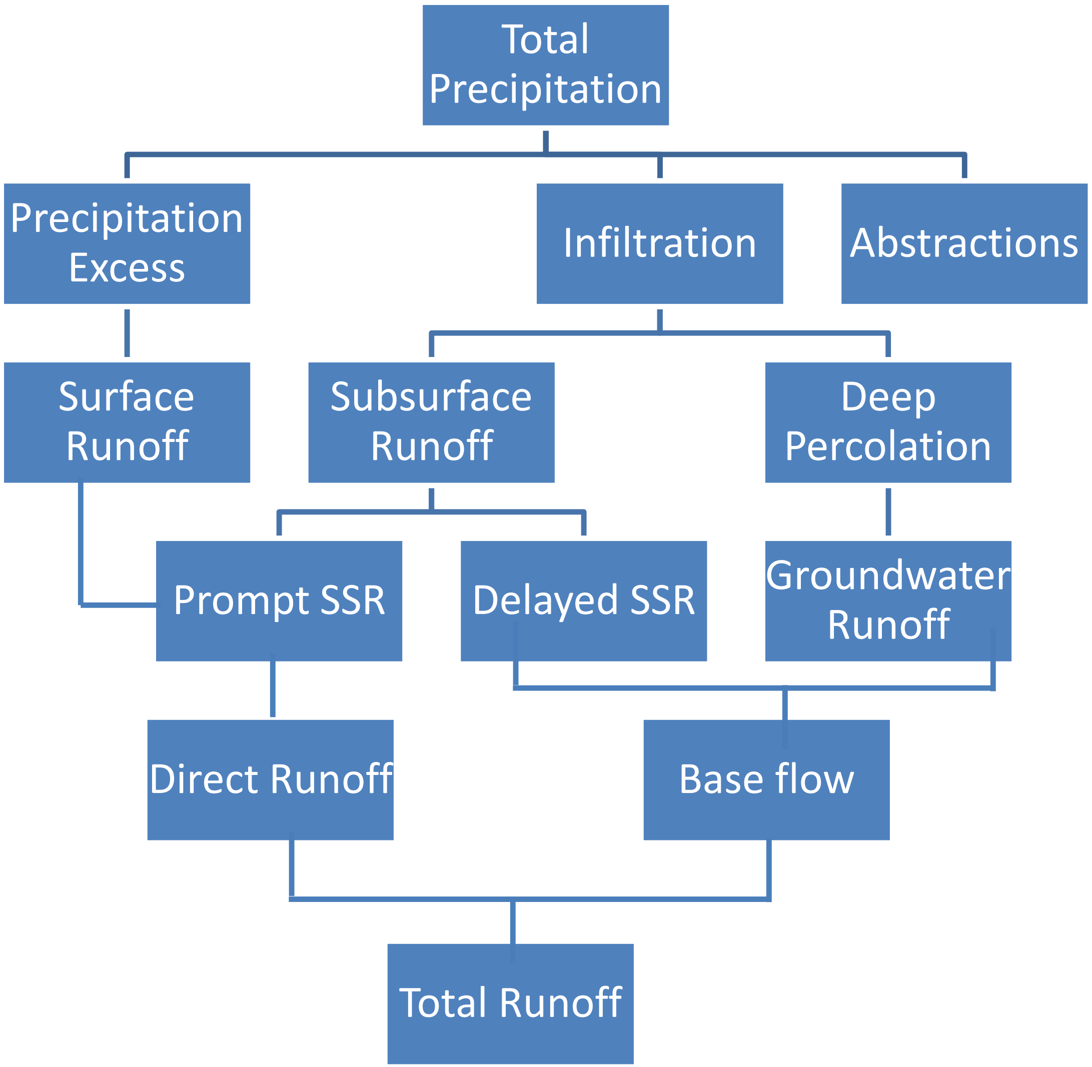
Runoff

Prof. M.M.M. Najim

- At the end of this section, students will be able to
  - Explain different types of runoff
  - Explain the factors affecting runoff
  - Apply rational method to estimate peak rate of runoff
  - Estimate the runoff coefficient for a heterogeneous watershed
  - Estimate time of concentration for a watershed

- Runoff is the portion of rainfall which flows through the rivers, streams etc.



Types of Runoff

- Surface runoff
  - Portion of rainfall (after all losses such as interception, infiltration, depression storage etc. are met) that enters streams immediately after occurring rainfall
  - After laps of few time, overland flow joins streams
  - Sometime termed prompt runoff (as very quickly enters streams)
- Subsurface runoff
  - Amount of rainfall first enter into soil and then flows laterally towards stream without joining water table
  - Also take little time to reach stream

