ENGINEERING HYDROLOGY

Learning Objectives

1. Hydrology & Hydrology Cycle
2. Rainfall Measurement
3. Analysis of Rainfall Records
4. Runoff Calculations
5. Abstraction from rainfall
   a) Evaporation
   b) Evapotranspiration
   c) Infiltration

1. Hydrology & Hydrology Cycle

Sources of Water:

Oceans	97.25%
Ice Caps and Glaciers	2.05%
Groundwater	0.68%
Lakes	0.01%
Soil Moisture	0.005%
Atmosphere	0.001%
Streams and Rivers	0.0001%

Definition of Hydrology:

Hydrology is a multidisciplinary subject that deals with the occurrence, circulation and
distribution of the waters of the Earth.

1. Hydrology & Hydrology Cycle

Application of Hydrology:

Hydrology is applied to major civil engineering projects such as

- Irrigation schemes,
- Dams and Hydroelectric Power Projects, and
- Water Supply Projects.

Scope of Hydrology:

The study of hydrology helps us to know

1.the **maximum probable flood** that may occur at a given site and its frequency; this is required for the safe design of drains and culverts, dams and reservoirs, channels and other flood control structures.

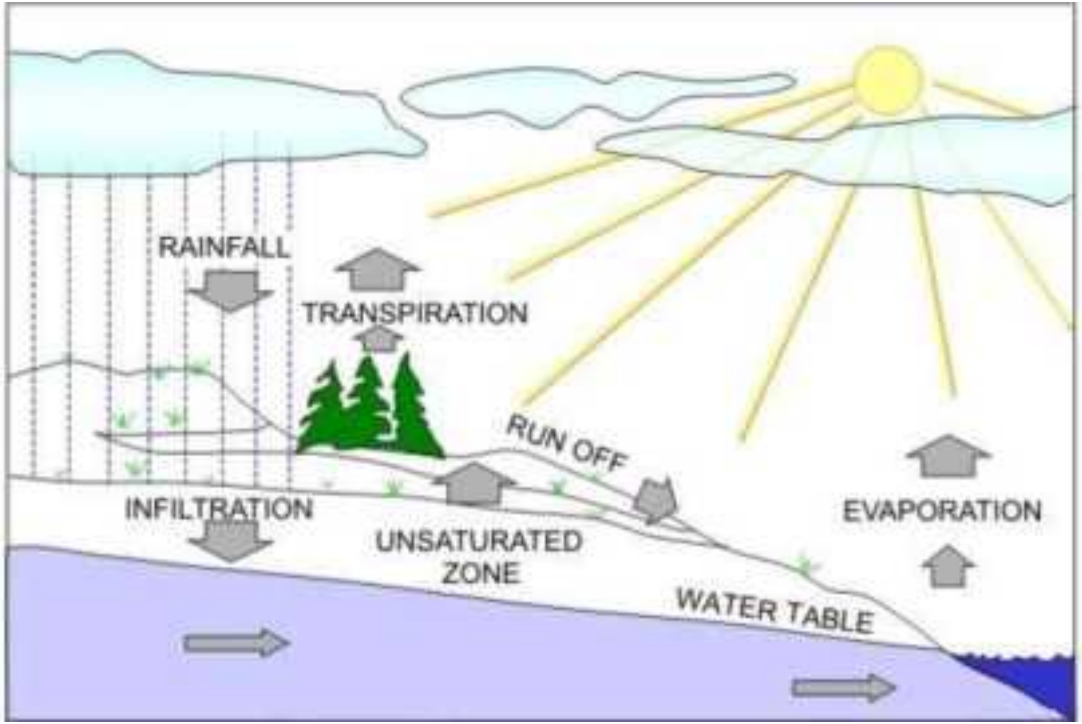
2. the **water yield from a basin** —its occurrence, quantity and frequency, etc; this is necessary for the design of dams, municipal water supply, water power, river navigation, etc.

3.the **ground water development** for which a knowledge of the hydrogeology of the area, i.e., of the formation soil, recharge facilities like streams and reservoirs, rainfall pattern, climate, cropping pattern, etc. are required.

4. the **maximum intensity of storm and its frequency** for the design of a drainage project in the

1. Hydrology & Hydrology Cycle

Hydrologic Cycle:
Journey of water from the ocean to atmosphere and back to the earth and ultimately to the ocean through the processes of evaporation, precipitation, percolation, runoff and return to the ocean is called hydrologic cycle.



1. Hydrology & Hydrology Cycle

Components of the Hydrologic Cycle :

Precipitation: Includes rain, snow and other forms of water falling from the atmosphere into the land & oceans.

Evaporation Physical process by which water is vaporized into the atmosphere from free water surface and land areas.

Transpiration: Water from the soil is absorbed by plant roots and eventually discharged into the atmosphere through little pores in the leaves called stomata.

Evapotranspiration: Combined processes by which water is transferred to the atmosphere from open water surfaces and vegetation.

Infiltration: Movement of water from the land surface to the upper layers of the soil.

Percolation: Movement of water through the subsurface down to the water table.

Overland flow: Portion of runoff that travels over the surface of the ground to reach a stream channel

Surface runoff: Includes all overland flow as well as precipitation falling directly onto stream channels.

1. Hydrology & Hydrology Cycle

Forms of Precipitation:

Drizzle: a light steady rain in fine drops (0.5 mm) and intensity <1 mm/hr

Rain: the condensed water vapour of the atmosphere falling in drops (>0.5 mm, maximum size—6 mm) from the clouds.

Glaze: freezing of drizzle or rain when they come in contact with cold objects.

Sleet: frozen rain drops while falling through air at subfreezing temperature.

Snow: ice crystals resulting from sublimation (i.e., water vapour condenses to ice)

Hail: small lumps of ice (>5 mm in diameter) formed by alternate freezing and melting, when they are carried up and down in highly turbulent air currents.

Dew: moisture condensed from the atmosphere in small drops upon cool surfaces.

