    - **A = Basin area (km^2)**
    - **Ls = Total stream length**
    - **N_s = Stream number**

$$D_d = \frac{L_s}{A}$$

$$D_s = \frac{N_s}{A}$$

- **Basin Geology**

Responsible for the infiltration rate of the basins . If good aquifer material forms in the basin infiltration increased and then surface runoff decreases.If the basin composed of impervious materials runoff will be highly peaked

- **Land cover and management**

Vegetation Cover →Grass Cover → Cultivation Plough and digging also facilitate infiltration and decrease runoff Ponding, tracing and other conservation structure reduce runoff

MEASURMENT OF RUNOFF

- Direct, continuous measurement is very difficult, or it is time-consuming, and costly procedure
- Thus measurements of river stage provides the best alternative.

steps

1. do detail discharge measurement and develop discharge –elevation relationship
2. the stage of stream observed routinely and inexpensive manner then the discharge is estimated using the developed relationship (rating curve)

Table 5-1.Recommended minimum density of hydrometric stations

Type of region	Range of norms for minimum network, area, km^2 per station	Range of provisional norms tolerated in difficult conditions area, km^2 per station
Flat regions of tropical, temperate and Mediterranean zones	1000 - 25000	3000 - 10000
Mountainous regions of tropical, temperate and Mediterranean zones	300 -100	1000 - 5000
Small mountainous islands with very irregular rainfall, very dense stream network	140 - 300	
Arid zone	5000 - 20000	

Site selection (WMO 1981):

- The general course of the stream is straight for about 100 meters upstream and downstream from the gauging site.
- The total flow is confined into the channel at all stages and no flow bypasses the site as sub-surface flow.
- The streambed is not subject to scour and fill and is free of aquatic growth. And the Banks are permanent, high enough to contain floods.
- Unchanging natural controls and far enough upstream from the confluence with another stream.

Measurement of stage

- Manual gauges, discrete stage measurements
- Recorders, continuous stage measurements

Measurement of stage

- **Staff gage**

Measurement of stage

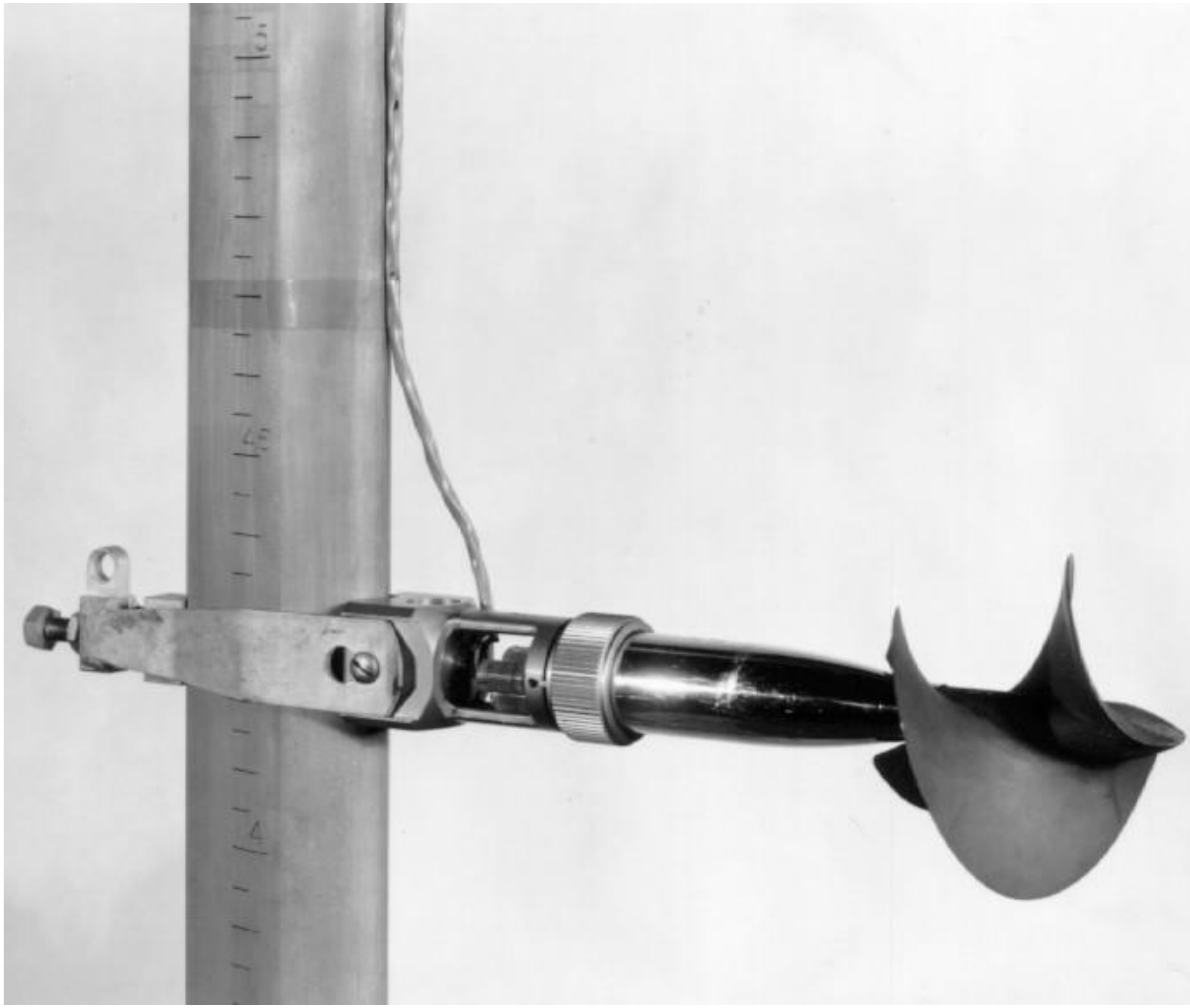
- **Wire gauge :** wire gauge consists of a reel holding a length of light cable with a weight affixed to the end of the cable.
- **Recording gauge:** recording gage measures stages continuously and records them on a strip chart. The mechanism of a recording gauge is either float actuated or pressure actuated.