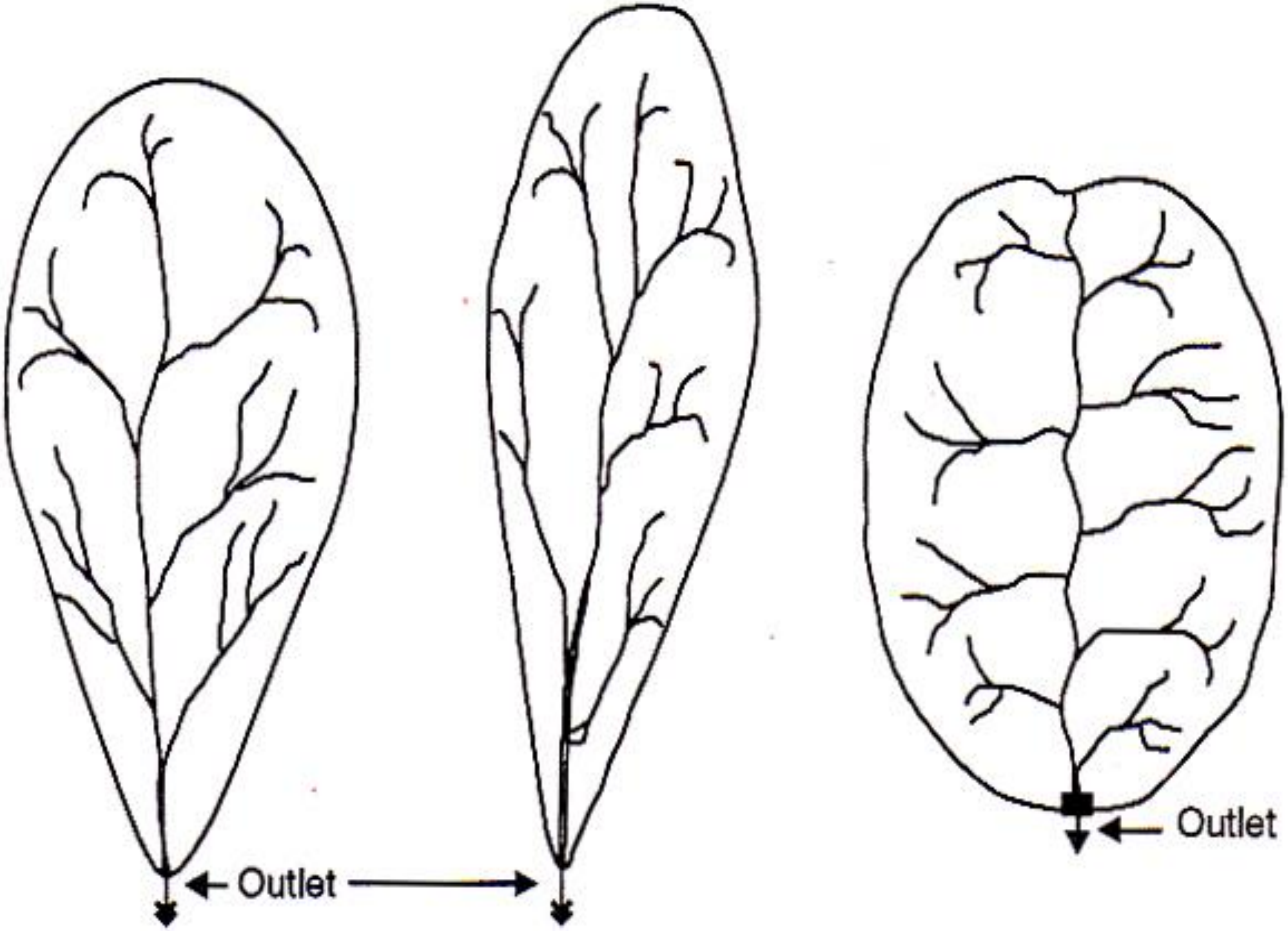
- Base flow
  - Delayed flow
  - Water that meets the groundwater table and join the stream or ocean
  - Very slow movement and take months or years to reach streams

Factors affecting runoff

- Climatic factors
  - Type of precipitation
    - Rain and snow fall
  - Rainfall intensity
    - High intensity rainfall causes more rainfall
  - Duration of rainfall
    - When duration increases, infiltration capacity decreases resulting more runoff
  - Rainfall distribution
    - Distribution of rainfall in a catchment may vary and runoff also vary
    - More rainfalls closer to the outlet, peak flow occurs quickly

- Direction of prevailing wind
  - If the wind direction is towards the flow direction, peak flow will occur quickly
- Other climatic factors
  - Temperature, wind velocity, relative humidity, annual rainfall etc. affect initial loss of precipitation and thereby affecting runoff

- Physiographic factors
  - Physiographic characteristics of watershed and channel both
  - Size of watershed
    - Larger the watershed, longer time needed to deliver runoff to the outlet
    - Small watersheds dominated by overland flow and larger watersheds by runoff
  - Shape of watershed
    - Fan shaped, fan shaped (elongated) and broad shaped



(a) Fan shaped (b) Fan shaped (Elongated) (c) Broad shaped

- Fan shaped – runoff from the nearest tributaries drained out before the floods of farthest tributaries. Peak runoff is less
- Broad shaped – all tributaries contribute runoff almost at the same time so that peak flow is more