Frost: a feathery deposit of ice formed on the ground or on the surface of exposed objects by dew

Fog: a thin cloud of varying size formed at the surface of the earth by condensation of atmospheric vapour

Mist: a very thin fog

1. Hydrology & Hydrology Cycle

Types of Precipitation

1. Convectional Precipitation

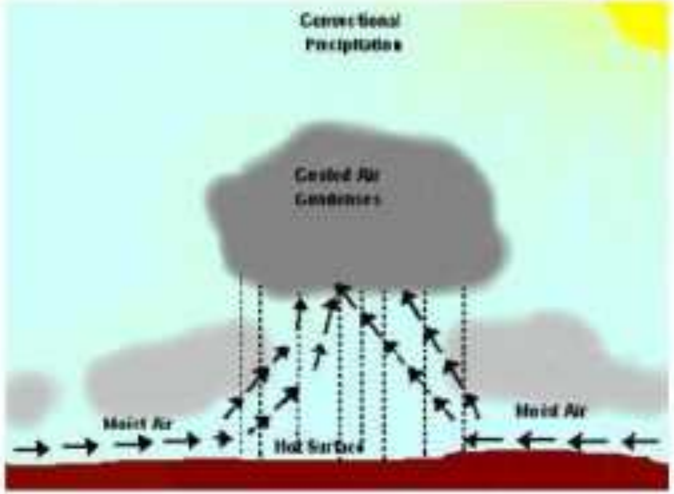
It results from the heating of the earth's surface. Due to this, the warm air rises rapidly into the atmosphere. As the air rises, it cools. Water vapour in the air condenses into clouds and precipitation.

2. Orographic Precipitation:

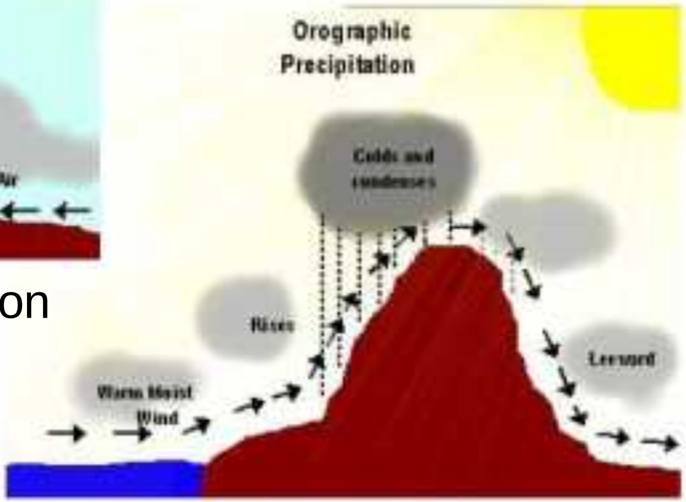
It results when warm moist air moving across the ocean is forced to rise by large mountains. As the air rises, it cools. As air cools, the water vapour in the air condenses and water droplets form. Precipitation occurs on the windward side of the mountain. The air is now dry and rises over top the mountain. As the air moves back down the mountain, it collects moisture from the ground via evaporation.

3. Cyclonic

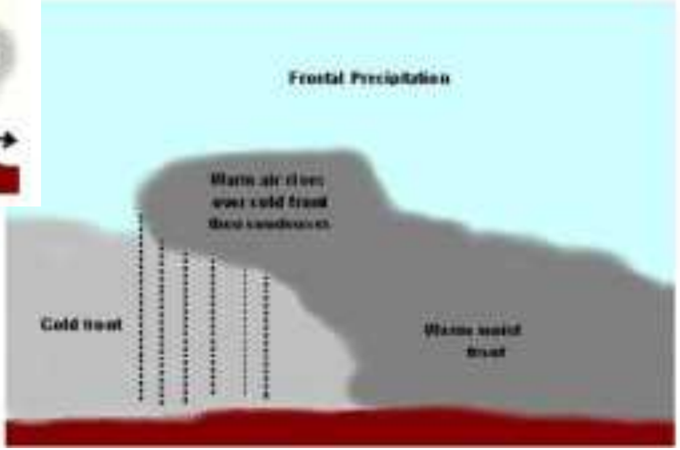
Cyclonic or Frontal precipitation results when the leading edge of a warm, moist air mass



Convectional Precipitation



Orographic Precipitation



Frontal Precipitation

2. Rainfall Measurement

Storm (Heavy Rain) Characteristics:

The characteristics of a storm, namely depth, duration, intensity and distribution, affect the
watershed response to the rainfall event.

- ❖ **Depth** – Amount of precipitation that falls (usually in or cm).
- ❖ **Duration** – Length of a storm (usually min, hr or day)
- ❖ **Intensity** – Depth of rainfall per unit time (usually in/hr or cm/hr). Rainfall intensity Changes continuously throughout a storm, but it may be averaged over short time intervals or over the entire storm duration.
- ❖ **Distribution** – Describes how rainfall depth or intensity varies in space over an area or watershed

2. Rainfall Measurement

Measurement of rainfall and optimum number of rain gauges:

The basic instrument for rainfall measurement is rain gauge, which samples the incidence of rainfall at a specific point, through an orifice of known area.

Types of Rain Gauges:

1. Non-Recording Rain Gauge

The non-recording rain gauge used in India is the Symon's rain gauge. The rainfall is measured every day at 08.30 hours IST. During heavy rains, it must be measured three or four times in the day, lest the receiver fill and overflow, but the last measurement should be at 08.30 hours IST.

2. Recording Rain Gauge

a) Tipping Bucket Rain Gauge
b) Weighing Type Rain Gauge
c) Floating Type Rain Gauge

This type of gauge is used by Indian Meteorological Department (IMD).

2. Rainfall Measurement

Optimum number of rain gauges:

Statistics has been used in determining the optimum number of rain gauges required to be installed in a given catchment. The basis behind such statistical calculations is that a certain number of rain gauge stations are necessary to give average rainfall with a certain percentage of error. If the allowable error is more, lesser number of gauges would be required. The optimum number of rain gauges (N) can be obtained using:

$$N = \left[\frac{C_v}{E} \right]^2$$

Where,

Cv = Coefficient of variation of rainfall based on the existing rain gauge stations;

= Mean / Standard Deviation of rainfall

E = Allowable percentage error in the estimate of basic mean rainfall

3. Analysis of Rainfall Records

Estimating missing rainfall data:

Due to the absence of observer or instrumental failure rainfall data record occasionally are incomplete. In such a case one can estimate the missing data by using the nearest station rainfall data. If for example rainfall data at day 1 is missed from station X having mean annual rainfall of Nx and there are three surrounding stations with mean annual rainfall of N1, N2, and N3 then the missing data Px can be estimated.

