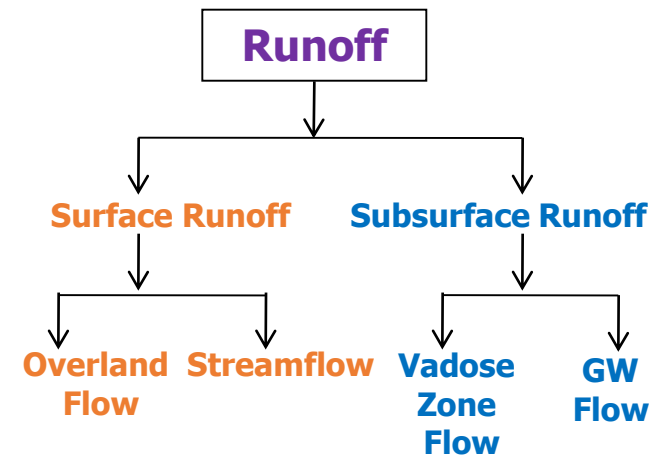
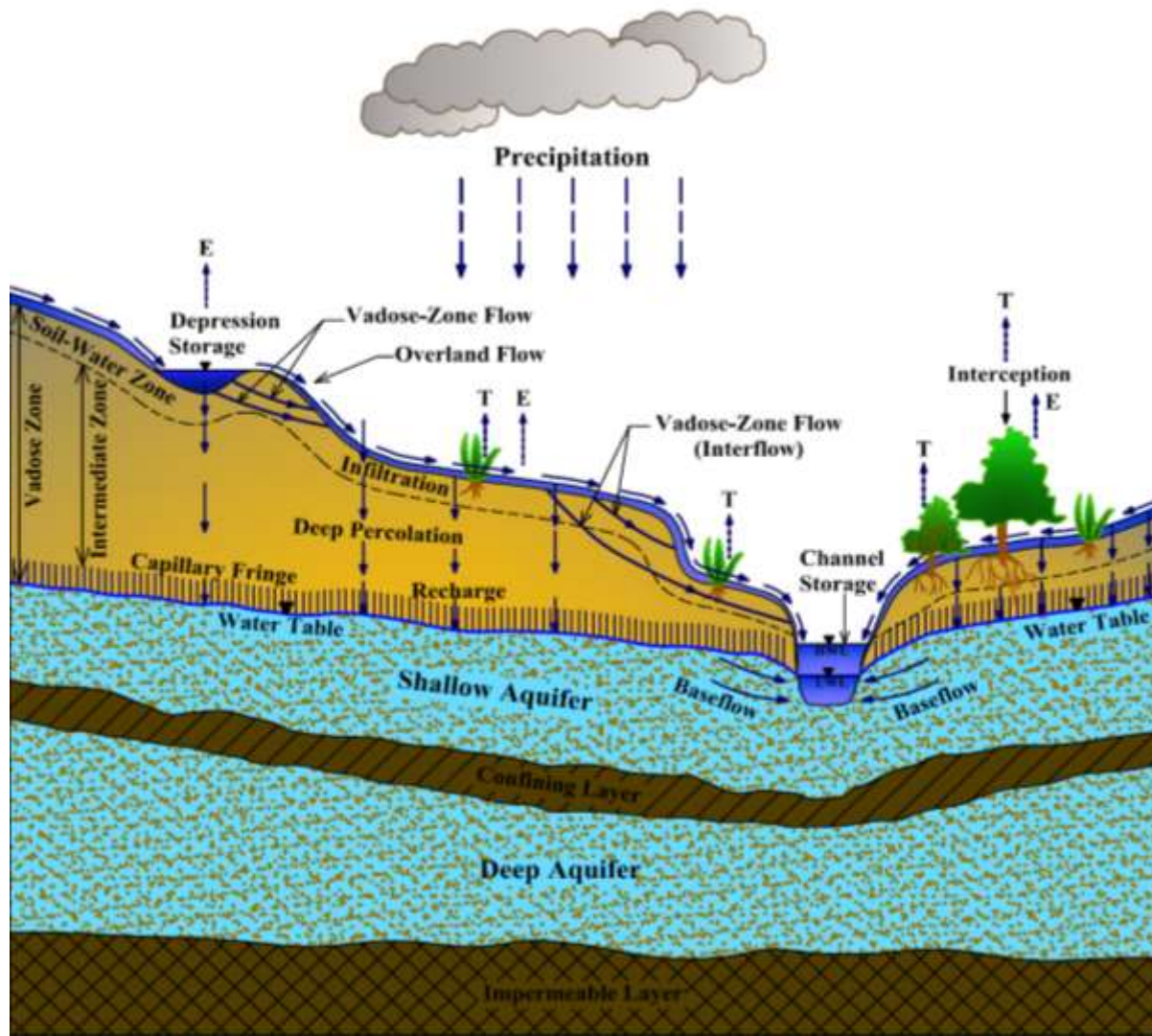


Watershed Hydrology

Runoff



Direct Runoff = Overland Flow + Interflow + rainfall on the surface of the stream