– Orientation of watershed

- Windward side of mountains get more rainfall than leeward side

– Landuse

- Forest – thick layer of organic matter and undercover – huge amounts absorbed to soil – less runoff and high resistance to flow
- barren lands – high runoff

- Soil moisture
  - Runoff generated depend on soil moisture – more moisture means less infiltration and more runoff
  - Dry soil – more water absorbed to soil and less runoff
- Soil type
  - Light soil (sandy) – large pores and more infiltration
  - Heavy textured soils – less infiltration and more runoff
- Topographic characteristics
  - Higher the slope, faster the runoff
  - Channel characters such as length, shape, slope, roughness, storage, density of channel influence runoff

– Drainage density

$$Drainage\ density = \frac{Total\ channel\ length}{Total\ area\ of\ watershed}$$

- More the drainage density, runoff yield is more

Runoff Computation

- Computation of runoff depend on several factors
- Several methods available
  - Rational method
  - Cook’s method
  - Curve number method
  - Hydrograph method
  - Many more

Rational Method

- Computes peak rate of runoff
- Peak runoff should be known to design hydraulic structures that must carry it.

$$Q_{Peak} = \frac{CIA}{360}$$

Q_{Peak} = Peak runoff rate (m^3/s)

C = runoff coefficient

I = rainfall intensity (mm/h) for the duration equal to the time of concentration

A = Area of watershed (ha)

- Runoff coefficient
  - Ratio of peak runoff rate to the rainfall intensity
  - No units, 0 to 1
  - Depend on landuse and soil type
  - When watershed has many land uses and soil types, weighted average runoff coefficient is calculated

$$C_w = \frac{C_1 a_1 + C_2 a_2 + C_3 a_3}{a_1 + a_2 + a_3}$$

$$Cw = \frac{\sum_{i=1}^{n} C_i a_i}{A}$$

Runoff coefficient for Rational Method

S.No.	*Land use and topography*	*Soil type*		
		Sandy loam	*Clay and silt loam*	*Tight clay*
1.	Cultivated land			
	(i) Flat	0.30	0.50	0.60
	(ii) Rolling	0.40	0.60	0.70
	(iii) Hilling	0.52	0.70	0.82
2.	Pasture land			
	(i) Flat	0.10	0.30	0.40
	(ii) Rolling	0.16	0.36	0.55
	(iii) Hilling	0.22	0.42	0.60
3.	Forest land			
	(i) Flat	0.10	0.30	0.40
	(ii) Hilling	0.30	0.50	0.60
4.	Populated land			
	(i) Flat	0.40	0.55	0.65
	(ii) Rolling	0.50	0.65	0.80

- Time of concentration (T_c)
  - Time required to reach the surface runoff from remotest point of watershed to its outlet
  - At T_c all the parts of watershed contribute to the runoff at outlet
  - Have to compute the rainfall intensity for the duration equal to time of concentration
  - Several methods to calculate T_c
  - Kirpich equation

$$T_c = 0.02\, L^{0.77}\, S^{-0.385}$$

T_c = time of concentration (min)
L = Length of channel reach (m)
S = Average channel slope (m/m)

- Computation of rainfall intensity for the duration of T_c

$$I = \frac{\text{Rainfall Depth}}{T_c} = \frac{cm\ or\ mm}{h}$$

- Assumptions of Rational Method
  - Rainfall occur with uniform intensity at least to the T_c
  - Rainfall intensity is uniform throughout catchment

- Limitations of Rational Method
  - Uniform rainfall throughout the watershed never satisfied
  - Initial losses (interception, depression storage, etc). are not considered

Cook's Method

- Computes runoff based on 4 characteristics (relief, infiltration rate, vegetal cover and surface depression)
- Numerical values are assigned to each

Steps in calculation

- Step 1
  – Evaluate degree of watershed characteristics by comparing with similar conditions

Numerical values for Cook's Method

S. No.	Range	Numerical values assigned for runoff producing wateshed's characteristics			
		Relief	*Soil infiltration*	*Vegetal cover*	*Surface storage*
1.	Low	(10 to 0) Land is relatively flat, average slope ranges from 0 to 5%.	(5) Infiltration rate is more than 2 cm/hour, soil contains high sand and loamy sand.	(5) About 9% of total area is covered under good vegetation either by forest or equivalent.	(5) Land consists of high surface depression, drainage system is not very well.
2.	Normal	(20 to 10) The land is rolling in shape and slope ranges from 5% to 10%.	(10) Infiltration rate varies from 0.75 to 2 cm/ hour, the soil is in normal and deep permeable nature.	(10) About 50% of total area is under good grass land or any other equivalent cover.	(10) Considerable depression storage, lakes, ponds and mar-shes are less than 2% of entire drainage system.
3.	High	(30 to 20) Lands are hilly in nature, ave-rage slope ran-ges from 10% to 30%.	(15) Infiltration rate ranges from 0.25 to 0.75 cm/ hour, the soil is relatively hard such as clay soil.	(15) Vegetal cover varies from poor to fair, less than 10% of total area is under grass cover.	(15) Surface de-pression is very low and area is well drained:
4.	Extreme	(40 to 30) Lands are steep and rugged terrain, slope ranges upto 30%.	(20) Infiltration rate is less.	(20) Land is bare, no effective grass cover.	(10) Surface depressions are negligible, drainage of land is very well. and no ponds or tanks are available.