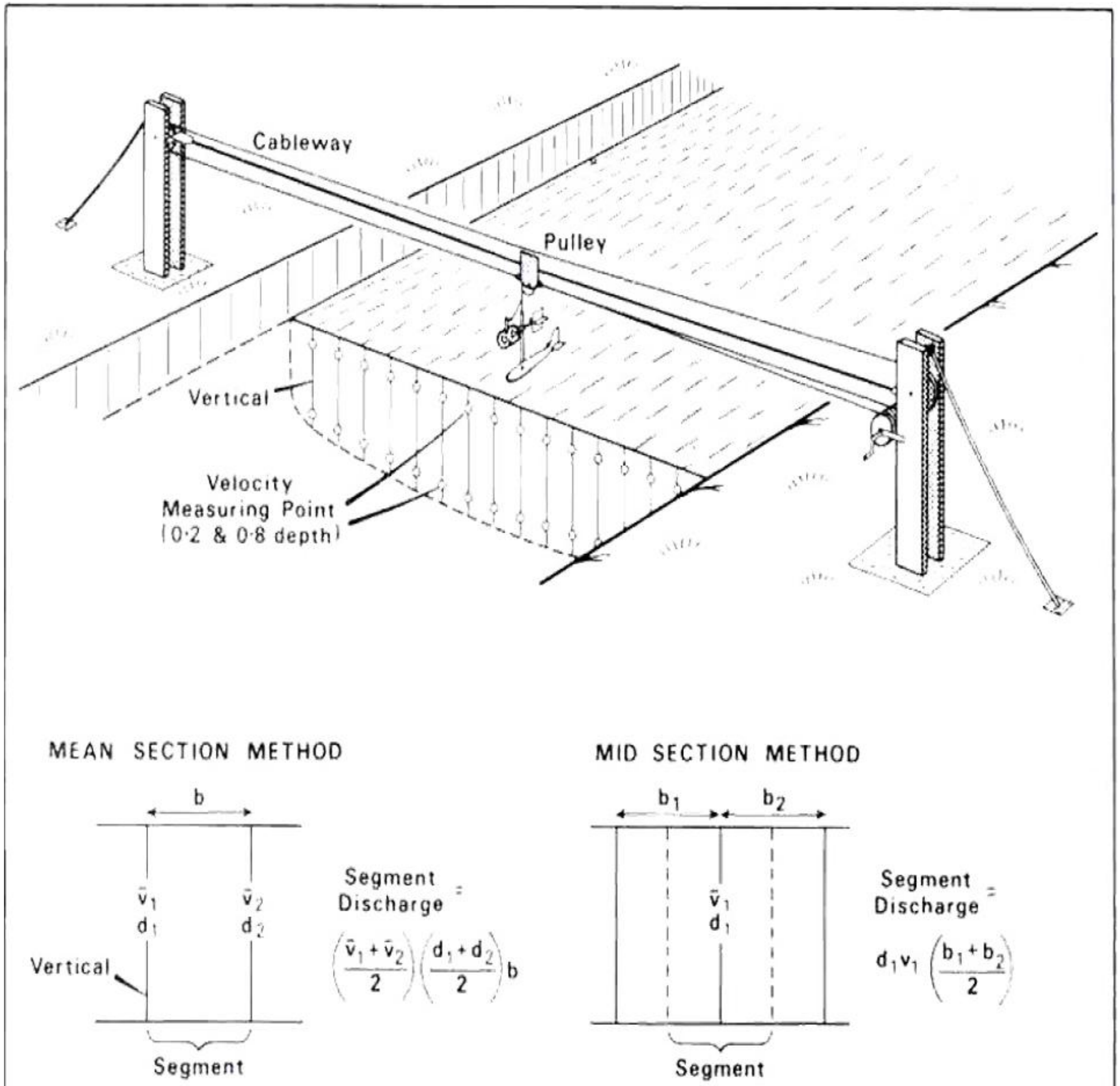
FLOW VELOCITY MEASUREMENT

- current meter is commonly used instrument for accurate determination of stream-velocity on field.
- Measurements are made at distinct stages(usually at 0.6D)