Streamflow (Total Runoff) = Overland Flow + Baseflow + Interflow

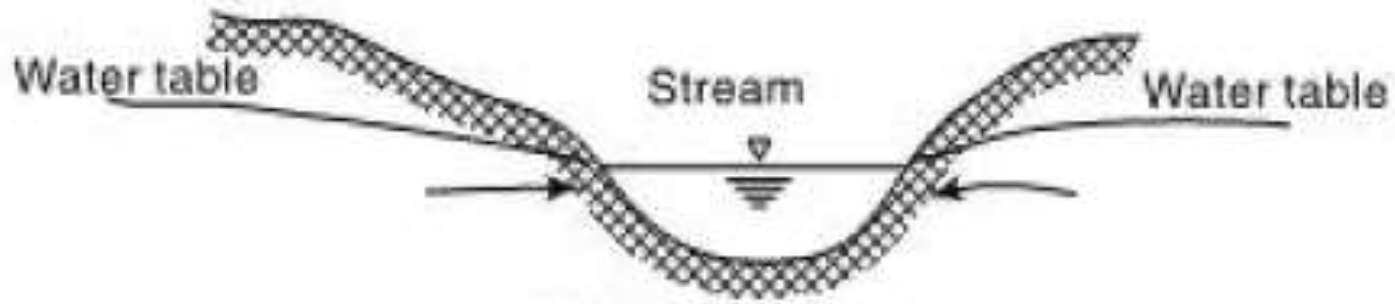
Vadose-Zone Flow = Deep Percolation + Shallow Interflow + Deep Interflow

Groundwater Flow = Baseflow + Other GW Discharge

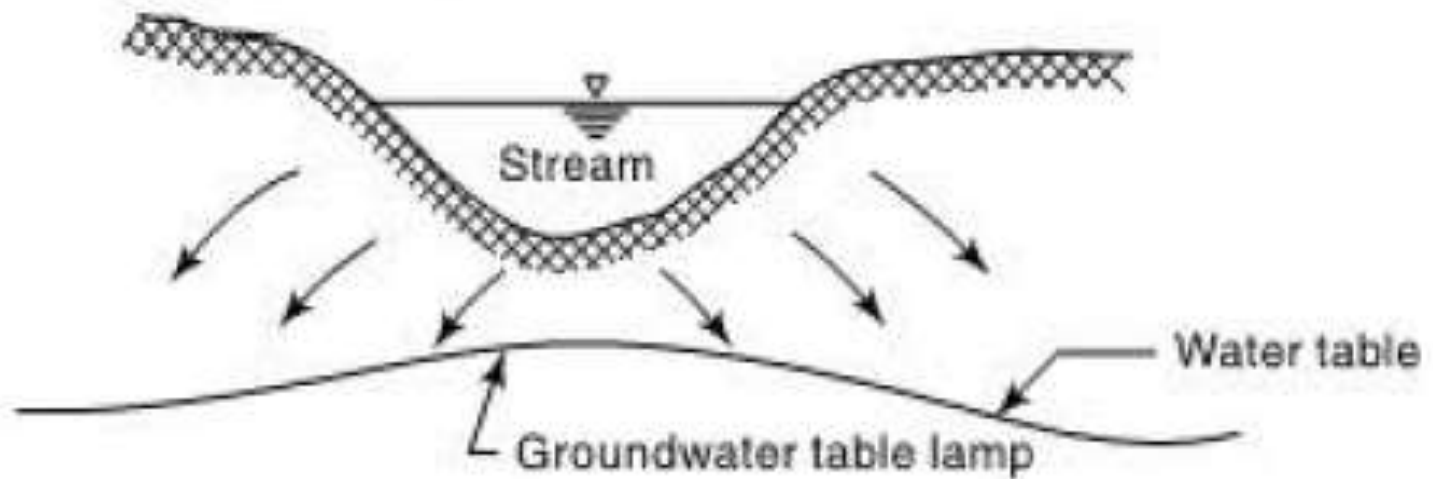
Fig. Surface and subsurface processes occurring at a watershed or basin scale.

Direct Runoff -It is the part of the runoff which enters the stream immediately after the rainfall.

Base flow- The delayed flow that reaches a stream essentially as groundwater flow.