- Step 2
  - Assign numerical value (W) to each of the characteristics
- Step 3
  - Find sum of numerical values assigned

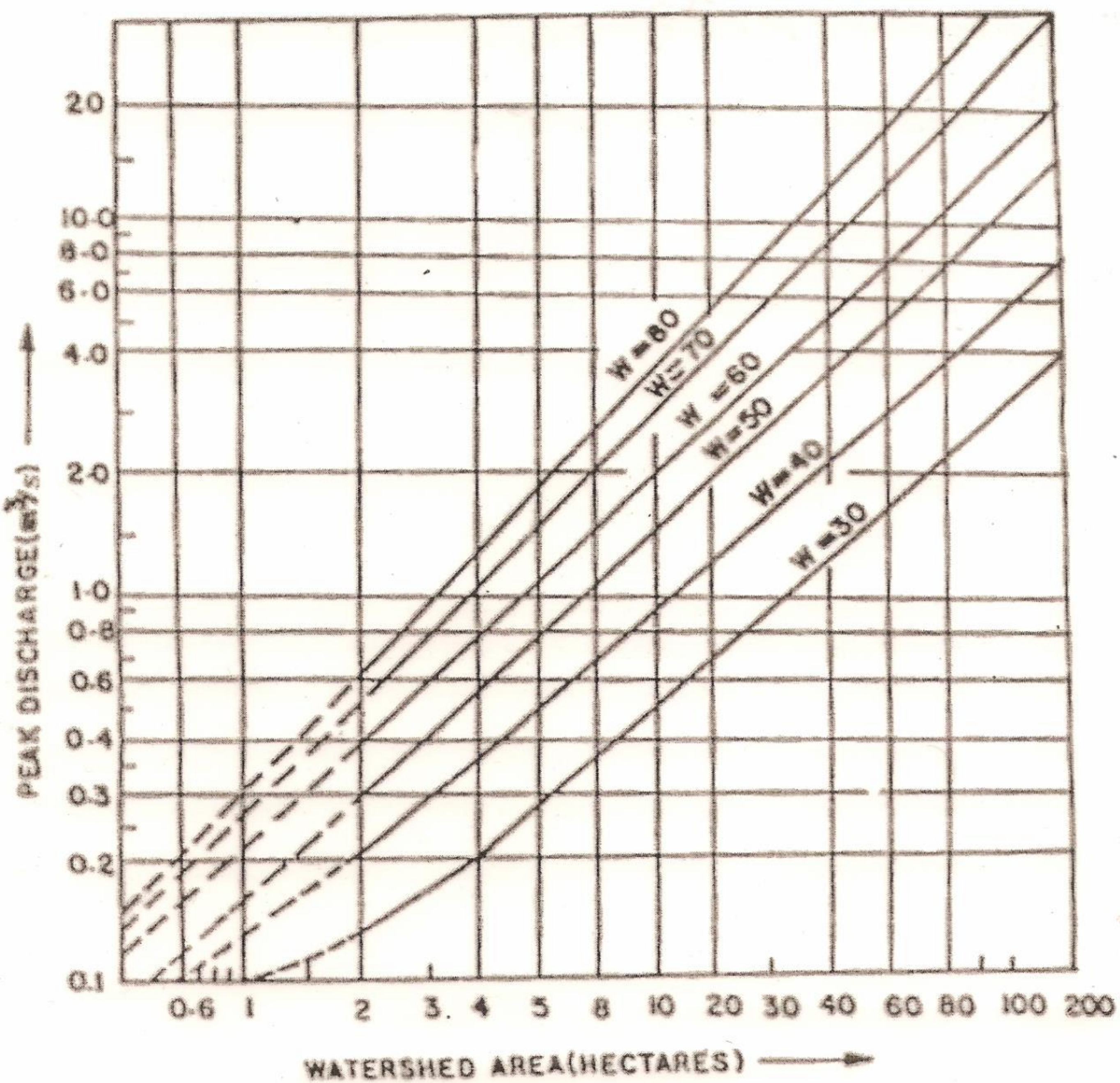
$$\sum W = R + I + \mathrm{V} + \mathrm{D}$$

ΣW = total numerical value

R, I, V, and D are marks given to relief character, initial infiltration, vegetal cover and surface depression respectively