1. Arithmetic Mean Method:

If N1, N2, and N3 differ within 10% of Nx, **Px = (P1 +P2 +P3)/3**

2. Normal Ratio Method:

If N1, N2, or N3 differ by more than 10% of Nx

$$P_x = \frac{1}{3}\left(P_1\frac{N_x}{N_1} + P_2\frac{N_x}{N_2} + P_3\frac{N_x}{N_3}\right)$$

3. Reciprocal Inverse Weighing Factor

$$P_x = \sum 1/Xn\,[\sum Pn/Xn]$$

Where Xn = Distance between the missing data gauge and the other gauges surrounding the missed gauge.

3. Analysis of Rainfall Records

Estimation of average depth of rainfall over a catchment:

1. Arithmetic Mean Method

The central assumption in the arithmetic mean method is that each rain gauge has equal weightage and thus the mean depth over a watershed is estimated by:

$$\overline{P} = \frac{P_1 + P_2 + \dots + P_i + \dots P_n}{N} = \frac{1}{N}\sum_{i=1}^{N} P_i$$

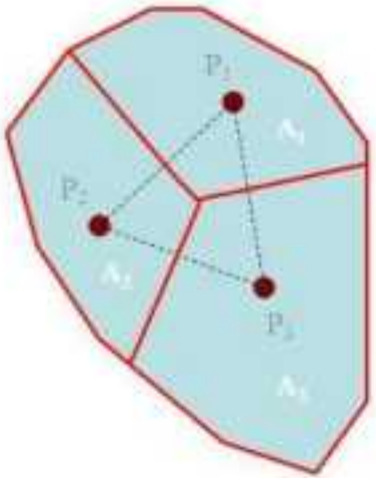
It is a simple method, and well applicable if the gages are uniformly distributed over the watershed and individual gage measurements do not vary greatly about their mean.

3. Analysis of Rainfall Records

2. Thiessen Polygon Method

- Any point in the watershed receives the same amount of rainfall as that at the nearest gage
- Rainfall recorded at a gage can be applied to any point at a distance halfway to the next station in any direction
- Steps in Thiessen polygon method
  1. Draw lines joining adjacent gages
  2. Draw perpendicular bisectors to the lines created in step 1
  3. Extend the lines created in step 2 in both directions to form representative areas for gages
  4. Compute representative area for each gage
  5. Compute the areal average using the following

$$\bar{P} = \frac{1}{A}\sum_{i=1}^{N} A_i P_i \qquad \bar{P} = \frac{12\times10+15\times20+20\times30}{47} = 20.7\ mm$$



$P_1 = 10$ mm, $A_1 = 12$ Km^2

$P_2 = 20$ mm, $A_2 = 15$ Km^2

$P_3 = 30$ mm, $A_3 = 20$ km^2

Disadvantage:

The disadvantages of the Thiessen method are its inflexibility that is addition of new station implies construction of new polygon, and it does not directly account for orographic influences of rainfall.

3. Analysis of Rainfall Records

3. Isoyhyets Method

- Isohyets are contours (or lines) linking points of equal rainfall (or precipitation rates)

- considered as one of the most accurate methods, although subjective and depends on skill and a good knowledge of catchment's rainfall characteristics

- isohyets are drawn at chosen intervals across the catchment by interpolating between the gauge measurements taking into account the topography

$$\overline{P}=\frac{1}{A}\sum_{j=1}^{J}A_j P_j, \quad A=\sum_{j=1}^{J}A_j$$

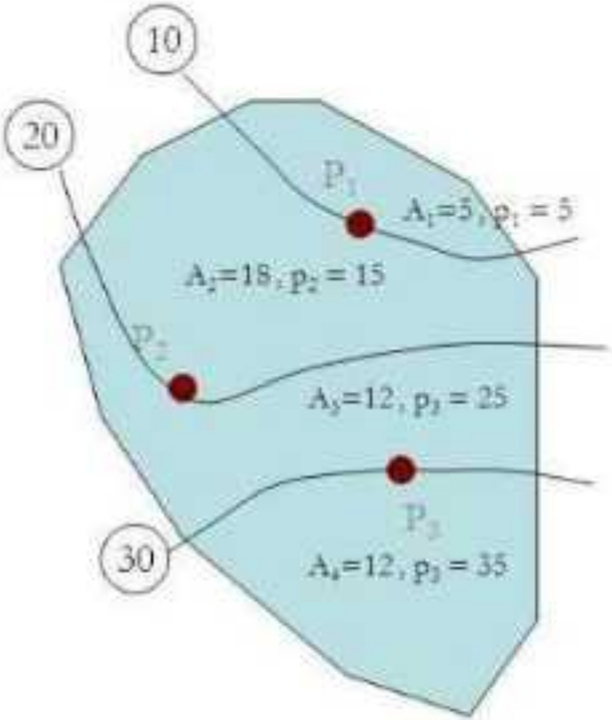
Advantage:

The method is good where there is a dense network of rain gauges. It is also flexible and considers orographic effect

- Steps
  - Construct isohyets (rainfall contours)
  - Compute area between each pair of adjacent isohyets (A_i)
  - Compute average precipitation for each pair of adjacent isohyets (p_i)
  - Compute areal average using the following formula

$$\bar{P} = \frac{1}{A}\sum_{i=1}^{N} A_i P_i$$

$$\bar{P} = \frac{5\times 5 + 18\times 15 + 12\times 25 + 12\times 35}{47} = 21.6\ mm$$



3. Analysis of Rainfall Records

Double Mass Curve:

It is used to detect if data at a site have been subjected to a significant change in magnitude due to external factors such as problems with instrumentation, observation practices, or recording conditions.

