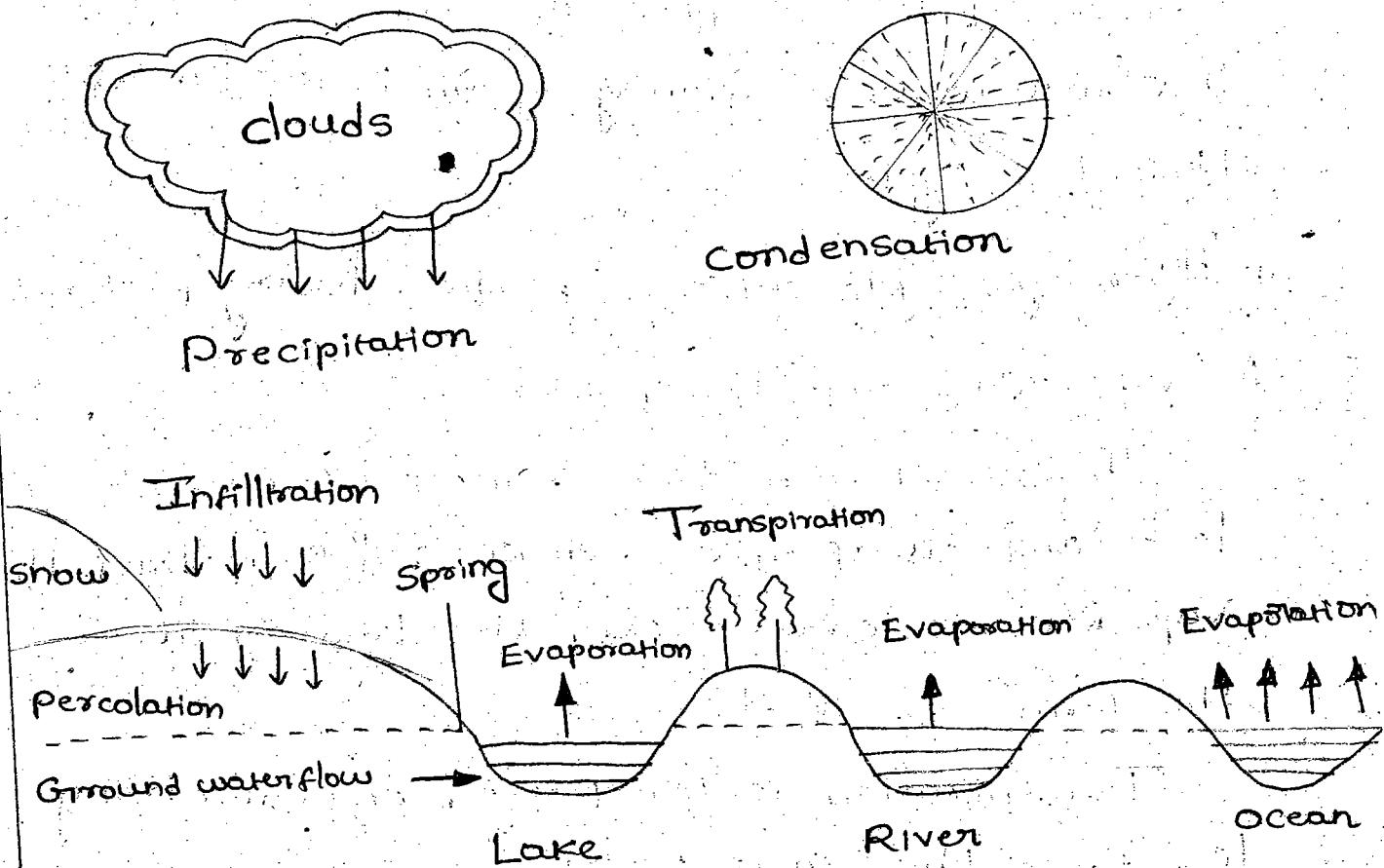


# UNIT - 1

## Introduction

22/11/2018.



## Hydrological Cycle

### Hydrology

Hydrology is the science which deals with the occurrence, distribution and movement of water on the earth including in the atmosphere and below the surface of the earth. Water occurs in the atmosphere in the form of vapour, on the surface as water, snow, (or) ice and below the surface as ground water occupying all the voids within a geologic stratum.