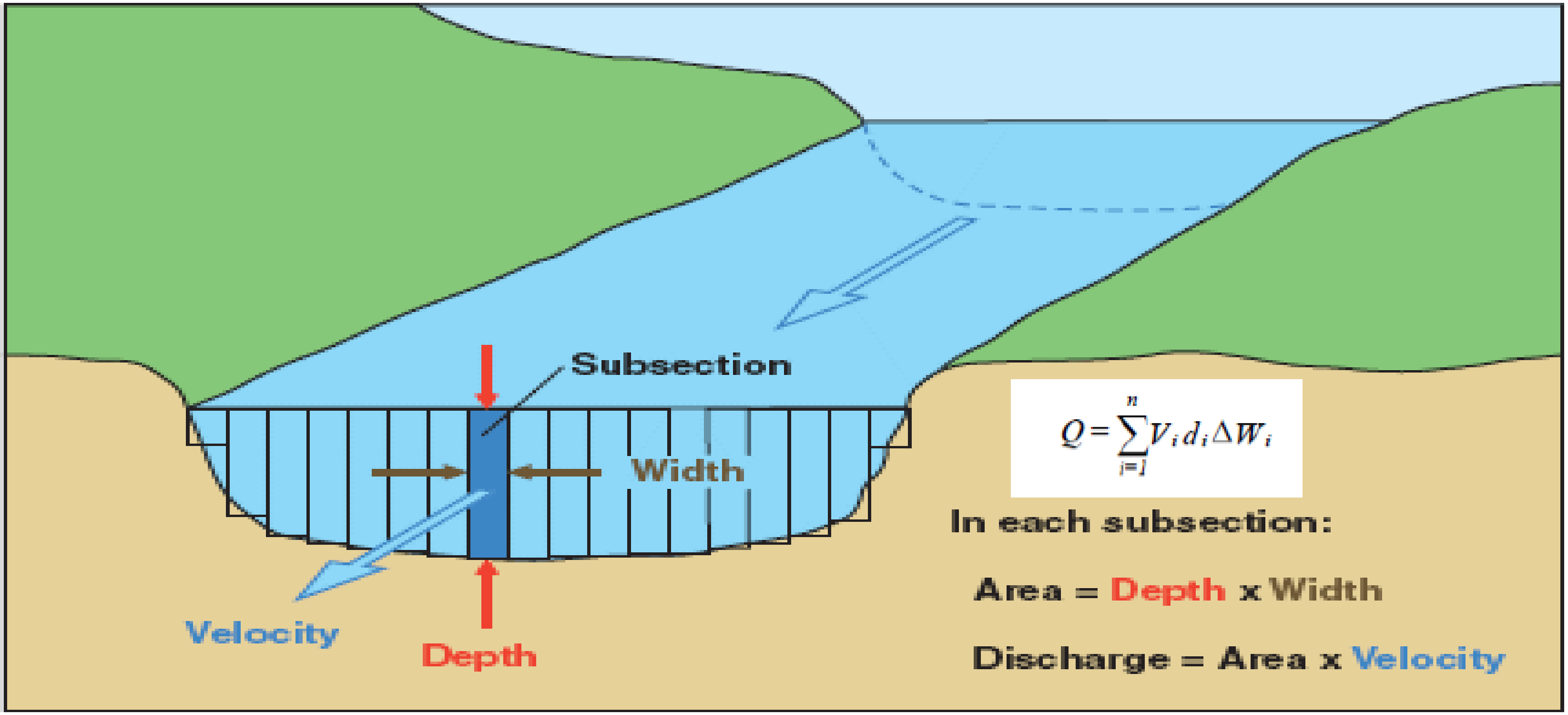
Vertical-axis current meters

Horizontal –axis current meters



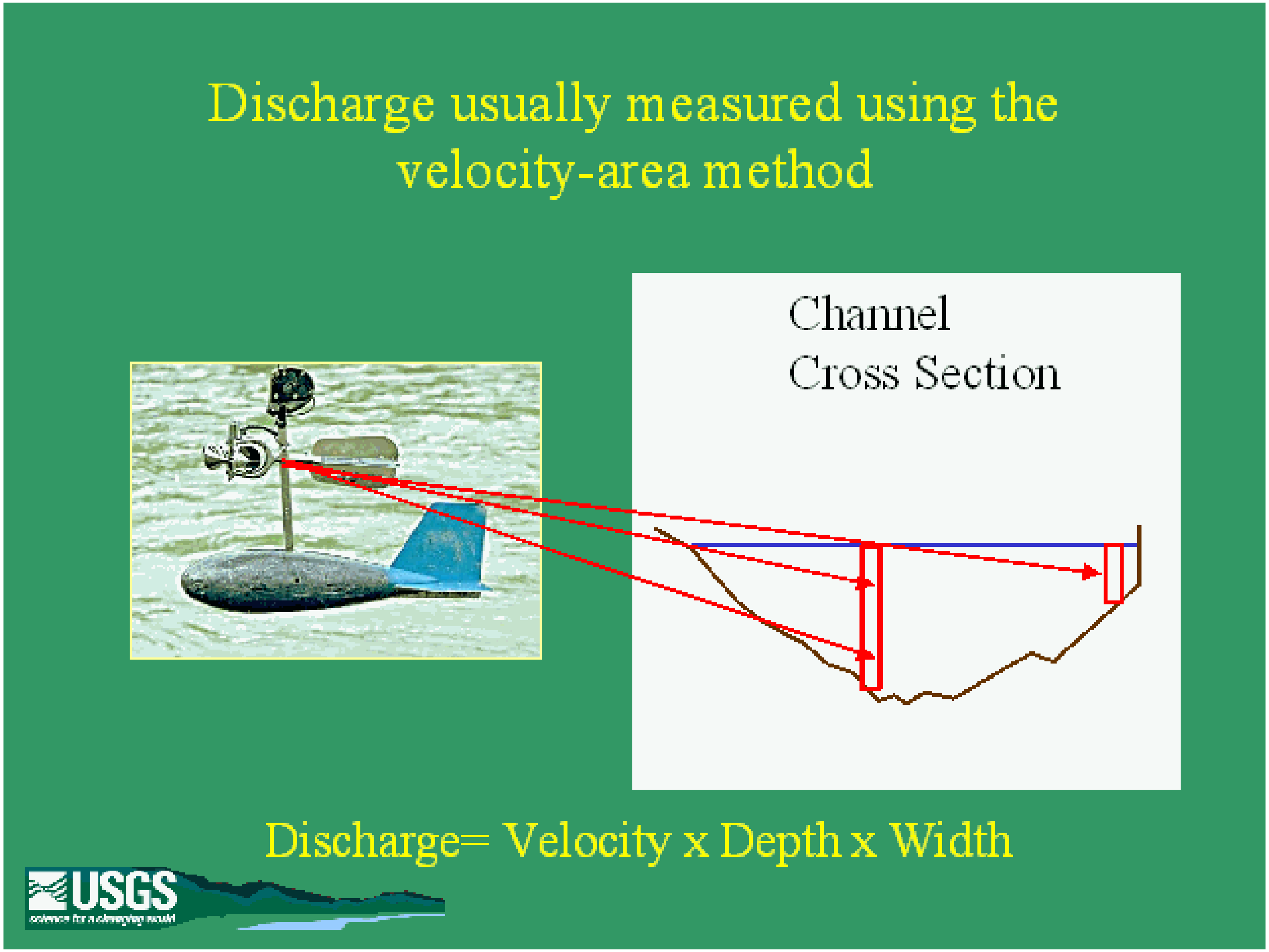

Cableway
Pulley
Vertical
Velocity
Measuring Point
(0·2 & 0·8 depth)
MEAN SECTION METHOD
b
v̄1
d1
v̄2
d2
Vertical
Segment
Segment Discharge =
$\left(\frac{\bar{v}_1 + \bar{v}_2}{2}\right)\left(\frac{d_1 + d_2}{2}\right) b$
MID SECTION METHOD
b1
b2
v̄1
d1
Segment
Segment Discharge =
$d_1 v_1 \left(\frac{b_1 + b_2}{2}\right)$

Velocity area method

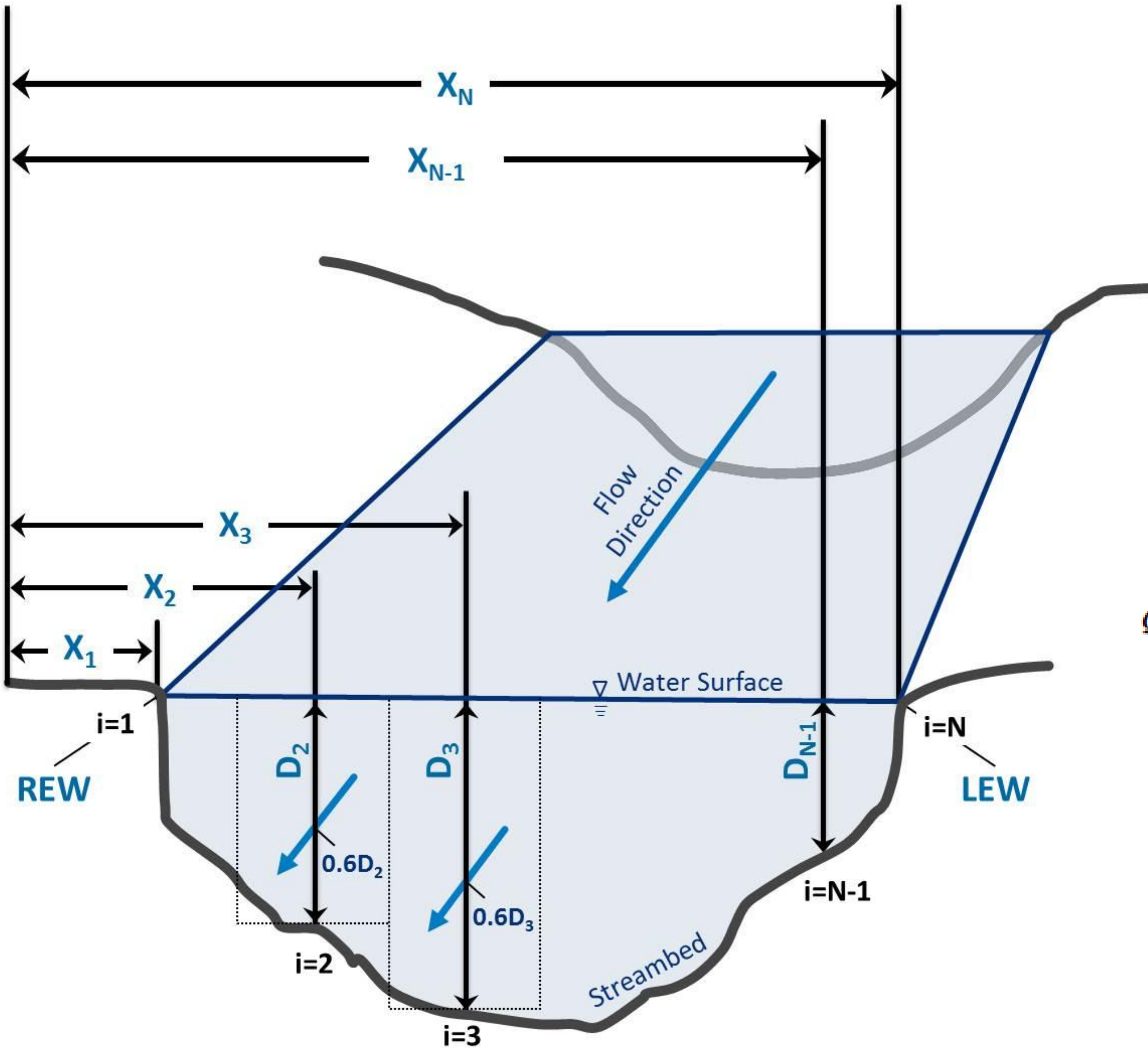


Current-meter discharge measurements are made by determining the discharge in each subsection of a channel cross section and summing the subsection discharges to obtain a total discharge.

Velocity area method



VELOCITY AREA METHOD



$$Q=\sum_{i=1}^{n} V_i d_i \Delta W_i$$

EXAMPLE 4.1 *The data pertaining to a stream-gauging operation at a gauging site are given below.*

The rating equation of the current meter is $v = 0.51\, N_s + 0.03$ m/s

Calculate the discharge in the stream.