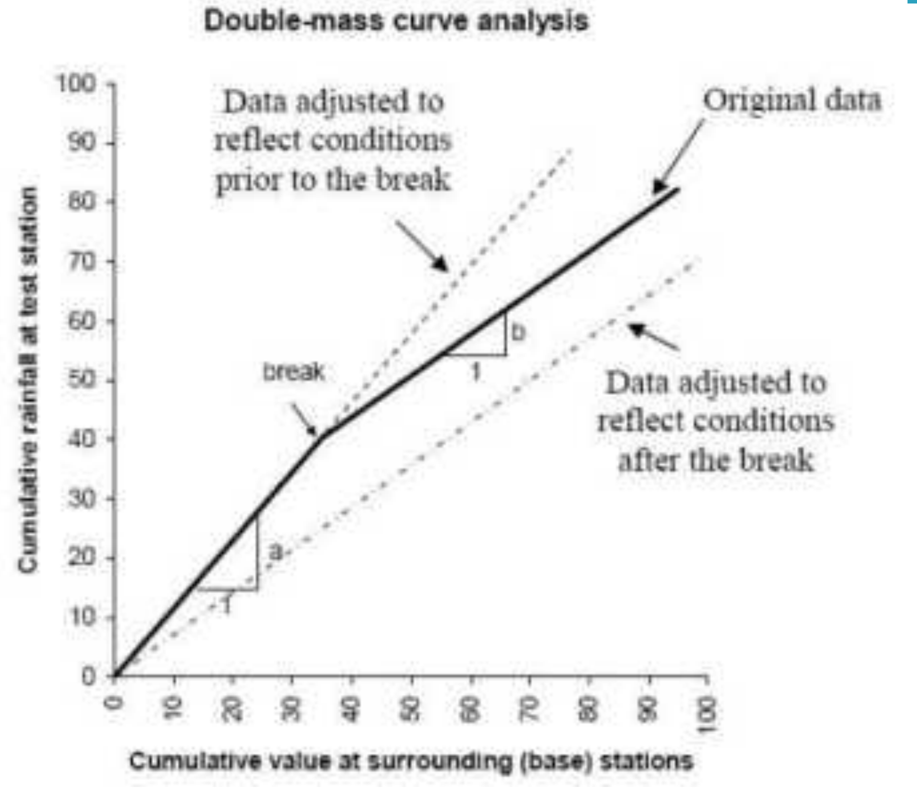
It consists of plotting cumulative rainfall values at a test station against the cumulative mean rainfall values at surrounding (base) stations. If the data are consistent, the double-mass curve will be a straight line of constant slope. If the data is not consistent, a break in the double-mass curve will be apparent.

The ratio of the slopes prior 'a' and after the break 'b' can be used to adjust the data in two ways:

1.The data can be adjusted to reflect conditions prior to the break. This is done by multiplying each precipitation value after the break by the ratio a/b.

OR

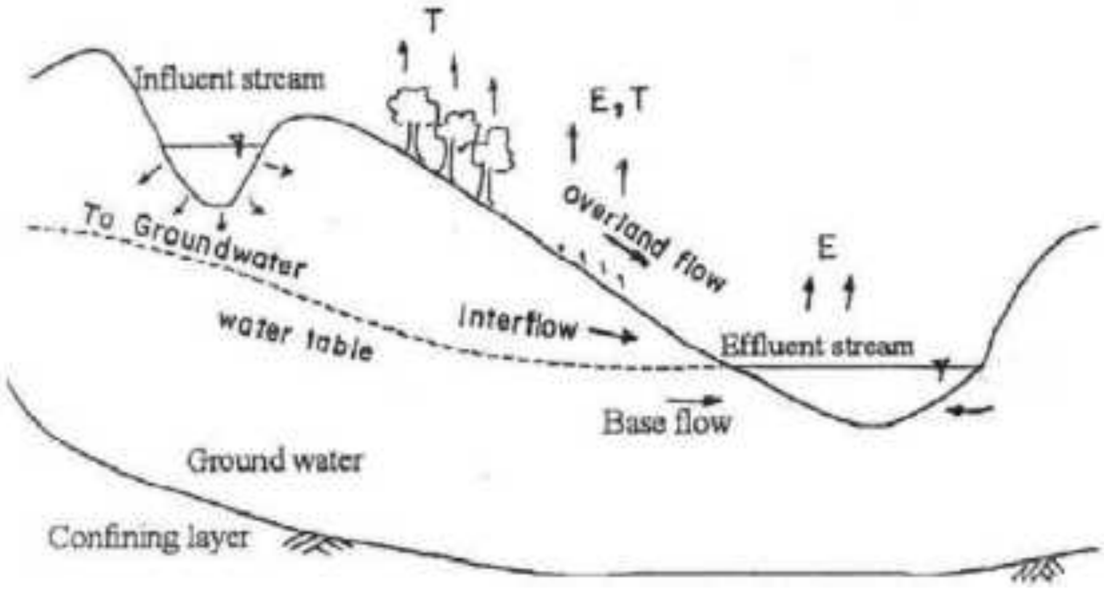
2.The data can be adjusted to reflect recent conditions after the break. This is done by multiplying each precipitation value prior



4. Runoff Calculations

Runoff:

Runoff is defined as the portion of precipitation that makes its way towards rivers or oceans as surface or subsurface flow