(a) Effluent stream

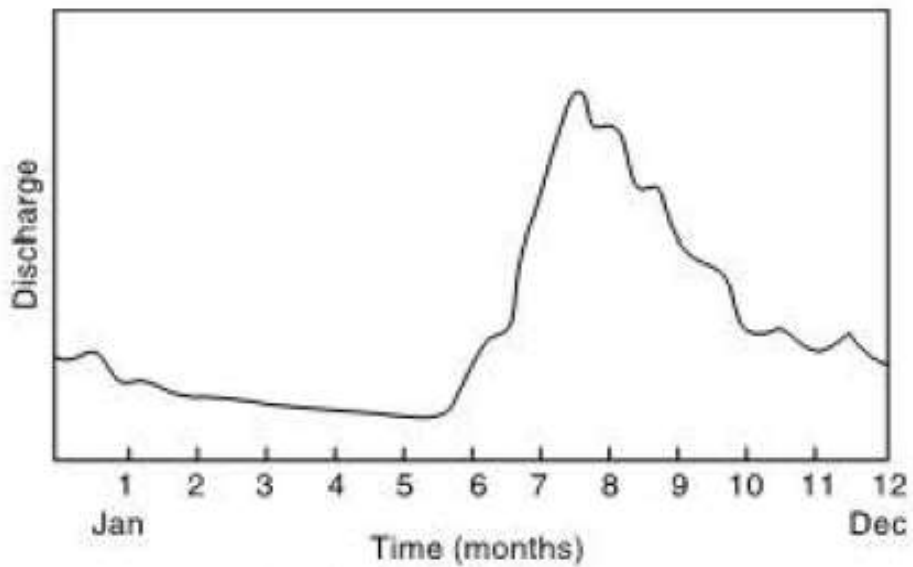


(b) Influent stream

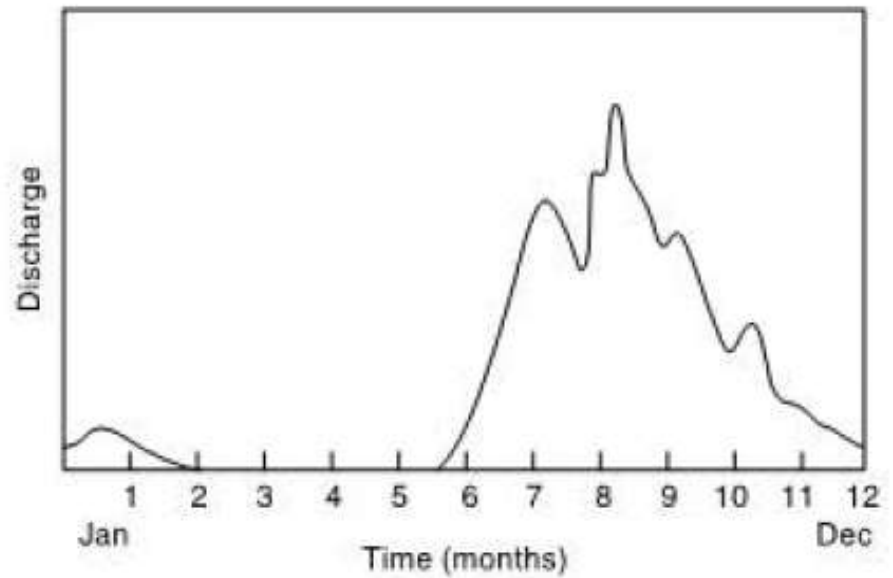
Effluent and Influent Streams

Effluent stream- The streams which receive groundwater flow.

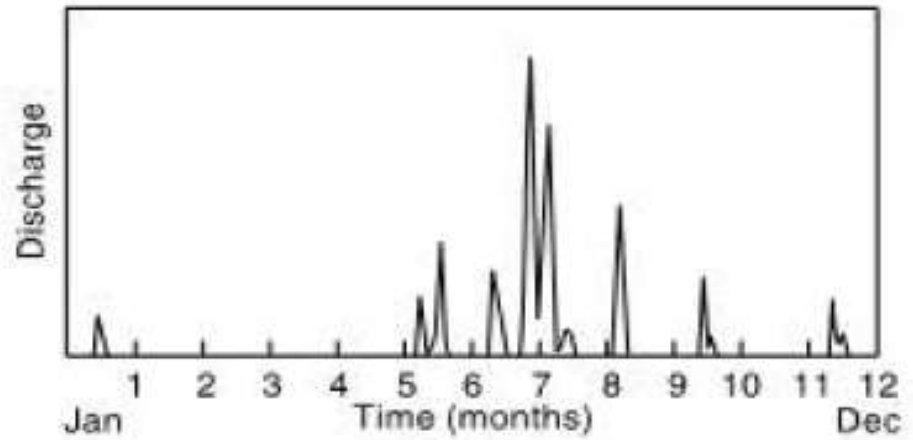
Influent stream- The streams which contribute to the groundwater flow.



Perennial stream



Intermittent stream



Ephemeral stream

Factors Affecting Runoff

The main factors affecting the runoff from a catchment area are:

- a) Precipitation characteristics
(Intensity and Duration)
- b) Shape and size of catchment
- c) Topography
- d) Geologic characteristics
- e) Meteorological characteristics
(Temperature, wind speed, and humidity)
- f) Storage characteristics of a catchment

Principal factors contributing to variability of hydrologic processes are

- Topography
- Soil
- Geology
- Vegetation
- Land use
- Stream network



Runoff volume
Peak discharge
Time to peak runoff
Base flow
Infiltration rate
Evapotranspiration
Interception
Erosion