Distance from left water edge (m)	0	1.0	3.0	5.0	7.0	9.0	11.0	12.0
Depth (m)	0	1.1	2.0	2.5	2.0	1.7	1.0	0
Revolutions of a current meter kept at 0.6 depth	0	39	58	112	90	45	30	0
Duration of observation (s)	0	100	100	150	100	100	100	0

SOLUTION ; The calculations are performed in a tabular form.
For the first and last sections,

$$\text{Average width,} \quad \overline{W} = \frac{\left(1+\frac{2}{2}\right)^2}{2 \times 1} = 2.0 \text{ m}$$

For the rest of the segments,

$$\overline{W} = \left(\frac{2}{2}+\frac{2}{2}\right) = 2.0 \text{ m}$$

Since the velocity is measured at 0.6 depth, the measured velocity is the average velocity at that vertical ($\overline{v}$).

The calculation of discharge by the mid-section method is shown in tabular form below:

Distance from left water edge (m)	Average width W (m)	Depth y (m)	Velocity $\overline{v}$ (m/s)	Segmental discharge ΔQ_i (m^3/s)
0	0	0	—	—
1	2.00	1.1	0.229	~~0.504~~ 0.38
3	2.00	2.0	0.326	1.304
5	2.00	2.5	0.411	2.055
7	2.00	2.0	0.336	~~1.344~~ 1.96
9	2.00	1.7	0.260	0.884
11	2.00	1.0	0.183	0.366
12	0	0		—
			$\Sigma \Delta Q_i =$	6.457

Total discharge Q = ~~6.457 m^3/s~~ 6.95 m^3/s

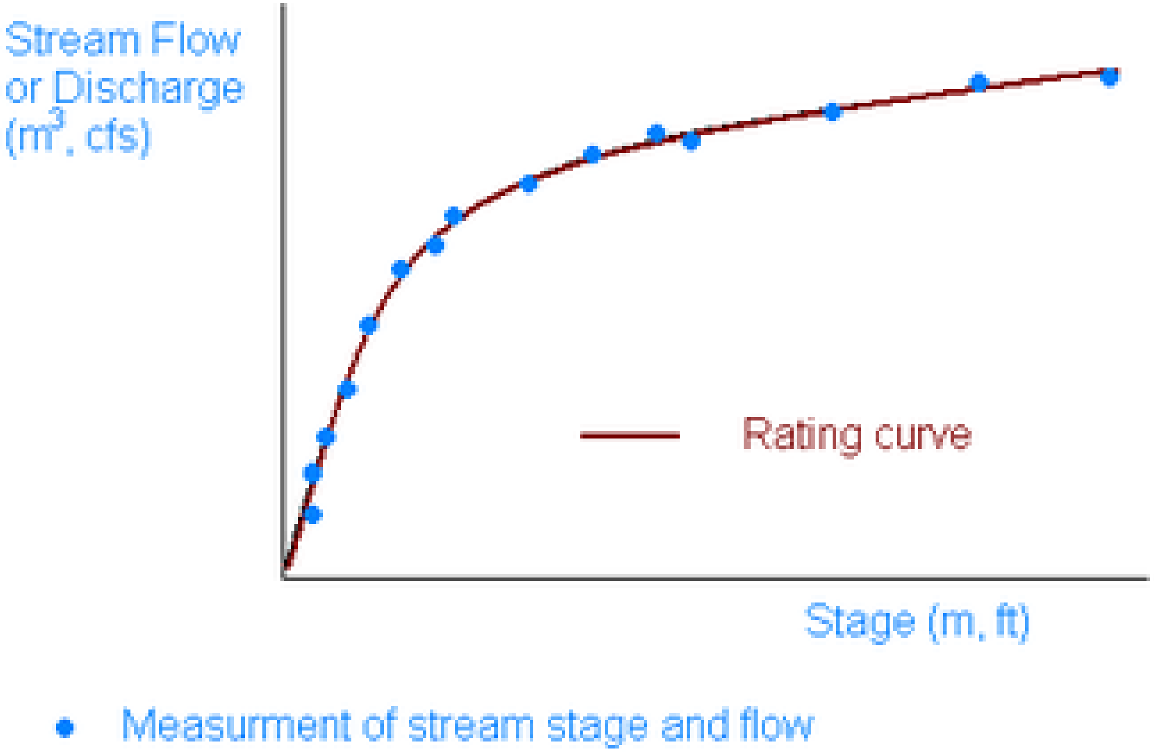
Rating curve

Curve showing Stage-Discharge Relationship

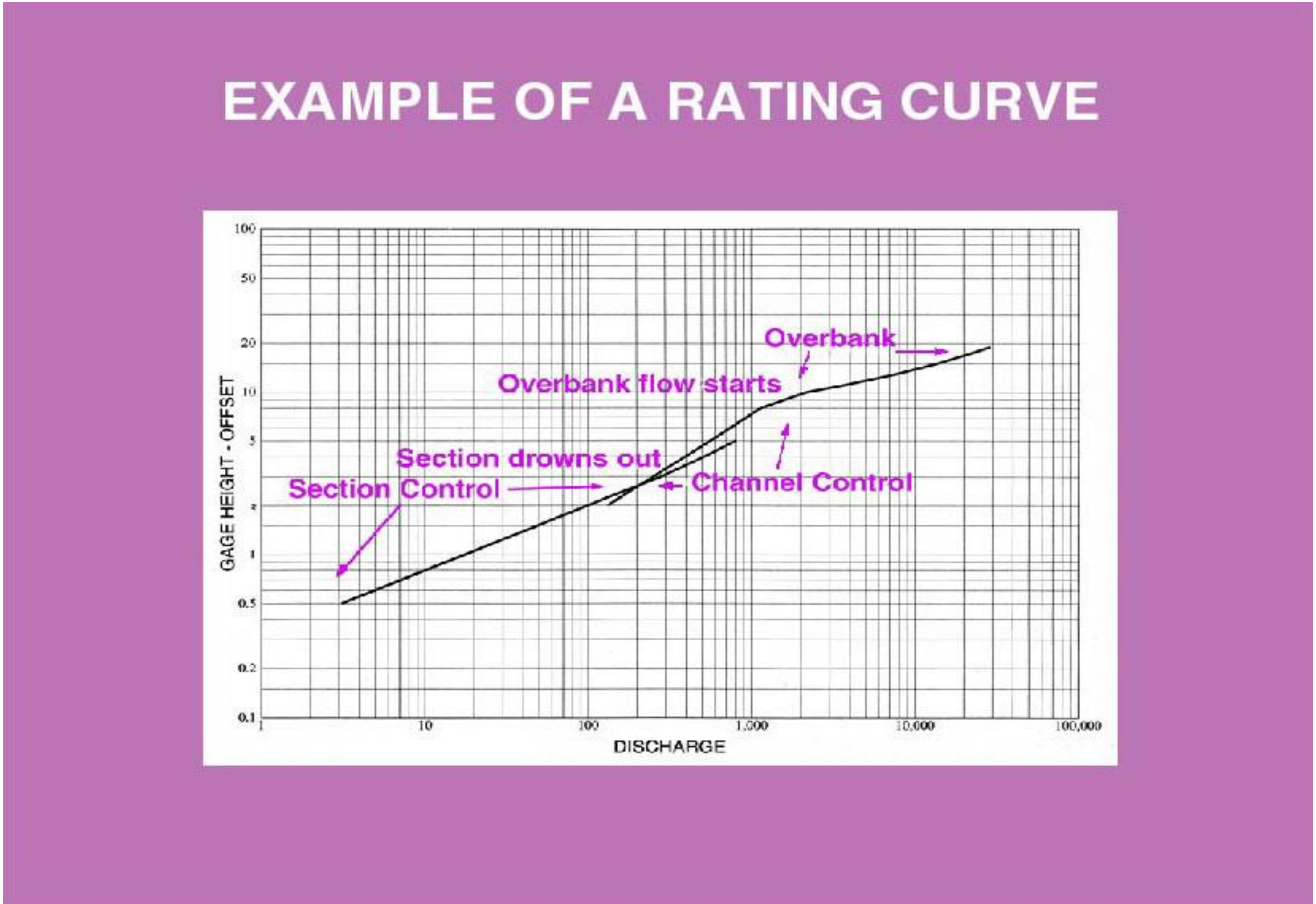
- Development of stage-discharge (H-Q) relationship or Rating curve
- Measuring the stage and read the discharge from the relation table or chart.
- $Q=a(H-H_0)^b$……………………general form