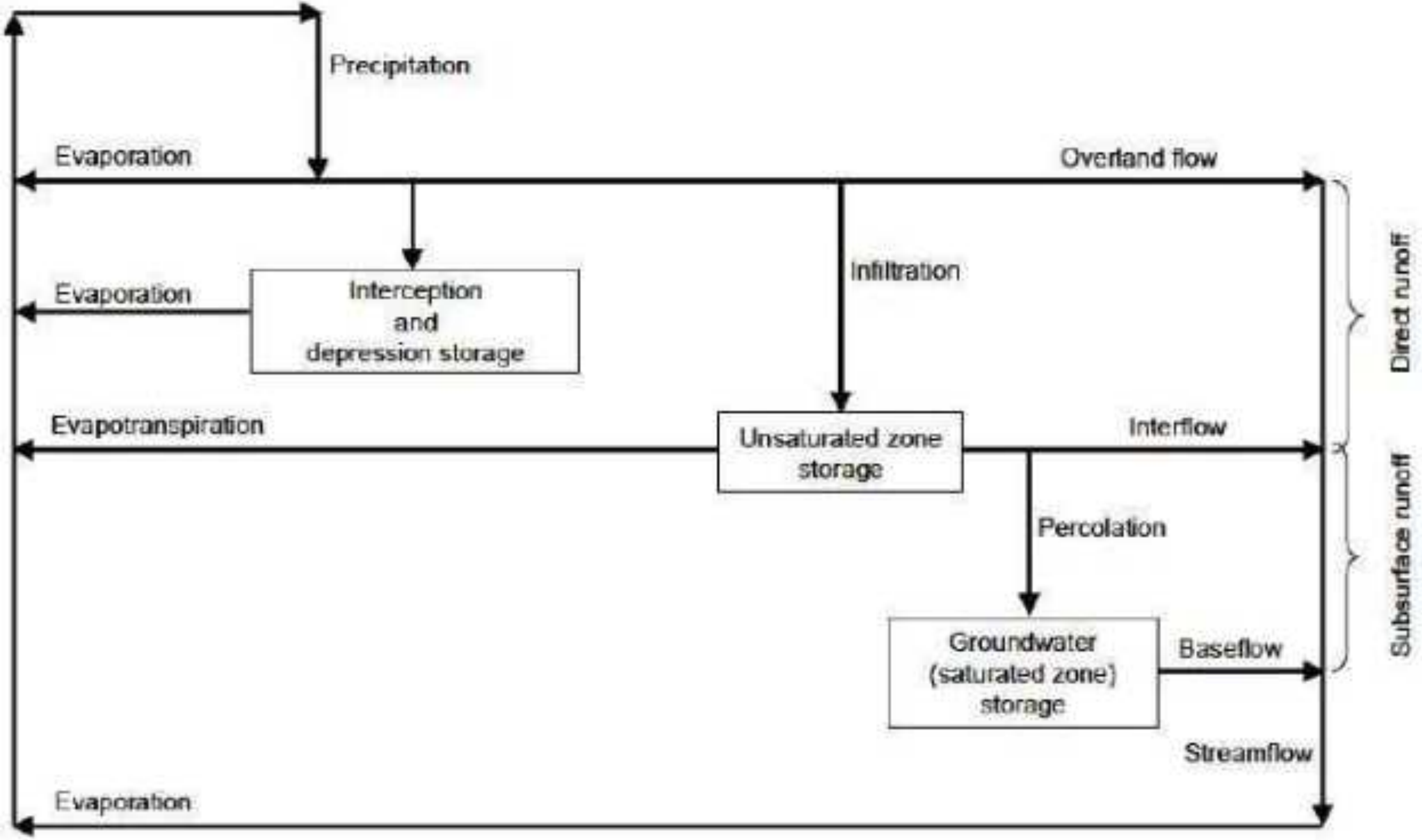


4. Runoff Calculations

Classification of runoff according to source:

1. **Surface runoff:** Includes all overland flow as well as precipitation falling directly onto stream channels.
   Overland flow: Portion of runoff that travels over the surface of the ground to reach a stream channel and through the channel to the basin outlet. This process occurs relatively quickly.

2. **Subsurface runoff:** Portion of runoff that travels under the ground to reach a stream channel and to the basin outlet. It includes: a) interflow, and b) groundwater runoff.
   Interflow: Portion of subsurface runoff that travels laterally through the unsaturated zone or through a shallow perched saturated zone towards a stream channel. This process is slower than surface runoff.
   Groundwater runoff: Portion of subsurface runoff that comes from infiltration and subsequently percolation down to the water table and eventually reaches a stream channel. This process occurs relatively slowly


Precipitation
Evaporation
Overland flow
Evaporation
Interception
and
depression storage
Infiltration
Direct runoff
Evapotranspiration
Unsaturated zone
storage
Interflow
Percolation
Subsurface runoff
Groundwater
(saturated zone)
storage
Baseflow
Streamflow
Evaporation

4. Runoff Calculations

Factors affecting Runoff:

1. Climate factors

a) Type of precipitation
b) Intensity of rainfall
c) Duration of rainfall
d) Area distribution of rainfall
e) Antecedent or Previous precipitation
f) Other climatic factors that effect evaporation and transpiration

2. Physiographic factors

a) Land use
b) Type of Soil
c) Area of the basin or catchment
d) Shape of the basin
e) Elevation
f) Slope
g) Orientation or Aspect
h) Type of drainage network
i) Indirect drainage
j) Artificial drainage

4. Runoff Calculations

Estimation of Runoff:

1. Empirical Formulae (to find peak runoff)
   a) Dicken’s formula
   b) Ryve’s formula
   c) Igles’s formula
   d) Khosla’s formula
2. Rational Method
3. Unit Hydrograph Method

4. Runoff Calculations

Dicken's Formula:

This formula was developed in the year 1865. It states that

$$Q_p = C_d A^{3/4}$$

Where,

Q_p = peak discharge rate (m^3/s)

C_d = a constant (Dickens'), ranging from 6 to 30

A = Drainage basin area (km^2).

For Indian conditions, suggested values for C_d are given as below:

Region	Topography	C_d
Northern states	Plains	6
	Hills	11-14
Central states	-	14.28
Coastal area	-	22.28.

4. Runoff Calculations

Ryve's Formula:

Ryve's formula was reported in the year 1884. It states that

$$Q_p = C_r A^{2/3}$$

Where,

Q_p = Peak discharge rate (m^3/s).

A = Drainage basin area (km^2).

C_r = A constant (Ryves), as shown below:

Region	C_r
Within 80 km from east coast	6.8
80-160 km from east coast	8.5
Hills	10.2

4. Runoff Calculations

Igles's Formula:

This formula was developed in areas of old Bombay state. It states that

$$Qp = \frac{123\,A}{\sqrt{A + 10.4}}$$

Where,

Q_p = Peak discharge in Cumecs (m^3/s).

A = Area of the catchment in sq km (km^2).

Khosla's Formula:

In this method, the amount of mean annual runoff is calculated by following formula:

$$R = P - (T / 3.74)$$

Where:

R = mean annual runoff of watershed by cm,

P = mean annual precipitation by cm, and

T = mean annual temperature by °C.