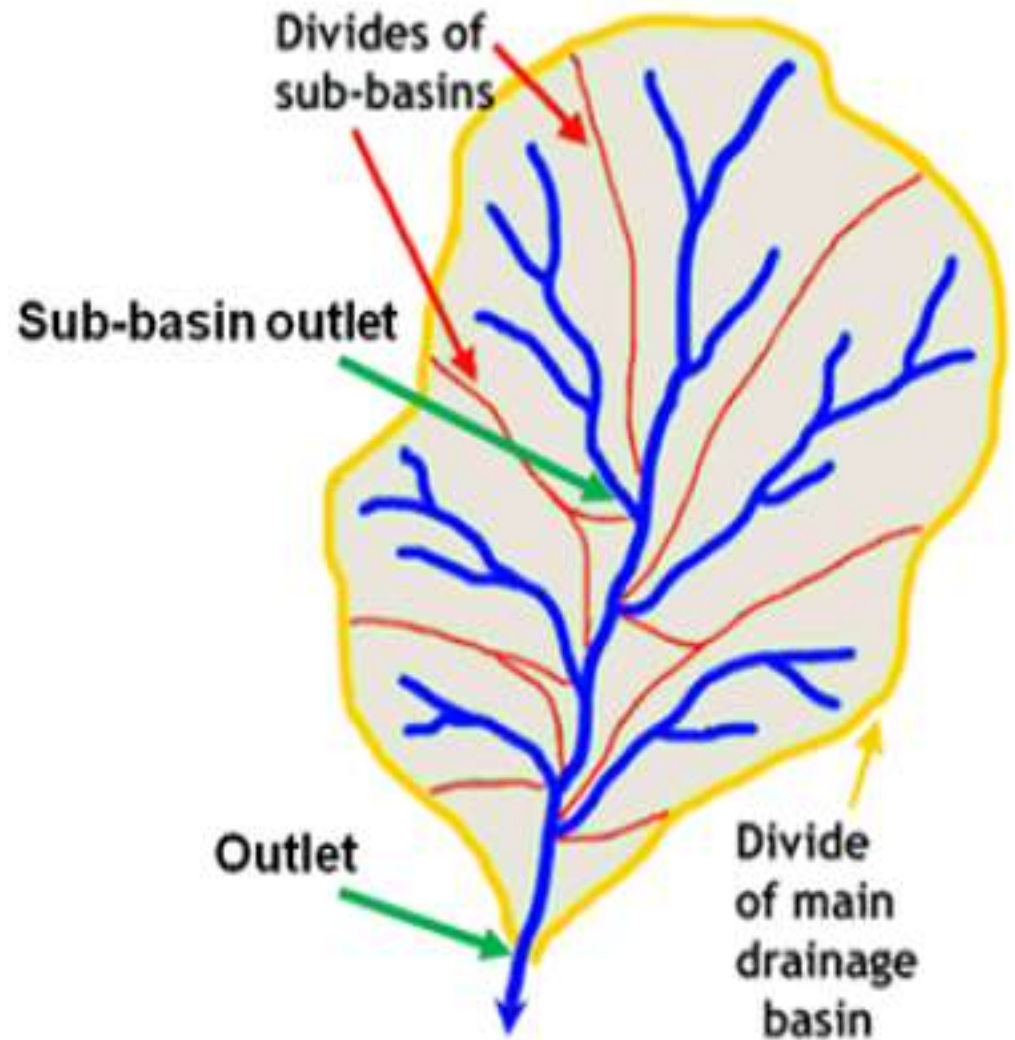
Types of Watersheds

- Size **
- Land use **
- Mean slope
- Length

Mini Watershed: 0.1 ha - 100 ha
Micro Watershed: 100 ha - 1000 ha
Mili Watershed: 1000 ha - 10000 ha
Sub Watershed: 10000 ha - 50000 ha
Watershed: 50000 ha - 2 lakh ha
Catchment : 2 - 10 lakh ha
Basin: 10 - 50 lakh ha

Classification of Watersheds by Size

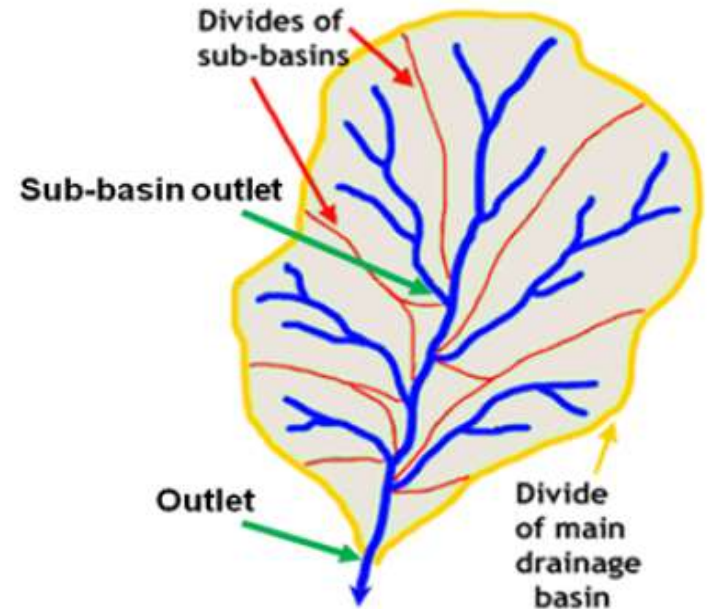
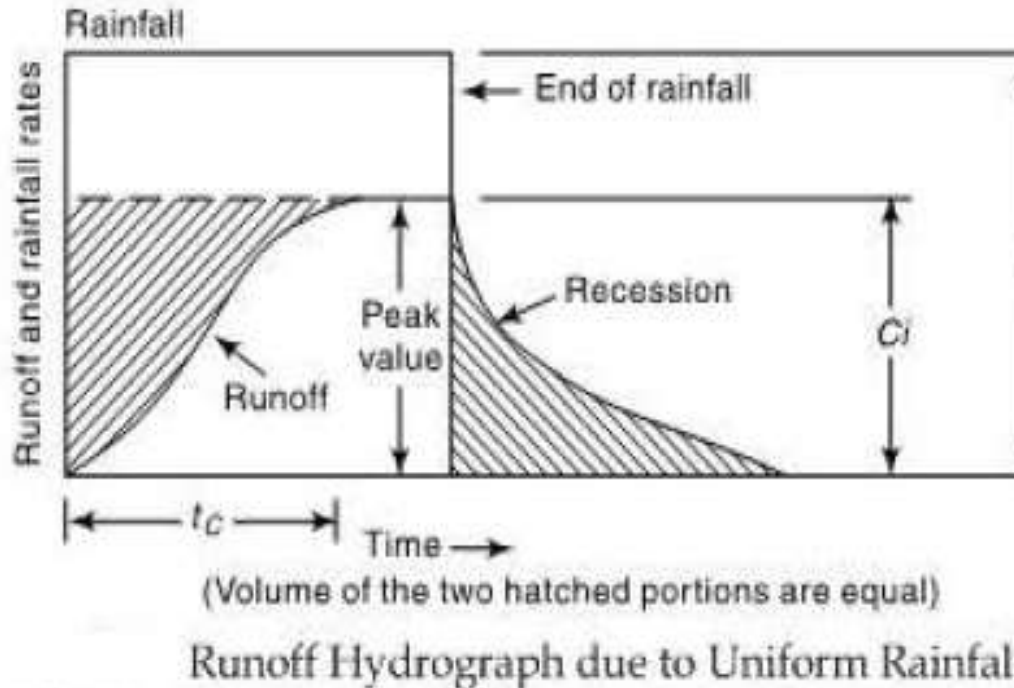
SIZE	AREA (km ²)
Small	<250
Medium	250 to 2500
Large	>2500



Drainage basin with its sub-basins.