## \* Hydrologic cycle

Except for the deep ground water, the total water supply of the earth, is in constant circulation from earth to atmosphere and atmosphere to earth. This earth water circulatory system is known as "Hydrologic cycle."

\* Hydrologic cycle consists of the following processes:

### i. Evaporation and Transpiration.

The water from the surfaces of rivers, oceans, lakes and also from the moist soil evaporates. The vapours are carried over the land by air in the form of clouds.

Transpiration is the process of water being lost from the leaves of the plant from their pores. Thus the total evaporation from the inclusive of the transpiration consists of

(i) Surface Evaporation

(ii) Water surface evaporation

(iii) From river surface.

(iv) From oceans

(v) Evaporation from plants and leaves (Transpiration)

(vi) Atmospheric evaporation

## \* Precipitation:

Precipitation may be defined as the fall of moisture from the atmosphere to the earthy surface in any form precipitation may be in 2 forms.

1. Liquid precipitation i.e Rainfall

2. Frozen precipitation

(i) Snow (iii) sleet

(ii) Hail (iv) Freezing Rain

## \* Run-off

Run-off is the portion of precipitation i.e not evaporated! When moisture falls to the earth surface, as precipitation or part of it is evaporated from the water surface, soil, vegetation and through transpiration by plants and the remainder precipitation is available as run-off which ultimately runs to the ocean through surface (i) subsurface streams. The run-off may be classified as follows:

### 1. Surface run-off:

Water flows over the land and is first to reach the streams & rivers, which ultimately discharge the water to the sea.

### 2. Subsurface run-off:

A portion of precipitation infiltrates into the surface soil and depending upon the geology of the basins runs as subsurface run-off and reaches the streams & rivers.

### 3. Ground waterflow (Ø) Base flow:

It is the portion of precipitation which after infiltration percolates down and joins the groundwater reservoir which is ultimately connected to the ocean.

Thus the hydrologic cycle may be expressed by the following equations:

$$\text{precipitation} = \text{evaporation} + \text{Run-off}$$

$$P = E + R.$$

### \* Hydrological data:

In the hydrological data the main components of the hydrological cycle are:

1. Precipitation

2. Evaporation

3. Run-off

Apart from information about the above components, information about climate, meteorology and geology is also required. Following hydrological data are required:

#### 1. Weather & climate records:

Data about temperature, humidity, radiation, wind etc. since these are directly effect hydrological parameters.

#### 2. Precipitation data:

These data helps in predicting run-off volume and its peak. It is also helpful in estimating the water budget equation for the basin.

### 3. Stream flow data:

These data helps in the planning of reservoir design of spillways, bridges, culverts and water power development. This data is also utilized for determination of floods, flood magnitude, flood frequency and water budget etc.

### 4. Evaporation and Transpiration data:

These data help for water budget for the river basin and reservoir capacity for water resource development.

### 5. Infiltration data:

This data helps in determining excess rainfall effect and run-off computation.

### 6. Groundwater characteristics:

This data helps in estimation & location of groundwater reservoir and for groundwater development.

### 7. Physical & Geological data:

This data helps in the determination of run-off pattern. Silt loam movement 'central water communication (cwc) mentions the stream flow data for major rivers.

## Water Budget:

(i) Global water budget: The total quantity of water in the world is 136 million cubic kilometre out of which about 97.2% is held up in seas & oceans and while about 2.1% is frozen in ice caps and about 0.81% is available as deep ground water. Thus about 99.6% of total water is of no use to men.

## (ii) India Water Budget:

India has a geographical area of nearly 3.3 million sq.cm normal annual rainfall varies from 100mm in western rajasthan to over 11000mm at Chirapunji in Meghalaya. In annual average rainfall over the country is of the order of 1170mm depth which is nearly  $4000 \text{ km}^3$ .

## Precipitation

Types: There are 4 types of precipitation

1. cyclonic precipitation
2. convection
3. Orographic
4. Precipitation due to turbulent ascent.

### cyclonic precipitation: (CP)

CP results from lifting of air mass converging into low pressure area of cyclone. This may be divided into (a) Frontal (b) Non-Frontal.

#### (a) Frontal precipitation:

A border region between adjacent air masses having different characteristics such as temperature & humidity is called a "Front".

When a flow of warm and moist air mass from the south meets cold air mass of polar region the cold air being heavier under runs the warm air flow in the form of flat wedge forcing the warm air aloft.