- Step 4
  - Determine runoff rate against ΣW using runoff curve (valid for specified geographical region and 10 year recurrence interval)
- Step 5
  - Compute adjusted runoff rate for desired recurrence interval and watershed location

$$Q_{Peak} = P.R.F.S$$



20.0
10.0
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.3
0.2
0.1
PEAK DISCHARGE(m³/s)
W=80
W=70
W=60
W=50
W=40
W=30
0.6
1
2
3.
4
5
8
10
20
30
40
60
80
100
200
WATERSHED AREA(HECTARES)

Q_{Peak} = Peak runoff for specified geographical location and recurrence interval (m^3/s)

P = Uncorrected runoff obtained from step 4

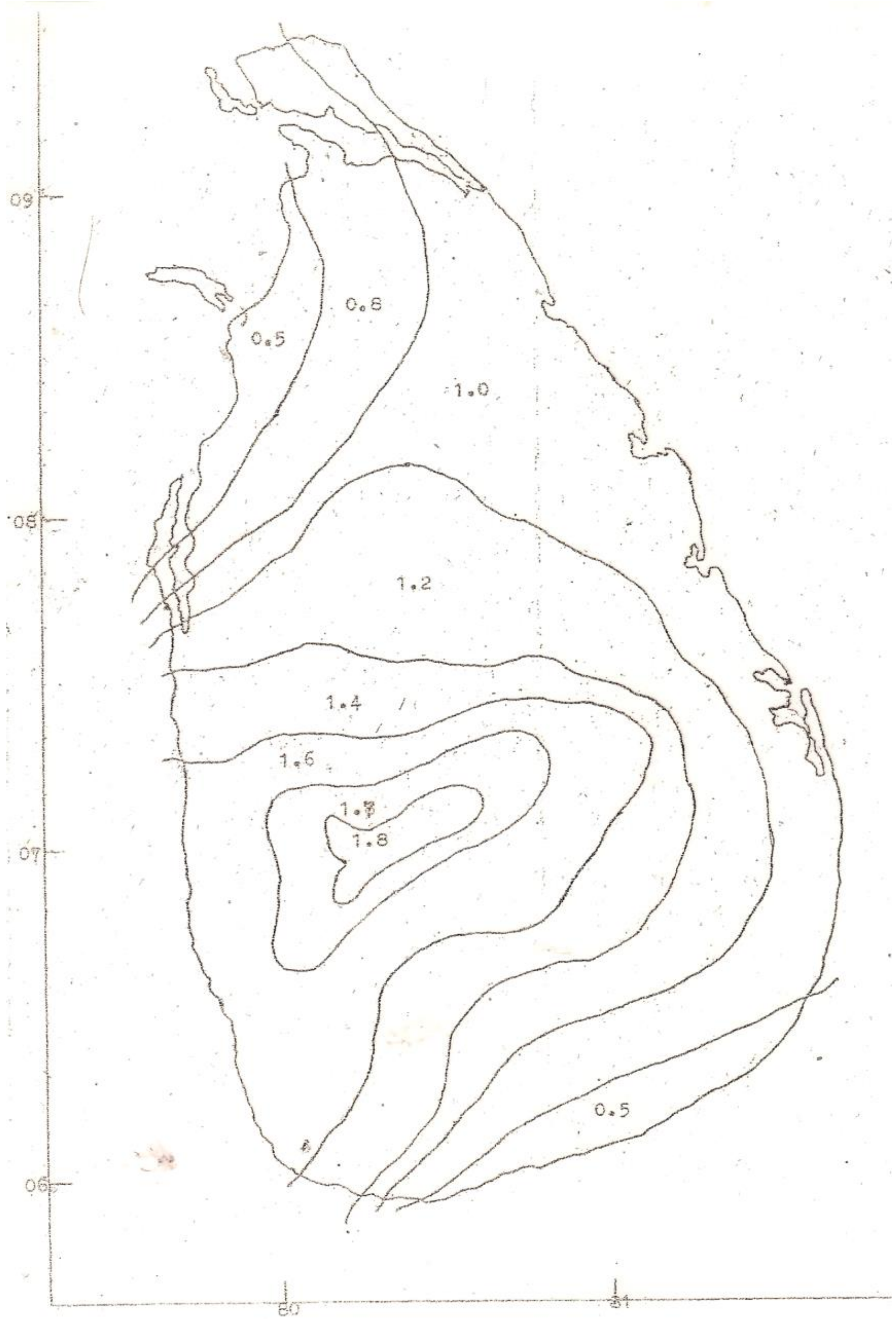
R = Geographic rainfall factor (Figures for Sri Lanka)

F = Recurrence interval factor (Figures for Sri Lanka)