4. Runoff Calculations

Rational Formula:

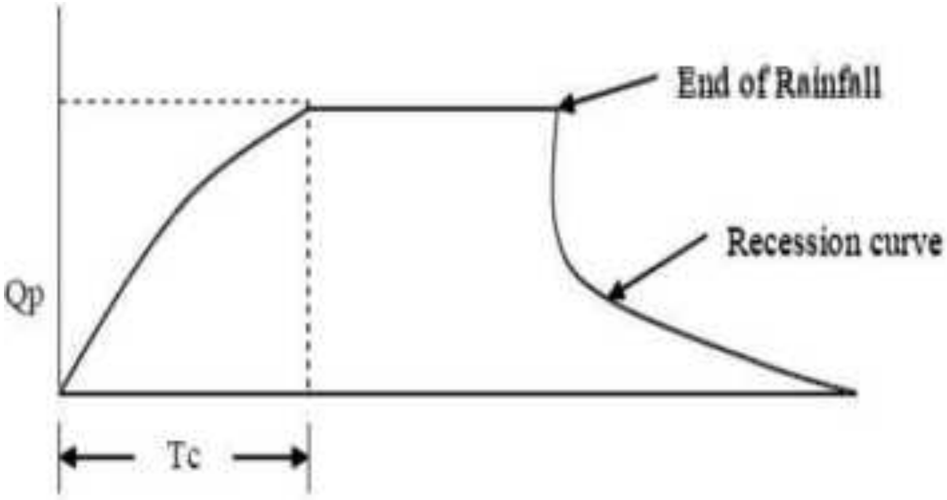
This method was originally developed for urban catchments. Thus, the basic assumptions for development of this method were made for urban catchments. However, this method is fairly applicable to small agricultural watersheds of 40 to 80 hectares size. The rational method takes into account the following hydrological characteristics or processes: (1) rainfall intensity, (2) rainfall duration, (3) rainfall frequency, (4) watershed area, (5) hydrologic abstraction, and (6) runoff concentration.

Assumptions:

The Rational method is based on the assumption that constant intensity of rainfall is uniformly spread over an area, and the **effective rain falling on the most remote part of the basin takes a certain period of time, known as the time of concentration (Tc)** to arrive at the basin outlet. If the input rate of excess rainfall on the basin continues for the period of time of concentration, then the part of the excess rain that fell in the most remote part of the basin will just begin its outflow at the basin outlet and with it, the runoff will reach its ultimate and the

4. Runoff Calculations

Consider a drainage basin, which has rainfall
of uniform intensity and of longer duration. On plotting the relationship between the cumulative runoff rate Q and time, the rate of runoff hows a gradual increase from zero to a constant value. The runoff increases with increase in flow from remote areas of the basin to its outlet. If the rainfall continues beyond the time of concentration, then there is no further increase in the runoff, and it remains constant at its peak value.



Runoff Hydrograph Due to Uniform Rainfall

4. Runoff Calculations

Peak runoff **Qp = 0.278 C I A**

where
Qp = Peak discharge in m³/s
C = coefficient of runoff
A = area of the catchment in Km^2
I = mean intensity of precipitation (mm/h)
= **Max. rainfall depth / Tc**

$$Tc = 0.01947\ L^{0.77} S^{-0.385}$$

Tc = Time of concentration (min)
L = maximum length of travel of water (m)

Runoff Coefficient Factor (C) for Different Soil Conditions in India:

Type of Vegetation	Slope Range (%)	Runoff Coefficient (C) in		
		Sandy Loam Soil	Loam / Loam Clay Soil	Stiff Clay Soil
Woodland and forests	0-5	0.1	0.3	0.4
	5-10	0.25	0.35	0.5
	10-30	0.3	0.5	0.6
Grassland	0-5	0.1	0.3	0.4
	5-10	0.16	0.36	0.55
	10-30	0.22	0.42	0.6
Agricultural land	0-5	0.3	0.5	0.6
	5-10	0.4	0.6	0.7
	10-30	0.52	0.72	0.82

5. Abstraction from rainfall

Abstraction:
The maximum amount of rainfall absorbed without producing runoff.

When there is precipitation, it may or may not result in overland flow into a stream depending upon its intensity and duration. The part of precipitation that is not available as surface runoff is referred to as precipitation loss or abstraction.