The lifted warm air mass cools down and higher altitudes and causing precipitation.

(b) Non-Frontal precipitation: In the case NFP the moist warm air mass is stationary and the moving cold air mass meets it.

Thus due to the warm air there is passive absence of warm air over cold air owing to the active undercutting. When the lifted-warm air cools down at higher altitude precipitation occurs.

## 2. Convective Precipitation:

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This is caused by natural rising of warmer lighter air in colder, denser surroundings. The difference in temperature may result from unequal heating at the surface, unequal cooling at the top of the air layer, (or) mechanical lifting when air is forced to pass over a denser colder air mass.

## 3. Orographic Precipitation:

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This is due to the lifting of warm moisture laden air masses due to topographic barriers such as mountains. As it reaches higher elevation it comes in contact with cold air and precipitation occurs. The zone to the other side of the mountain will be the zone of rain shadow area where the rainfall may not occur.

Hail: Hail is lumps of ice over 5mm<sup>Ø</sup> formed by alternate freezing (or) melting as they are carried up & down in highly turbulent air currents.

#### 4. Precipitation due to turbulent ascent:

Air mass is forced to rise up due to greater friction of earth surface after its travel over ocean. The air mass rises up because of increased turbulence and friction when it ultimately condenses and precipitation occurs.

#### \* Forms Of Precipitation:

The various forms of precipitation are

Drizzle: When the size of water droplets is under 0.5mm & its intensity is less 1mm/hr because of the lightness the droplets appeared to be floating in air.

Rain: When the size of droplets is more than 0.5mm. The max. size of water drop is generally 6.25mm as drops greater than these tend to breakup they fall through the air.

Glaze: When the drizzle (rain) freezes as it comes in contact with cold objects it is known glaze.

Sleet: It is frozen raindrops cools to the ice stage while falling through air at subfreezing temperature.

Snow: Precipitation in the form of ice-crystals

Snow flakes: No. of ice crystals joined together forms snowflakes.

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## \* Rainfall in India:

The major rainfall season in India is June to October. India lies in the tropical belt and has the four distinct weather periods.

1. Monsoon Period [June to October]
2. Coast monsoon period [October to November]
3. Winter rainfall period [December to February]
4. Summer rainfall period [March to May]

## \* Measurement of Rainfall:

The amount of precipitation is expressed as the depth in cm (or) inches which falls on a level surface and is measured by rain gauge. The following are the main types of rain gauge.

### 1. Non-automatic Rain gauge:

This is also known as non recording rain gauge.

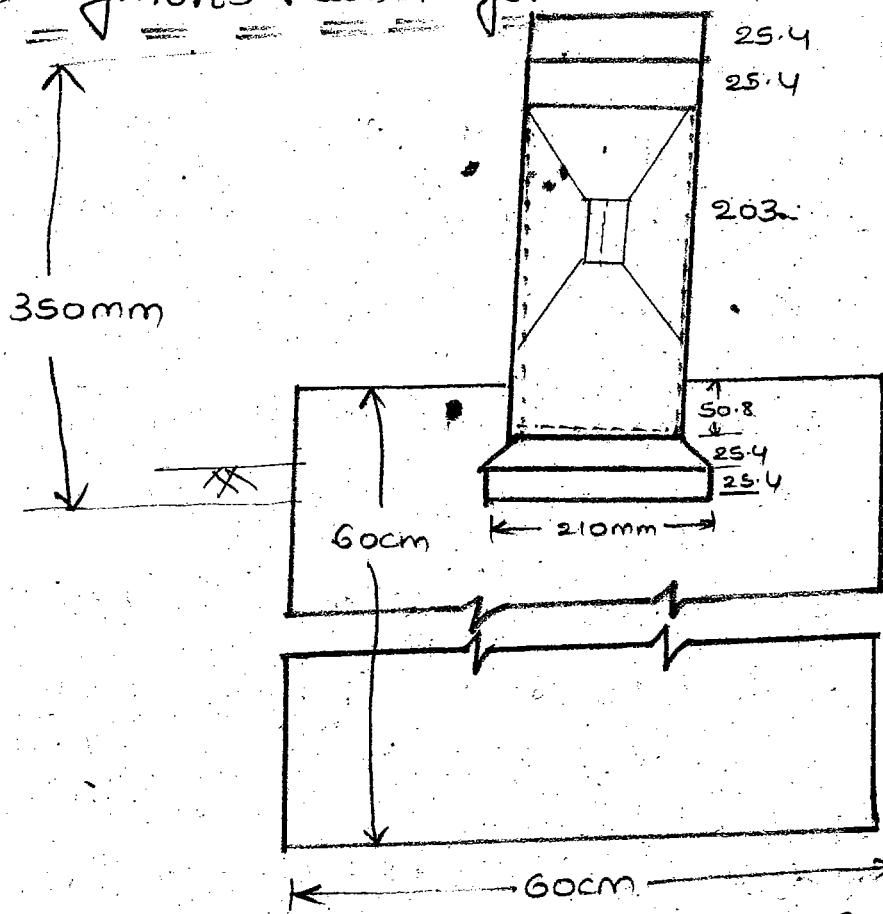
Symon's Rain gauge instrument prescribed by used at all Govt.雨 gauge stations throughout India.