Estimation of Peak Runoff Rate

- ✓ Consider a rainfall of uniform intensity and very long duration occurring over a basin/watershed/catchment.



- ✓ The runoff rate gradually increases from zero to a constant value
- ✓ Time taken for a drop of water from the farthest part of the catchment to reach the outlet as $t_c =$ time of concentration, it is obvious that if the rainfall continues beyond t_c , the runoff will be constant and at the peak value.

Peak Runoff Rate (rational method)

$$Q_p = \frac{CIA}{360} \quad \text{for } t \geq t_c$$

Where,

C is coefficient of runoff = (runoff/rainfall),

A is area of the catchment (ha)

I is the mean intensity of rainfall (mm/hr) for a duration equal to t_c .

Time of Concentration(t_c) Kirpich Equation (1940)

$$t_c = 0.01947 L^{0.77} S^{-0.385}$$

Where,

t_c is time of concentration (minutes);

L is maximum length of travel of water(m)

S is slope of the catchment = $\Delta H/L$ (ΔH is difference in elevation between the most remote point on the catchment and the outlet)

Value of the Coefficient C

Types of area	Value of C
A. Urban area ($P = 0.05$ to 0.10)	
Lawns: Sandy-soil, flat, 2%	0.05–0.10
Sandy soil, steep, 7%	0.15–0.20
Heavy soil, average, 2.7%	0.18–0.22
Residential areas:	
Single family areas	0.30–0.50
Multi units, attached	0.60–0.75
Industrial:	
Light	0.50–0.80
Heavy	0.60–0.90
Streets	0.70–0.95
B. Agricultural Area	
Flat: Tight clay;cultivated	0.50
woodland	0.40
Sandy loam;cultivated	0.20
woodland	0.10
Hilly: Tight clay;cultivated	0.70
woodland	0.60
Sandy loam;cultivated	0.40
woodland	0.30

Values of C in Rational Formula for Watersheds with Agricultural and Forest Land Covers

Sl. No	Vegetative cover and Slope (%)	Soil Texture			
		Sandy Loam	Clay and Silty Loam	Stiff Clay	
1	Cultivated Land	0-5	0.30	0.50	0.60
		5-10	0.40	0.60	0.70
		10-30	0.52	0.72	0.82
2	Pasture Land	0-5	0.10	0.30	0.40
		5-10	0.16	0.36	0.55
		10-30	0.22	0.42	0.60
3	Forest Land	0-5	0.10	0.30	0.40
		5-10	0.25	0.35	0.50
		10-30	0.30	0.50	0.60

An urban catchment has an area of 85 ha. The slope of the catchment is 0.006 and the maximum length of travel of water is 950m. The maximum depth of rainfall with a 25 year return period is as below:

Duration (min)	5	10	20	30	40	60
Depth of rainfall (mm)	17	26	40	50	57	62

If a culvert for drainage at the outlet of this area is to be designed for a return period of 25 years, estimate the required peak-flow rate, by assuming the runoff coefficient as 0.3.

If in the urban area of, the land use of the area and the corresponding runoff coefficient are as given below, calculate the equivalent runoff coefficient.

Land Use	Area (ha)	Runoff coefficient
Roads	8	0.7
Lawn	17	0.1
Residential area	50	0.3
Industrial area	10	0.8

Large watersheds

- **Less sensitive** to high-intensity-rainfalls of short duration
- Well-developed channel networks and channel phase, and, thus, channel storage is dominant.

Small watersheds

- Dominant land phase and overland flow.
- Relatively less evident channel phase.
- **Highly sensitive** to high-intensity, short duration rainfalls.

- Two watersheds of the same size may behave very differently if they do not have similar land and channel phases
- Small watersheds are usually **least heterogeneous** and large watersheds are **most heterogeneous** (Spatial variability of watershed characteristics increases with size).
- As the watershed size increases, **storage increases** and **averaging of hydrologic processes increases** as a result. The effect of averaging is to **linearise** the watershed behavior. On the average, small watersheds are more **nonlinear** than large watersheds

Classification of Watersheds by Land Use

- Urban watersheds: urban hydrology
- Agricultural watersheds: agricultural hydrology
- Forest watersheds: forest hydrology
- Mountainous watersheds: mountain hydrology
- Desert watersheds: desert hydrology
- Coastal watersheds: coastal hydrology
- Wetland/marsh watersheds: wetland hydrology

SCS Curve Number Method

- Developed by Soil Conservation Service(SCS) of USA in 1969
- It relies on Curve Number Parameter
- It is based on the water balance equation and two fundamental hypothesis.