S = Shape factor

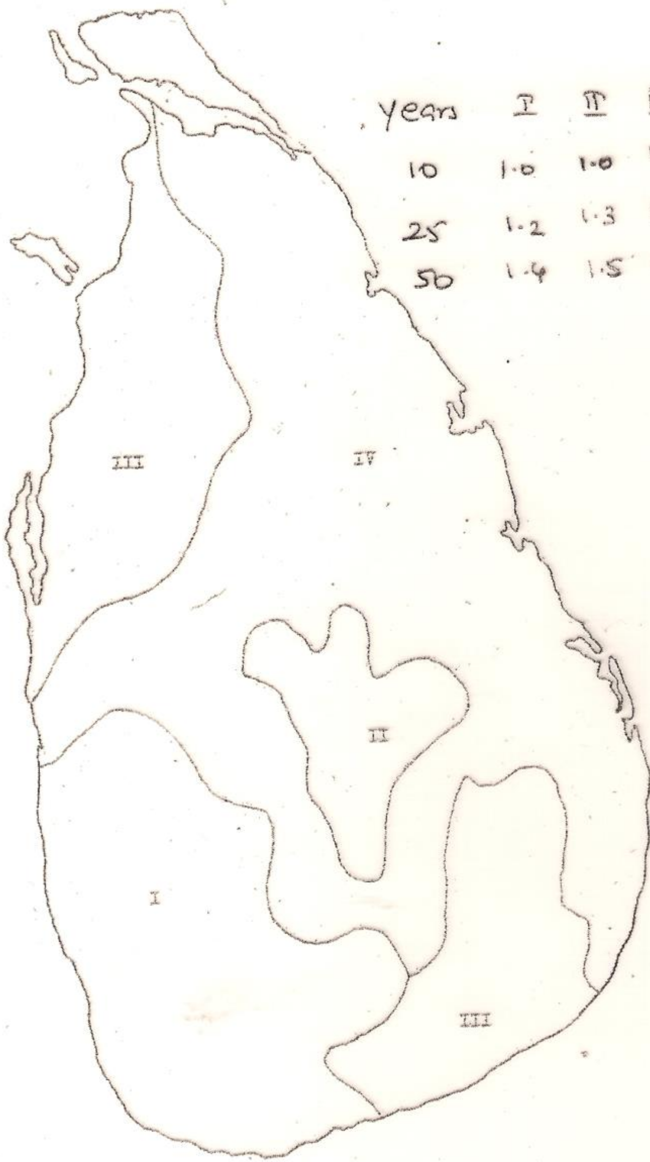
Shape factor for Cook's method

Ratio of length to breadth	Watershed area in hectares				
	20	40	80	200	240
1	1.00	1.00	1.00	1.00	1.00
1- 1 ½	0.92	0.92	0.91	0.90	0.90
2	0.88	0.87	0.86	0.84	0.83
2- 2 ½	0.85	0.84	0.82	0.80	0.78
3	0.81	0.80	0.78	0.76	0.74
4	0.76	0.75	0.73	0.71	0.69
5	0.74	0.72	0.70	0.68	0.66
6	0.72	0.70	0.68	0.66	0.64
7	0.70	0.68	0.66	0.64	0.62



Rainfall Factor

Frequency Factor



Years	I	II	III	IV
10	1.0	1.0	1.0	1.0
25	1.2	1.3	1.3	1.0
50	1.4	1.5	1.6	1.5

Curve Number Method

- Calculates runoff on the retention capacity of soil, which is predicted by wetness status (Antecedent Moisture Conditions [AMC]) and physical features of watershed
- AMC - relative wetness or dryness of a watershed, preceding wetness conditions
- This method assumes that initial losses are satisfied before runoff is generated

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad CN = \frac{2540}{(25.4 + S)}$$

Q = Direct runoff

P = Rainfall depth

S = Retention capacity of soil

CN = Curve Number

- CN depends on landuse pattern, soil conservation type, hydrologic condition, hydrologic soil group

Land use pattern	Treatment/practice adopted	Hydrologic condition	Hydrologic soil group			
			A	B	C	D
Fallow-row crops	Straight row	—	77	86	91	94
		Poor	72	81	88	91
		Good	67	78	85	89
	Contoured + terraced condition	Poor	70	79	84	88
Small grain	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Contoured condition	Poor	63	74	82	85
		Good	63	75	83	87
	Contoured + terraced condition	Poor	61	72	79	82
		Good	59	70	78	81
Seeded	Straight row	Poor	66	77	85	89
Legumed		Good	55	69	78	83
Pasture land	Contoured condition	Poor	47	67	81	88
		Fair	25	59	75	83
		Good	6	35	70	79
Farm		Poor	45	66	77	83
Woodland		Fair	36	60	73	79
		Good	25	55	70	77
Hard surface			74	84	90	92
Farm steads			59	74	82	86
Meadow			330	58	71	78

- Curve Numbers

Procedure

- Step 1
  - Find value of CN using table
  - Calculate S using equation
  - Use equation and calculate Q (AMC II)
  - Use correction factor if necessary to convert to other AMCs)