### 2. Automatic Rain gauge:

There are 3 types

- (i) Weighing bucket rain gauge
- (ii) Tipping bucket rain gauge
- (iii) Float type rain gauge

### (i) Symon's Rain Gauge:



Symon's rain gauge consists of cylindrical vessel 127mm India with a base enlarged to 210mm diameter. The top section is a funnel provided with circular brass rim exactly 127mm in internal diameter. The funnel shank is inserted in the neck of a receiving bottle which is 75 to 100mm diameter. A receiving bottle of rainfall and as during in heavy rainfall the quantity is frequently exceeded, the rain should be measured in a 3(8) 4 times in a day on day of heavy rainfall. The receiver fill should overflow. A cylindrical graduated measuring glass is furnished with each instrument which reads to 0.2mm. The rainfall should be estimated to nearest 0.1mm.

The rain gauge is setup in a concrete block 60cmx60cmx60cm

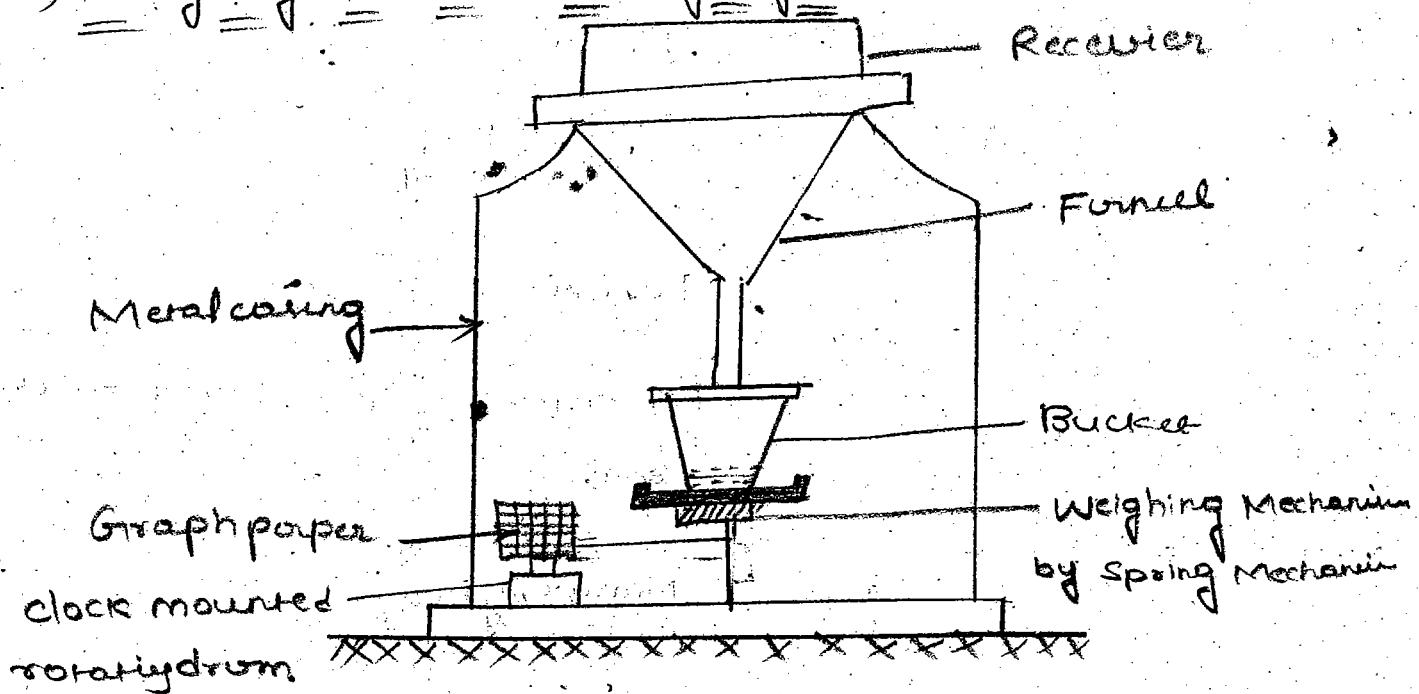
The following important points should be kept in mind while selecting site for a rain gauge station. [common for all type of RG]