- Water Balance Equation

$$P = I_a + F + Q \quad \text{-----}(1)$$

Where P = Precipitation

I_a = Initial abstraction

Q = Direct surface runoff

F = Cumulative Infiltration

- 1st Hypothesis

Ratio of the actual amount of direct surface runoff (Q) to the total maximum potential surface runoff ($P - I_a$) is equal to the ratio of the amount of actual infiltration (F) to the amount of the potential maximum retention (S)

$$Q/P - I_a = F/S \quad \text{-----}(2)$$

SCS Curve Number Method

- 2nd Hypothesis

The amount of initial abstraction is some fraction of the potential maximum retention

$$I_a = \lambda S \text{ -----(3)}$$

Where λ is fraction

Combining equation 1 and 2

$$Q = (P - I_a)^2 / (P - I_a + S) \text{ ----- (4)}$$

Put the value of I_a in equation 4 we get

$$Q = (P - \lambda S)^2 / P + S(1 - \lambda)$$

- S depends upon Soil, Vegetation, Land Use, Antecedent Moisture Content and expressed in terms of CURVE NUMBER .

SCS Curve Number Method

- 2nd Hypothesis

The amount of initial abstraction is some fraction of the potential

$$S = (25400/CN) - 254$$

Here S is expressed in mm

$$CN = 25400 / (S + 254)$$

Range of CN is $100 \geq CN \geq 0$

When CN is 100 then, Potential retention(S) = 0

When CN is 0 then, Potential retention(S) = 100 (Infinity abstraction by Catchment)

- CN depends on-
 - 1) Soil type
 - 2) Land Use Land Cover
 - 3) Antecedent Moisture Condition

SCS Curve Number Method

- Soil type

- Group A : Low runoff Potential means high infiltration rate
 - Example: Deep Sand, Aggregated Silt
- Group B: Moderately low runoff potential means moderate infiltration rate
 - Example: Sandy loam, red sandy loam
- Group C: Moderately high runoff potential means low infiltration rate when thoroughly wetted
 - Example: Clayey loam, Shallow sandy loam
- Group D: High runoff Potential means Soil having very low infiltration rate
 - Example: Deep black clay Soil, Saline soil

SCS Curve Number Method

- Antecedent Moisture Condition
 - AMC 1 : Soil is dry but not to wilting point
 - AMC 2: Avg. condition of soil moisture
 - AMC 3: Sufficient rainfall occurs in past 5 days

Quantitative Characteristics of Watershed

Physical Characteristics

- ✓ Drainage area
- ✓ Basin slope
- ✓ Basin shape
- ✓ Centroid or Centre of gravity of the basin

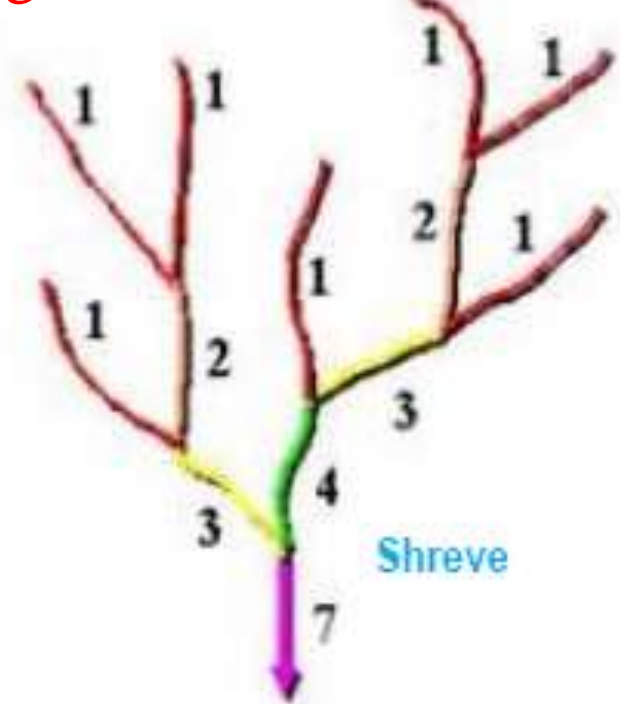
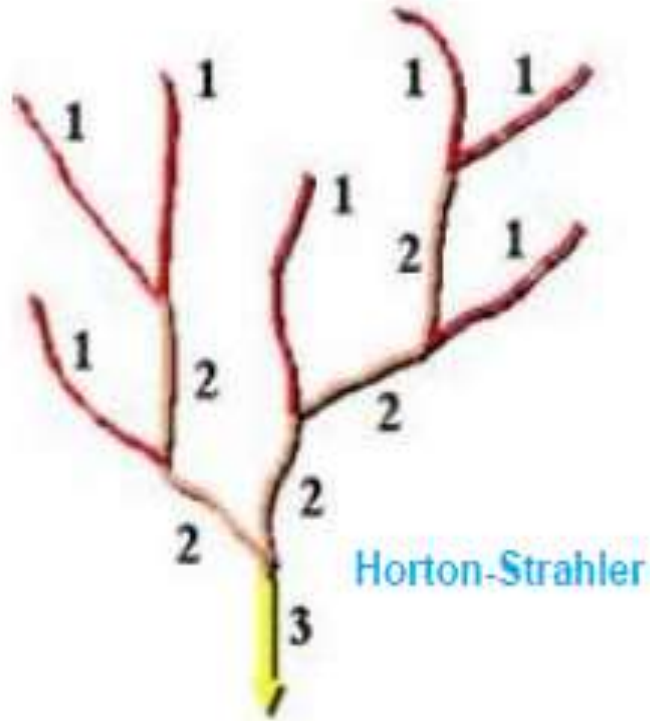
Stream Characteristics

- ✓ Stream order/ channel order
- ✓ Stream frequency
- ✓ Stream length
- ✓ Channel slope
- ✓ Channel profile
- ✓ Drainage density