- Three AMC conditions

Factors for converting AMC II to AMC I or AMR III

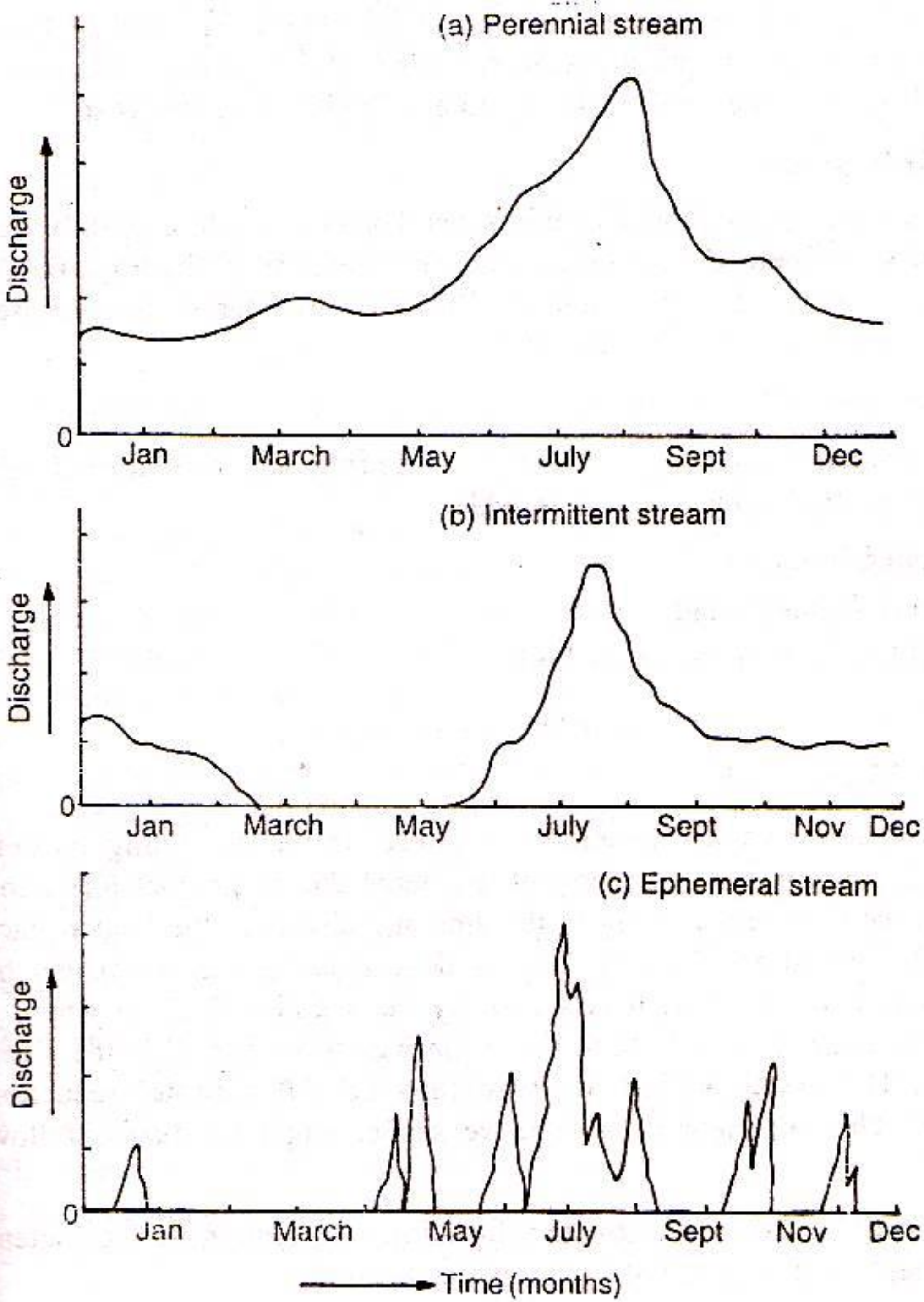
CN – AMC II	Conversion Factor	
	AMC I	AMC III
10	0.40	2.22
20	0.45	1.85
30	0.50	1.67
40	0.55	1.50
50	0.62	1.40
60	0.67	1.30
70	0.73	1.21
80	0.79	1.14
90	0.87	1.07
100	1.00	1.00

- AMC I – Lowest runoff generating potential – dry soil
- AMC II – Average moisture status
- AMC III – Highest runoff generating potential – saturated soil

- Soil A – low runoff generating potential, sand or gravel soils with high infiltration rates
- Soil B – Moderate infiltration rate, moderately fine to moderately coarse particles
- Soil C – Low infiltration rate, thin hard layer prevents downward water movement, moderately fine to fine particles
- Soil D – High runoff potential due to very low infiltration rate, clay soils

Classification of Streams

- Based on flow duration, streams are classified into
  - Perennial
    - Streams carry flow throughout the year
    - Appreciable groundwater contribution throughout the year
  - Intermittent
    - Limited groundwater contribution
    - In rainy season, groundwater table rises above stream bed
    - Dry season stream get dried
  - Ephemeral
    - In arid areas
    - Flow due to rainwater only
    - No base flow contribution