The hydrologic equation states that

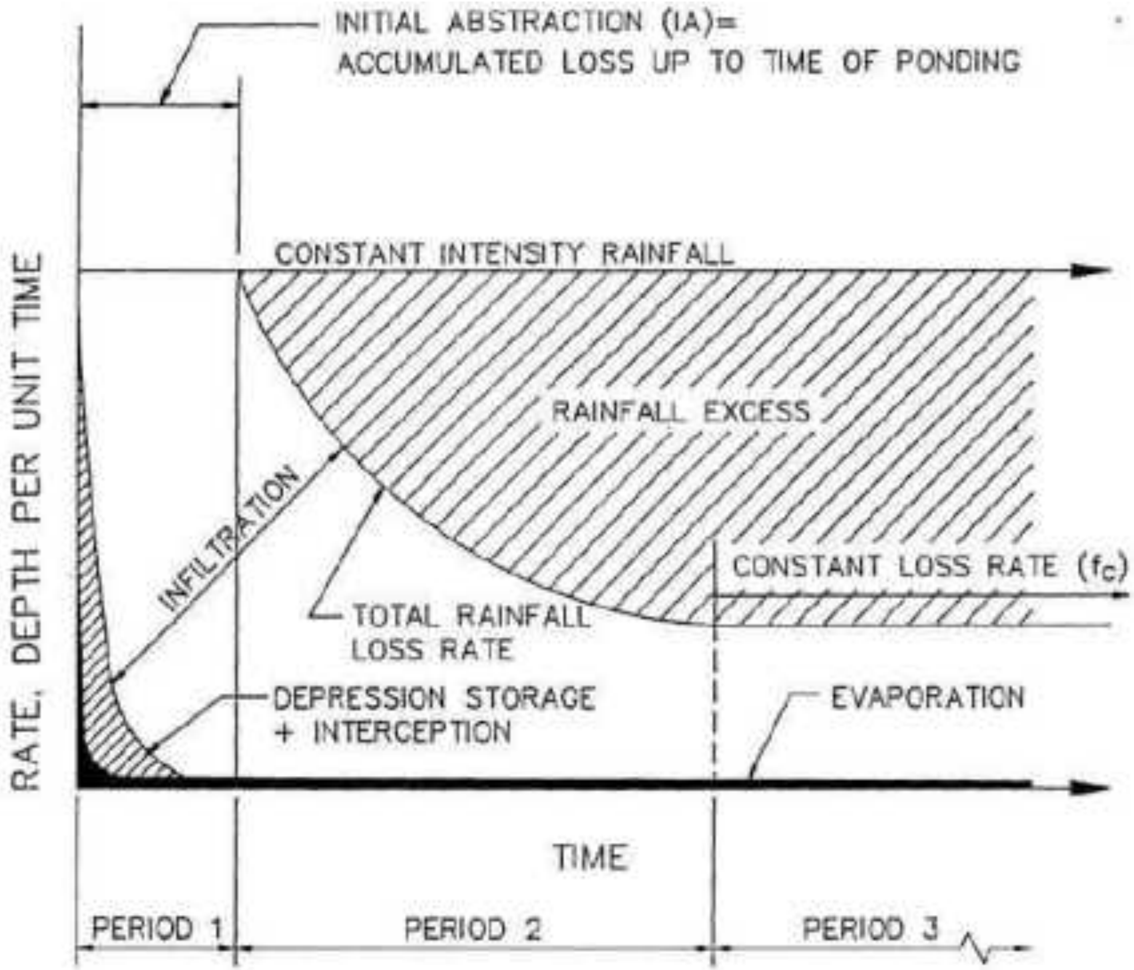
Rainfall – Losses = Runoff

5. Abstraction from rainfall

Hydrologic Abstractions:

1. **Interception:** loss due to surface vegetation and buildings. Interception loss is high in the beginning of storms and gradually decreases.
2. **Evaporation (**a) from water surface, i.e., reservoirs, lakes, ponds, river channels, etc. (b) from soil surface, appreciably when the ground water table is very near the soil surface.
3. **Transpiration** from plant leaves. Transpiration is the transfer of soil moisture from the soil to the atmosphere by the action of vegetation. Plants transpire water vapor through their foliage.
4. **Evapotranspiration -** Combined processes by which water is transferred to the atmosphere from open water surfaces and vegetation.
5. **Infiltration** takes place as part of the rain percolates through the soil. Infiltration usually is the largest abstraction and therefore has the most significant effect on runoff. Infiltration rates generally decrease with time as the rainfall proceeds and the soil becomes saturated.
6. **Surface Detention** - Water temporarily detained on the surface. Controlling factors are surface micro-relief, vegetation, surface slope, topography, rainfall excess.
7. **Surface Retention** - Water retained on the ground surface in micro depressions. This water will either evaporate or infiltrate into the soil. Nature of depressions as well as their size is largely a function of the original land form and local land use practices and erosion pattern.

Hydrologic Abstractions



5. Abstraction from rainfall

Factors affecting Evaporation:

- **Temperature** - Warmer the evaporating surface, higher the rate of evaporation.
- **Relative Humidity** - drier air evaporates more water than moist air
- **Wind Speed -** When the winds are light, evaporation is very low

Area of the Evaporating Surface – Larger areas of evaporating surface increase the rate of evaporation

Air Pressure - Lower pressure on open surface of the liquid results in the higher rate of
evaporation.

Composition of Water - Rate of evaporation is always greater over fresh water than over salt water

5. Abstraction from rainfall

Methods of measurement of evaporation:

A) Direct methods

- Water Budget Technique
- Lysimeter
  - Weighing Type
  - Non-weighing Type

B) Indirect methods

- Aerodynamic method or Mass Transfer Method
- Energy Budget Method
- **Penman Equation**
- **Blaney & Criddle Method**
- Jensen Haise method
- Hargreaves method or Pan Evaporation Method

5. Abstraction from rainfall

Transpiration:

Transpiration is the process by which the water vapour escapes from the living plant leaves and enters the atmosphere.

Evapotranspiration

Evapotranspiration is the combined processes by which water is transferred to the
atmosphere from open water surfaces and vegetation

5. Abstraction from rainfall

Factors affecting Evapotranspiration

- Climatological factors like percentage sunshine hours, wind speed, mean monthly
temperature and humidity.
- Crop factors like the type of crop and the percentage growing season.
- The moisture level in the soil.

Estimation of Evapotranspiration

- Lysimeter
- Class ‘A’ Pan Method
- Penman Method
- Hargreaves Method
- Blaney & Criddle Method

5. Abstraction from rainfall

Infiltration is the process of water entry into a soil from rainfall, or irrigation.

Percolation is the process of water flow from one point to another point within the soil.

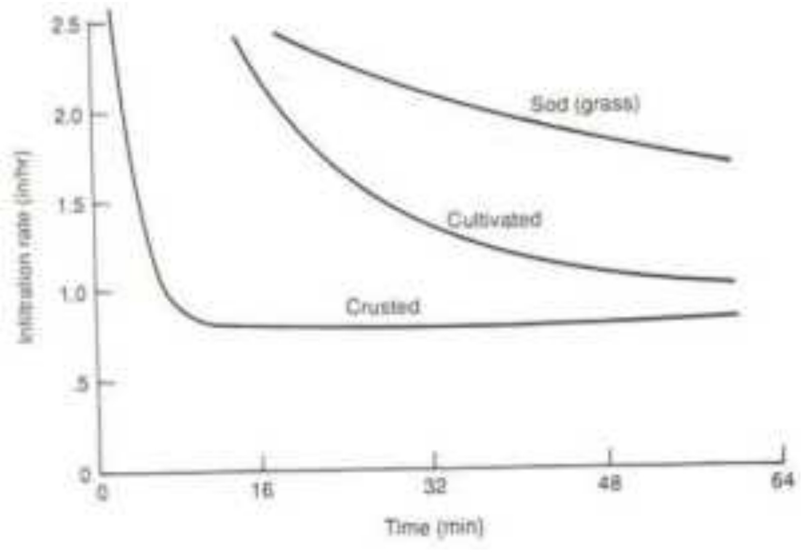
Infiltration rate is the rate at which the water actually infiltrates through the soil during a storm and it must be equal the infiltration capacities or the rainfall rate, whichever is lesser.

Infiltration capacity is the maximum rate at which a soil in any given condition is capable of absorbing water.