Stream Ordering System

- ✓ Horton-Strahler's ordering scheme
- ✓ Shreve's ordering scheme

The order of the basin is the order of its highest order stream



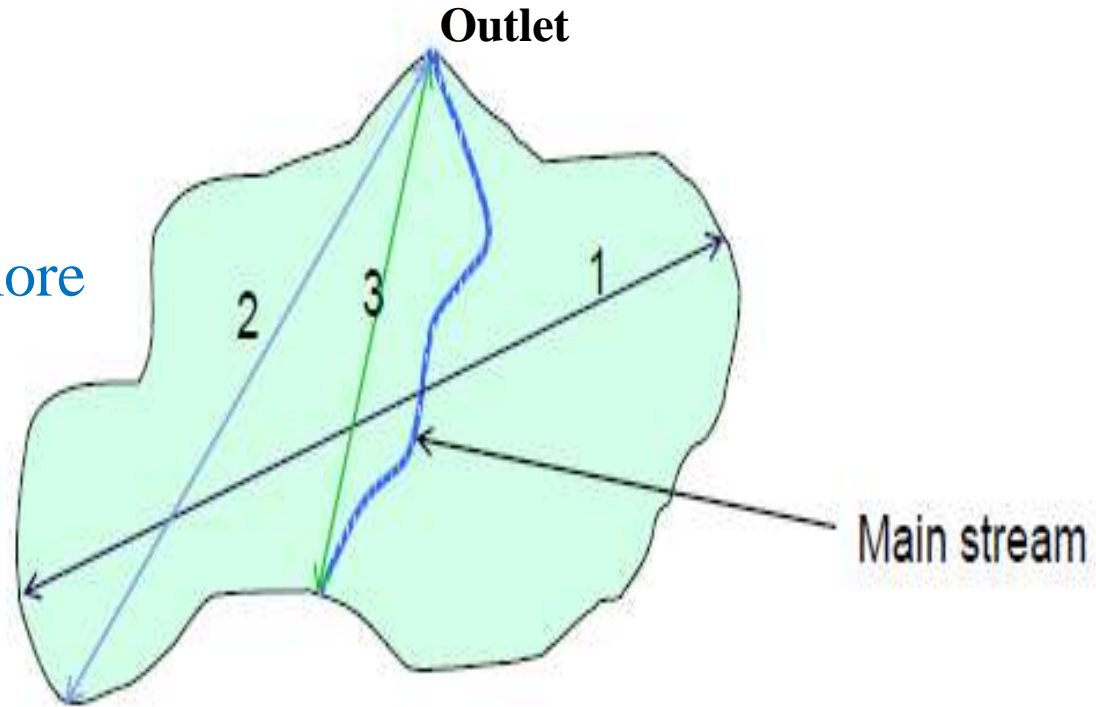
- **First-order** streams are defined as those channels that have no tributaries (Discharge depends fully on overland flow)
- The junction of two first-order streams form a **second-order stream**
- A **third-order channel** is formed by the junction of two second-order channels

Stream frequency

The number of stream channels per unit area is called the stream frequency

Basin Length (L_b)

Basin length is defined in more than one way:



1. The greatest straight-line distance between any two points on the perimeter.
2. The greatest distance between the outlet and any point on the perimeter.
3. The length of the main stream from its source (projected to the perimeter) to the outlet (**most commonly used**).

Drainage Density

- Drainage density (D_d) is defined as the length of stream channel per unit area.

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

L = Total length of all channels of all orders, A = Basin area;

- Drainage basins with **high drainage densities** indicate that a large proportion of the **precipitation runs off**
- On the other hand., **low drainage densities** indicate that **most rainfall infiltrates** the ground