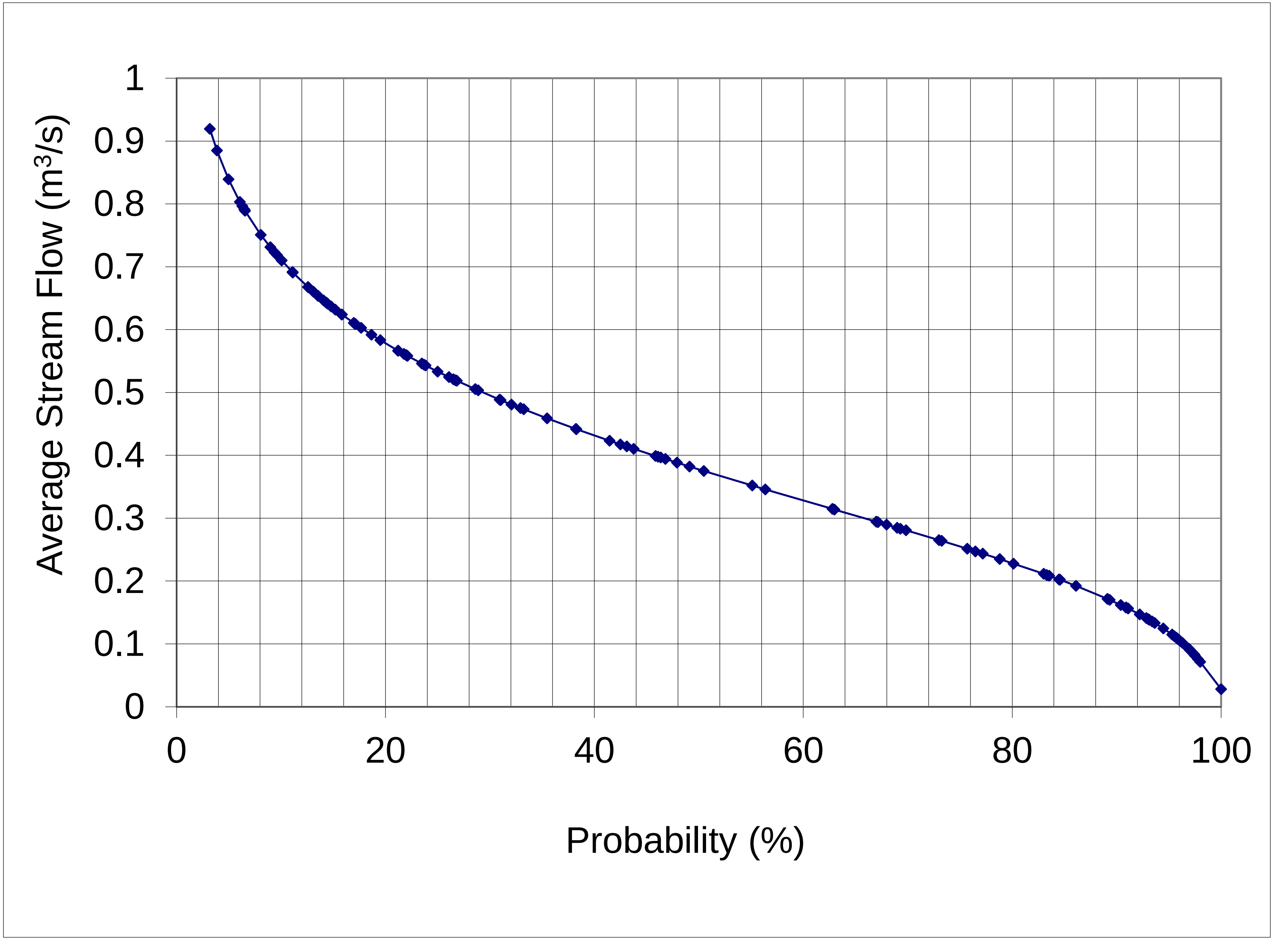

(a) Perennial stream
Discharge
0
Jan
March
May
July
Sept
Dec
(b) Intermittent stream
Discharge
0
Jan
March
May
July
Sept
Nov
Dec
(c) Ephemeral stream
Discharge
0
Jan
March
May
July
Sept
Nov
Dec
Time (months)

Flow Duration Curve

- Gives the variability of stream flow in a year
  - Arrange stream flow data in descending order
  - Assign rank number
  - Calculate plotting position (Probability)

$$P = \left(\frac{m}{n+1}\right)100$$

  - Plot plotting position and discharge


Average Stream Flow (m³/s)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
Probability (%)

- Characteristics of flow duration curve
  - Steep slope – highly variable flow
  - Flat slope – little variation in the flow
  - Flat portion at top of curve – stream has large flood plain
  - Flat portion at lower end – considerable baseflow

- Uses of flow duration curve
  - Discharge for any probability can be known
  - Variation of flow within a year can be known
  - Plan water resources projects
  - Design of drainage structures
  - Decide on flood control structures to be used
  - Evaluate hydropower potential
  - Determine sediment load carried by stream