Rating curve

- ***Permanent control :*** If the stage-discharge relationship doesn't change with time

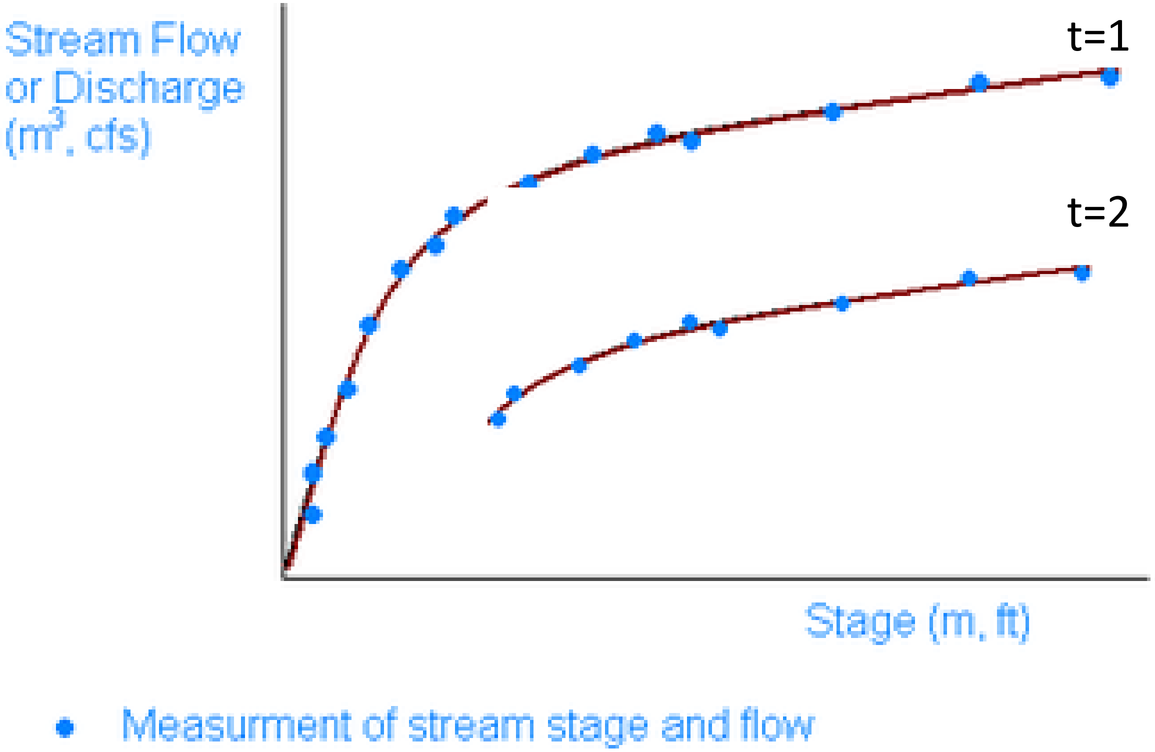


Rating curve



Rating curve

- ***shifting control:-*** If the stage-discharge relationship changes with time



Rating curve EQUATIONS

- $Q=a(H-H_0)^b$

$\text{Log } Q = \log a + b\log(H-H_0)$

- $Y = K + bX$

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

$$\text{Log a} = \text{k} = \frac{\sum Y - b(\sum x)}{N}$$

Rating curve EQUATIONS

Correlation coefficient (goodness of fit)

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

r=[0,1]

example

1. Stage and corresponding discharge values of a river site are given as follows. Use 7.50m stage as zero discharge and

I) *develop the stage-discharge relationship*

ii) *calculate the discharge corresponding to stage of 10.5m*

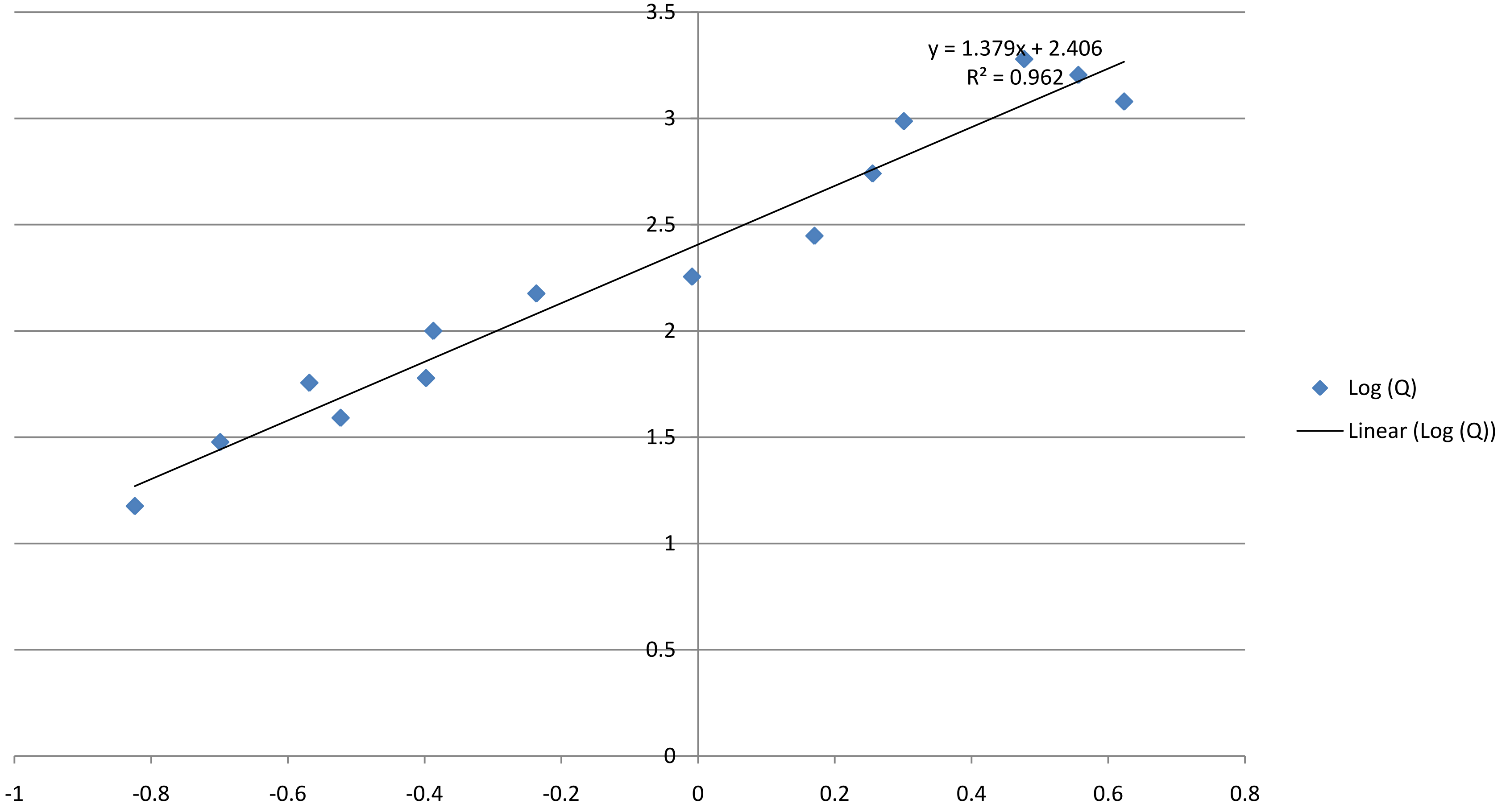
example

Stage reading (m)	Discharge (m3/sec)	Stage reading (m)	Discharge (m3/sec)
7.65	15	8.48	180
7.7	30	8.98	280
7.77	57	9.3	550
7.8	39	9.5	970
7.9	60	10.5	1900
7.91	100	11.10	1600
8.08	150	11.70	1200