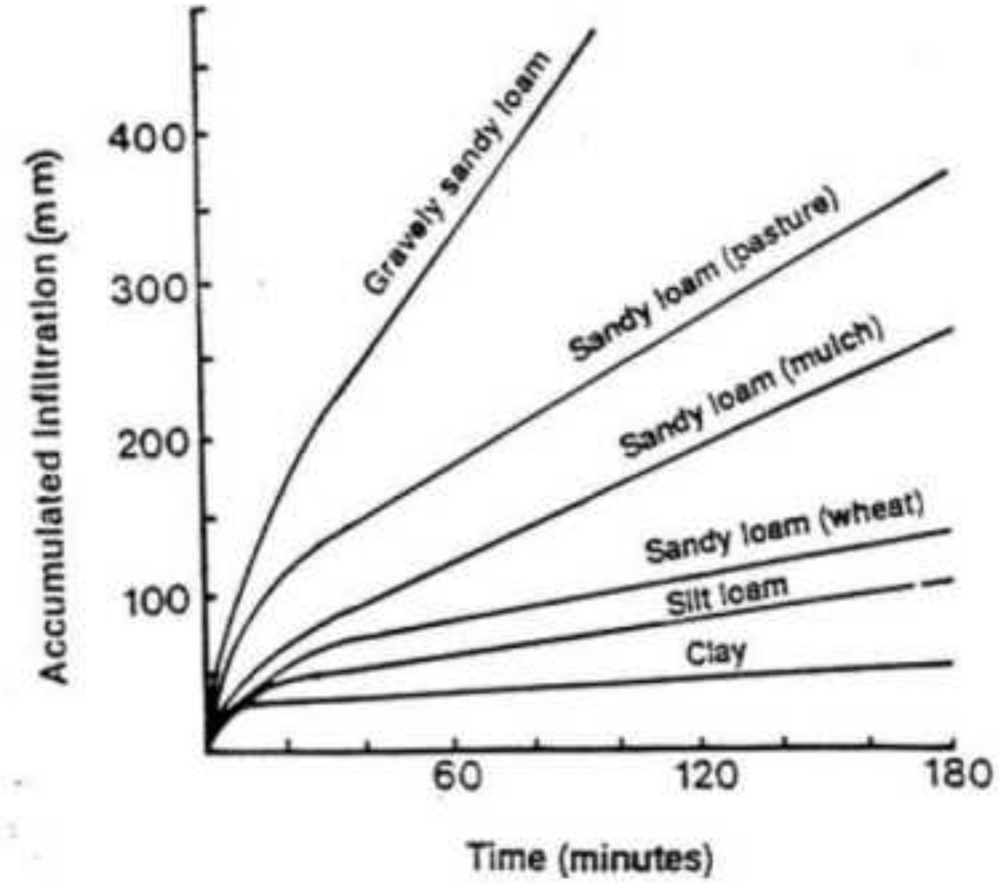
5. Abstraction from rainfall

Factors affecting infiltration

- Condition of the land surface (cracked, crusted, compacted etc.)
- Land vegetation cover
- Surface soil characteristics (grain size & gradation),
- Storm characteristics (intensity, duration & magnitude)
- Surface soil and water temperature, chemical properties of the water and soil.



Surface factors



Soil factors

5. Abstraction from rainfall

Measurement of Infiltration

The rate of infiltration is initially high. It goes on reducing with time and after some time it becomes steady. The rate of infiltration for a soil is measured in the field as well as in the laboratory. These are known as **Infiltrometers**

Types of Infiltrometers:

- Flooding-type Infiltrometers
    - o Single-tube flooding Infiltrometers
    - o Double-tube flooding Infiltrometers
- Sprinkling-type Infiltrometers or Rain Simulators
    - o Needle drip systems
    - o Stand pipes
    - o Sprinkler nozzles
    - o Rotating boom

Infiltration of various soil types

Sand	124 mm/hr
Sandy loam	50 mm/hr
Loam	13.2 mm/hr
Silt loam	1.05 mm/hr
Light clay	0.44 mm/hr

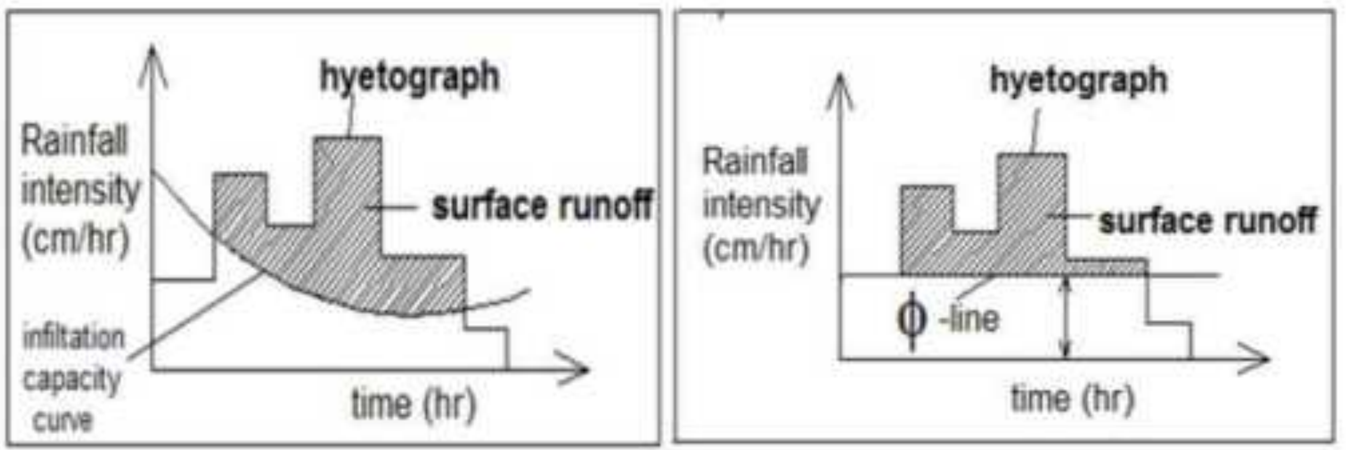
5. Abstraction from rainfall

Infiltration indices:

The average value of infiltration **is called Infiltration Index.**

Types:

- Φ - Index
- W – Index



$$w\text{-index}=(P-R-I_a)/t_e$$

$$\phi\text{-index}=(P-R)/t_e$$

Where,

P = total storm precipitation (cm), R = total surface runoff (cm) , Ia = Initial losses (cm)

t_e = elapsed time period (in hours)