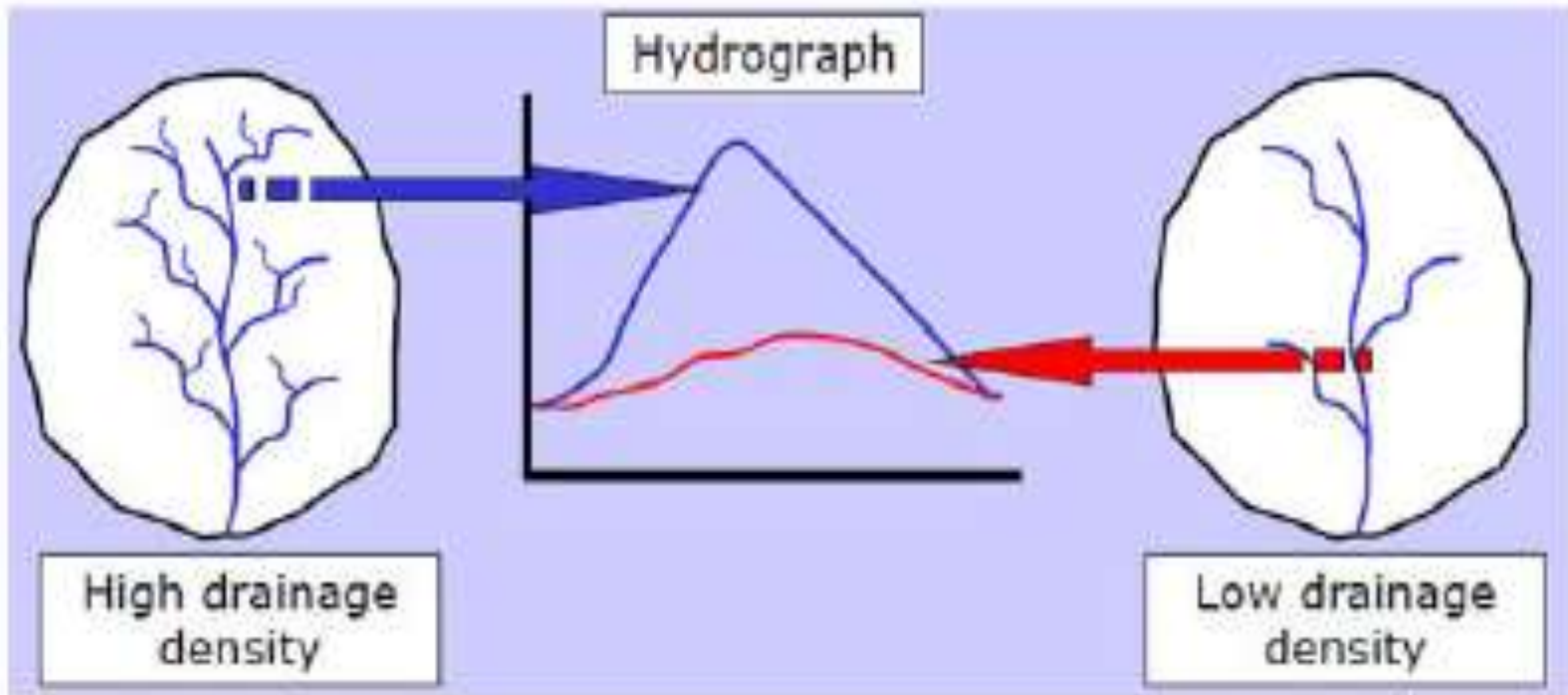
Basin Slope

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

h = fall in meters,

L = horizontal distance (length) over which the fall occurs
(longest path of travel of the stream)

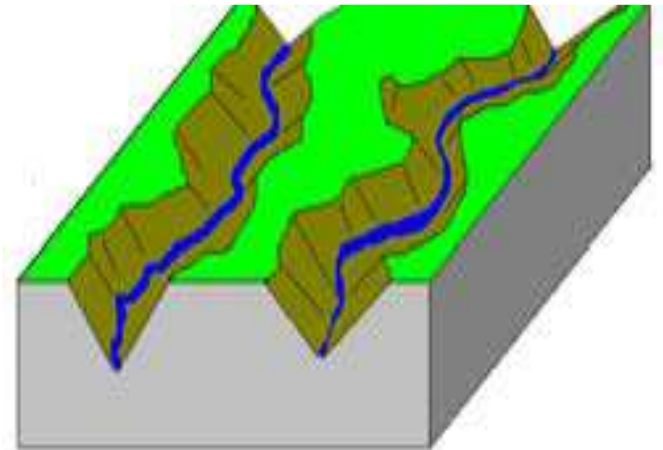
Effect of Drainage Density on Runoff



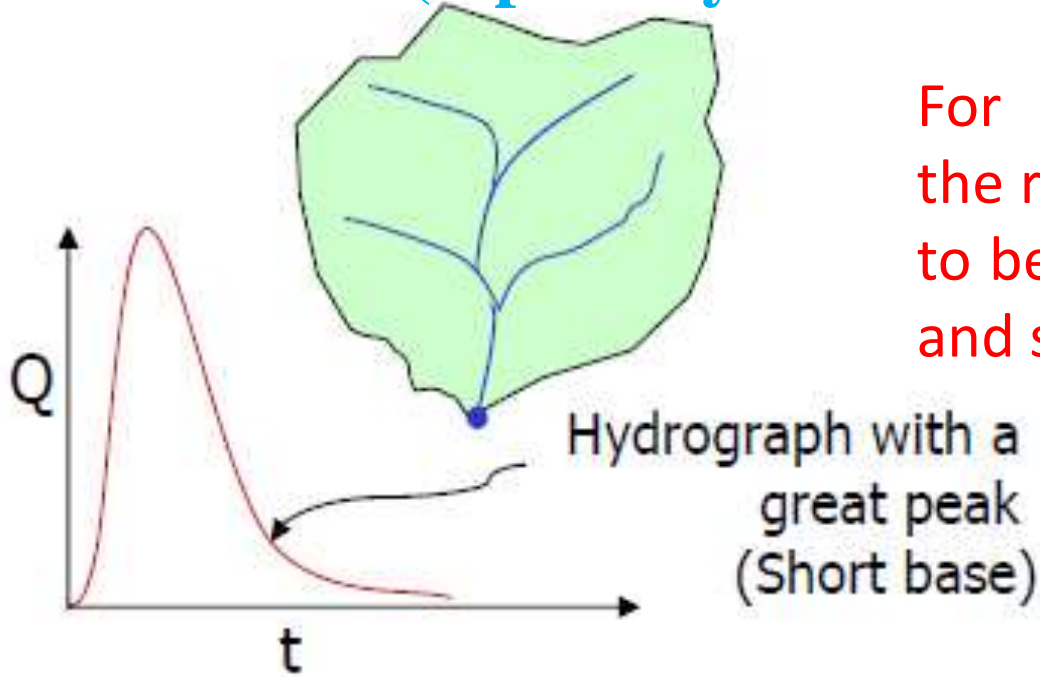
Length of Overland Flow (L_0)

- It is defined as the maximum length of surface flow

$$L_0 = \frac{1}{2(D_d)}$$



Watershed shape influences the hydrograph shape (especially for small watersheds)



For more compact watersheds, the runoff hydrograph is expected to be sharper with a greater peak and shorter duration

If a watershed is long and narrow, then it will take longer for water to travel from watershed extremities to the outlet and the resulting runoff hydrograph will be flatter