Excel SOLUTION

- example.xlsx

Excel SOLUTION



Hydrograph

- Hydrograph is the graphical representation of the instantaneous rate of discharge of a stream plotted with respect to time
- Factors affecting the hydrograph shape.

1) surface runoff,
2) interflow,
3) ground water or base flow, and
4) channel rainfall.

Hydrograph

$$Q = Q_b + (Q_p - Q_b)\left(\frac{t}{t_p}\right)^m e^{[(t_p - t)/(t_g - t_p)]}$$

Q = flow rate (m^3/s)

Q_b = baseflow (m^3/s)

Q_p = peak flow (m^3/s)

t_p = time to peak (hr)

t_g = time -to-centroid (hr)

t = time (hr)

$m = t_p/(t_g - t_p)$

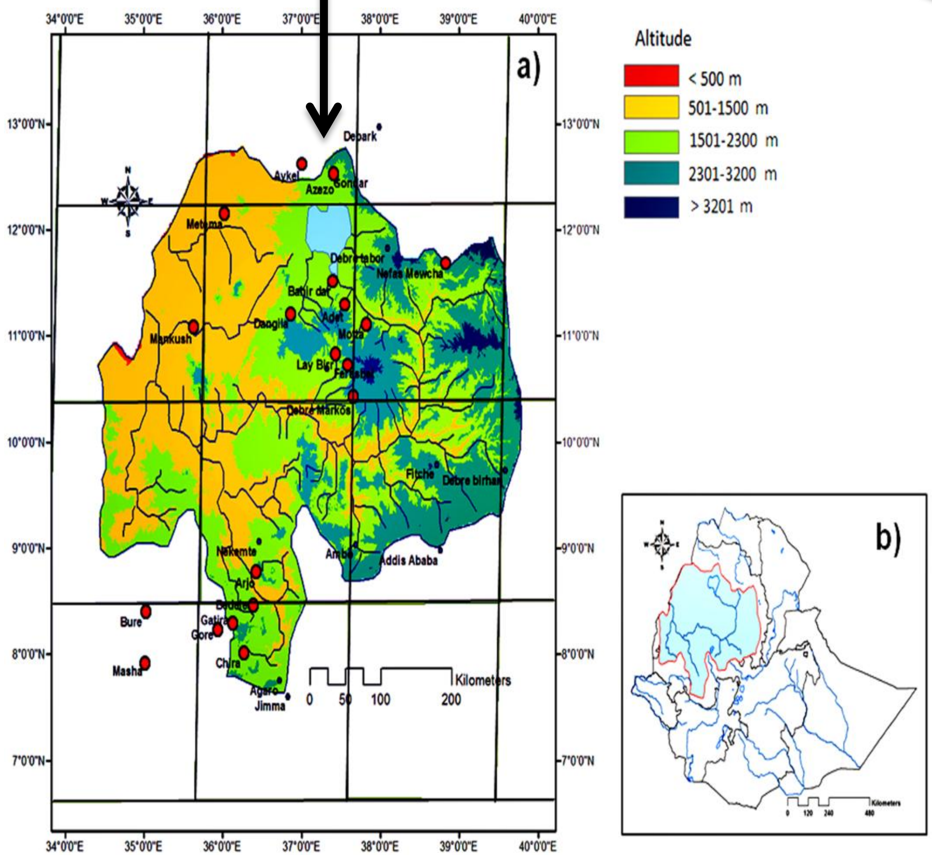
For values of tg > tp equation 5.24 exhibits positive skewness.

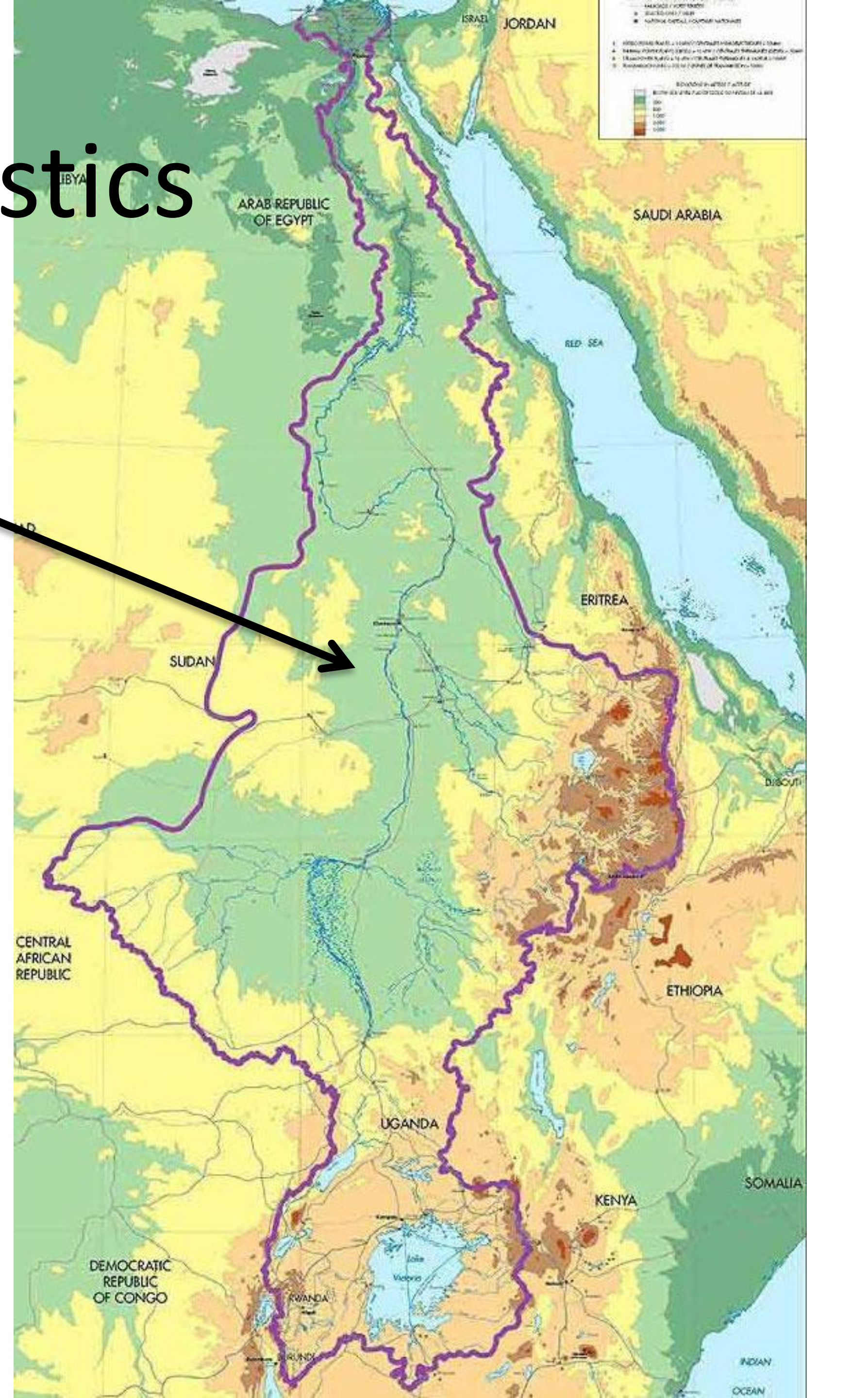
Runoff Estimation from Rainfall

- Rainfall-Runoff relations are the major means to compute the runoff of a given watershed with the help of rainfall information.
- watershed characteristics are base for determining the rainfall runoff relationship.
- A watershed is the area of land where all of the water that falls in it and drains off of it goes into the same place

watershed characteristics

- Watershed area





watershed characteristics

Watershed area

$$Q_p = cA^n \tag{6.1}$$

Where: Q_p = peak flow
A = watershed area
c and n = parameters to be determined by regional regression

Watershed shape: horizontal projection of a watershed

$$K_f = \frac{A}{L^2} \tag{6.2}$$

Where: K_f = form ratio
A = watershed area
L = watershed length measured along the longest watercourse.

watershed characteristics

- **Watershed relief:** Relief is the elevation difference between two reference points.

- Maximum watershed relief= elev. highest point- elev. watershed outlet
- Relief ratio= Maximum watershed relief/L

 Where L= watershed’s longest horizontal straight distance in a direction parallel to that of the principal watercourse.

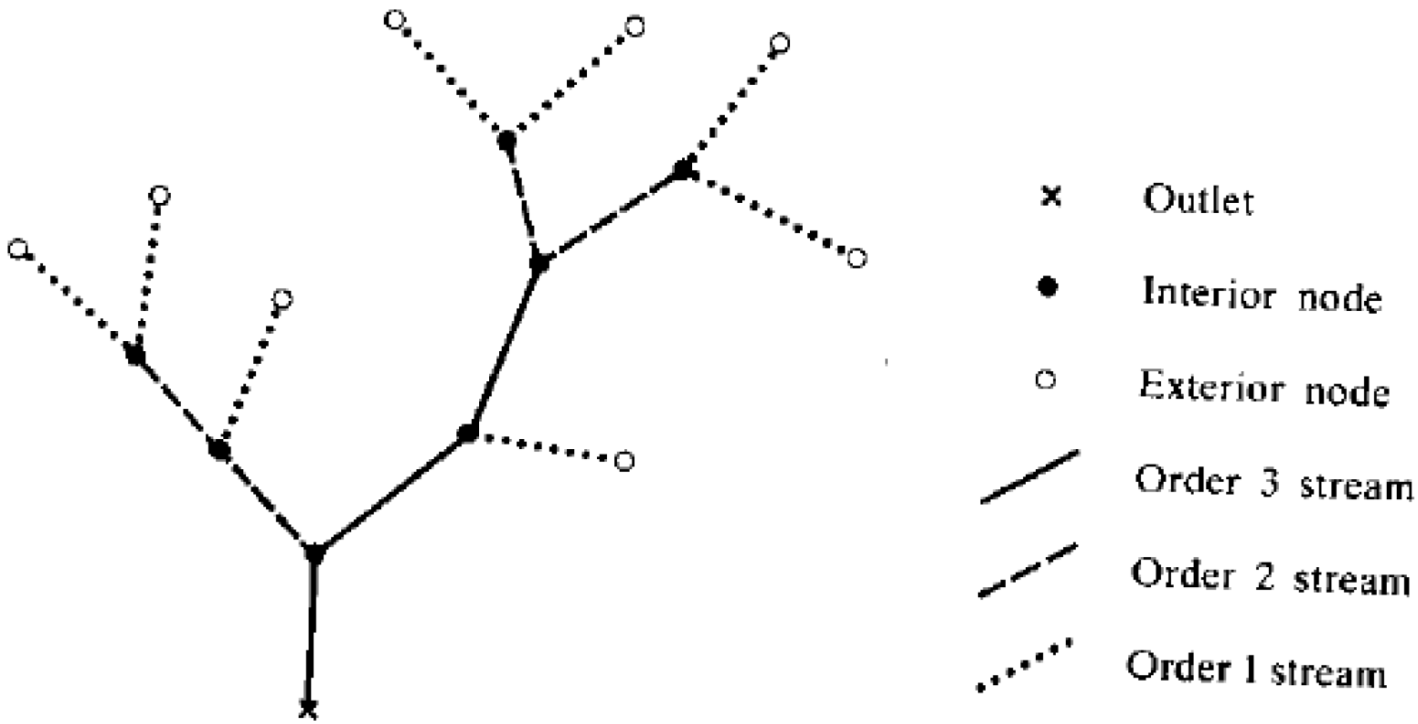
watershed characteristics

elev.highest point

elev.watershed outlet

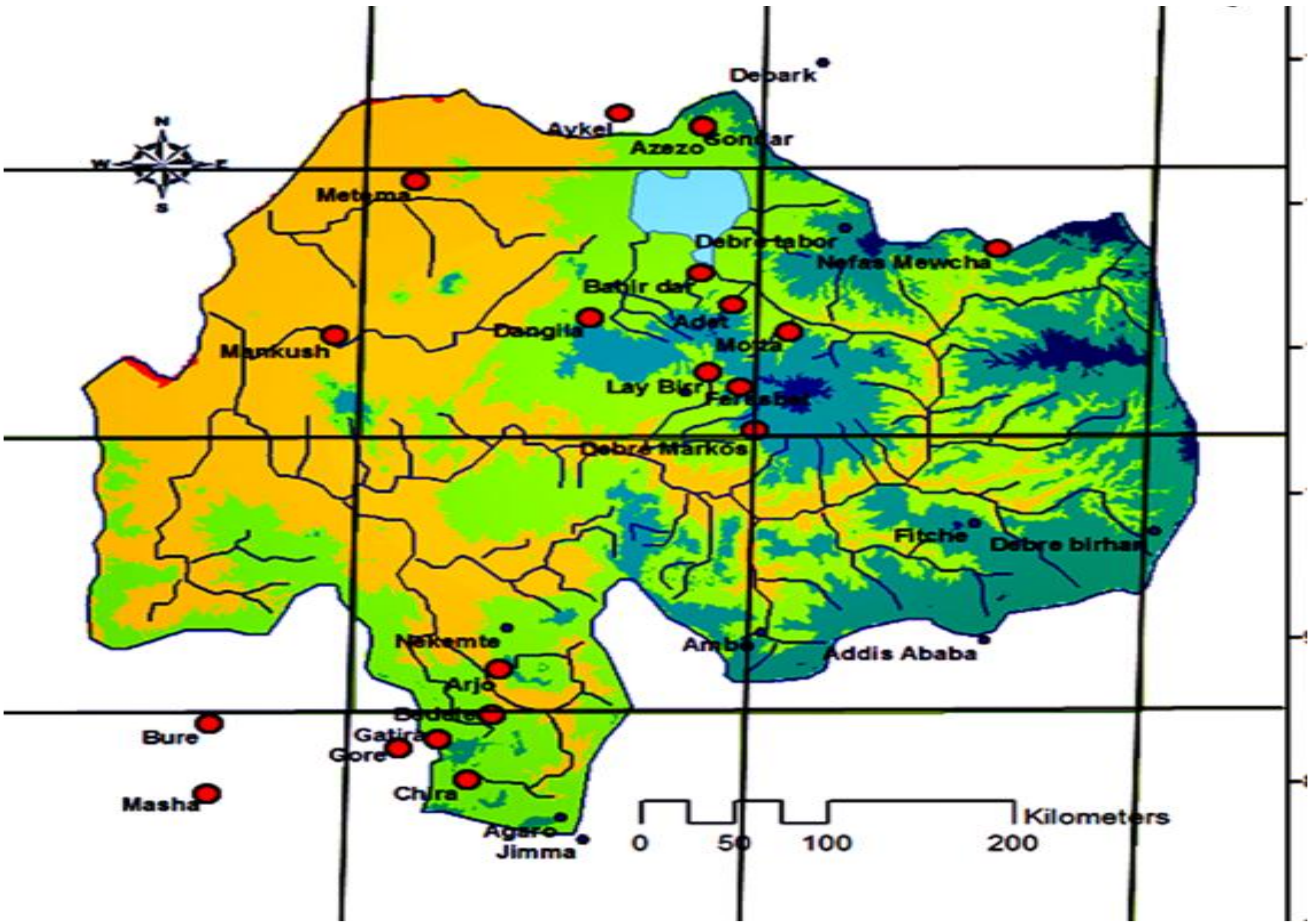
watershed characteristics

Stream networks



Strahler Stream Ordering Illustrating Nodes and Links

watershed characteristics



Empirical Equations

- Barlow’s Tables
- Khosla’s Formula

Barlow’s Tables

$$R = k_b P$$

where kb = runoff coefficient which depends on type of catchment and nature of monsoon rainfall

TABLE 3.1 BARLOW'S RUNOFF COEFFICIENT K_b IN PERCENTAGE (Developed for use in UP)

Class	Description of catchment	Values of K_b (percentage)		
		Season 1	Season 2	Season 3
A	Flat, cultivated and absorbent soils	7	10	15
B	Flat, partly cultivated, stiff soils	12	15	18
C	Average catchment	16	20	32
D	Hills and plains with little cultivation	28	35	60
E	Very hilly, steep and hardly any cultivation	36	45	81

Season 1: light rain, no heavy downpour
Season 2: Average or varying rainfall, no continuous downpour
Season 3: Continuous downpour

Khosla's Formula

$$R_m = P_m - L_m$$

$$L_m = 0.48 T_m \; for \; T_m > 4.5^o C$$

Where Rm=runoff

Pm=rainfall(precipitation)

L_m = monthly losses in cm

T_m = mean monthly temperature of the catchment in ° C

For $T_m \leq 4.5°$ C, the loss L_m may provisionally be assumed as

T° C	4.5	−1	−6.5
L_m (cm)	2.17	1.78	1.52

Annual runoff = ΣR_m

example

2. For a catchment UP the mean monthly rainfall and temperature are given. Calculate the annual runoff and runoff coefficient by Khosla's formula.

Rational method

- The Rational Method is used to calculate the peak surface runoff rate for design of storm water management structures, like storm drains, storm sewers, and storm water detention facilities. Values for the runoff coefficient, drainage area, time of concentration and design return period are needed.
- The rational method is widely used around the world for flood estimation on small rural watersheds and urban drainage design

- The equation that is the centerpiece of the Rational Method is: $q = 0.278CiA$,

where q is the peak surface runoff rate from

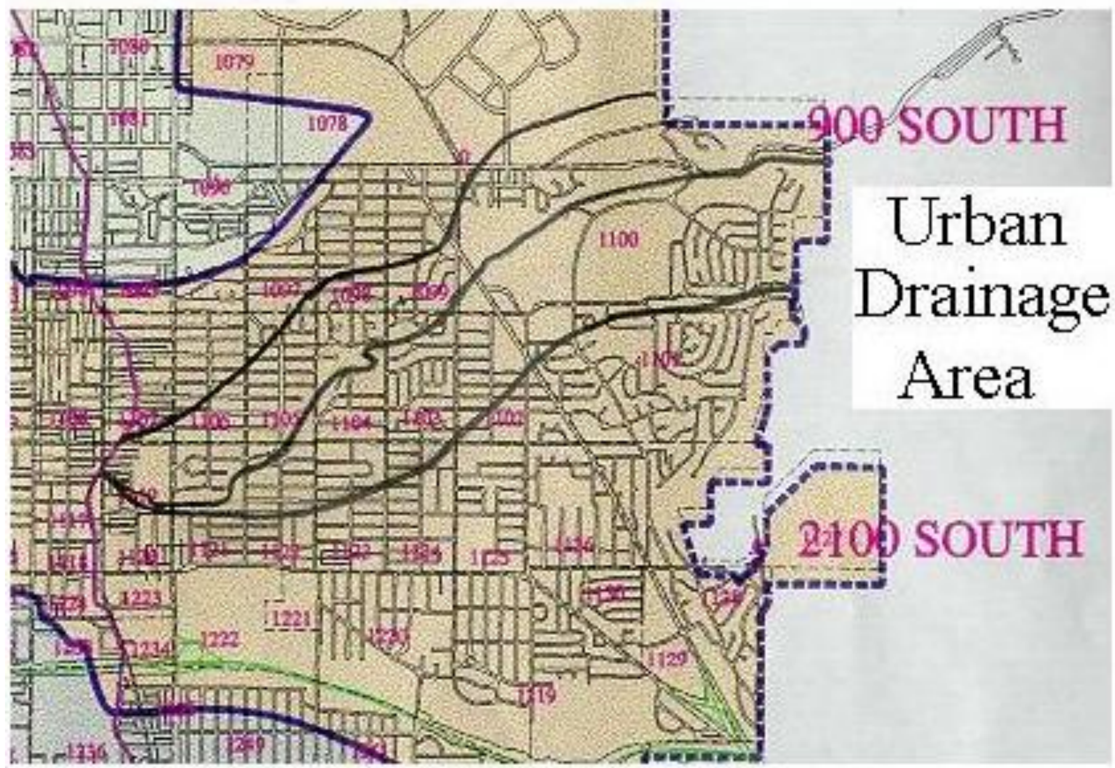
A watershed of area, and,

C runoff coefficient *due to a*

i storm of intensity

A watershed of area

- determined from a map which includes the drainage area of interest



The Runoff Coefficient, C

- is the fraction of rainfall striking the drainage area that becomes runoff from that drainage area
- empirically runoff coefficients determined constant, dependent on the nature of the drainage area surface.

Type of Area	Typical Range for Runoff Coefficient
Concrete Pavement	0.70-0.95
Park or Cemetary	0.10-0.25
Downtown Business	0.70-0.95
Single Family Residential Area	0.30-0.50

The Design Rainfall Intensity, i

- is the intensity of a constant intensity design storm with the specified design return period and duration equal to the time of concentration of the drainage area.
- The time of concentration of a drainage area is the time required for runoff from the farthest part of the drainage area to reach the outlet
- the design rainfall intensity can be determined from an appropriate **intensity-duration-frequency** graph or equation for the location of the drainage area

$$t_c = 3.976 L^{0.77} S^{-0.385} \quad (7.2)$$

Where:

L = the length of channel from divide to outlet (km)

S = the average channel slope (m/m)

t_c.= the time of concentration (min)

example

Example 7.1 A watershed has a runoff coefficient of 0.20, area 150 ha with the general slope of 0.001 and maximum length of travel of overland flow of 1.25 km. Information on the storm of 50 years return period is given as follows:

Duration (min)	15	30	45	60	80
Rainfall (mm)	40	60	75	100	120

Estimate the peak flow to be drained by a culvert for a 50-year storm.