- The site where a Rain gauge is setup should be an open place
- The distance b/w the rain gauge and the nearest object should atleast twice the height of the object.

In no case should it be nearer to the obstruction than 30m.

- The rain gauge should never be situated on the site (8) top of a hill if a suitable site on a level ground can be found.
- In the hills where it is difficult to find levelspace, this site for the gauge should be chosen where it is best shielded from high winds and where the wind does not cause eddy's.
- A fence if erected to protect the cage from cattle etc.... It should be located that distance of the fence is not less than twice its height.

## 2) Weighing bucket rain gauge:



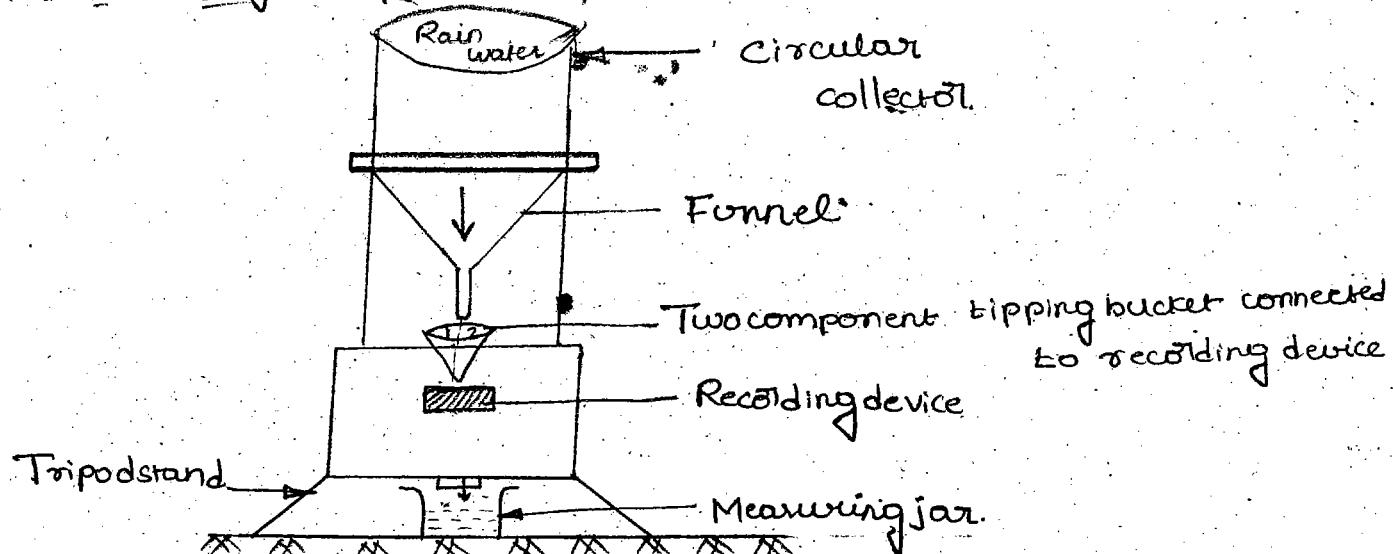
## Weighing bucket rain gauge

Self recording gauges are used to determine rates of rainfall over short periods of time. The most common type of self recording gauge is the weighing bucket type.

This雨gauge essentially consists of a receiver bucket supported by a string (or lever balance or) any other weighing mechanism. The movement of the bucket due to increasing weight is transmitted to a pen which traces the record on a clock driven chart.

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### (iii) Tipping Bucket Rain Gauge:

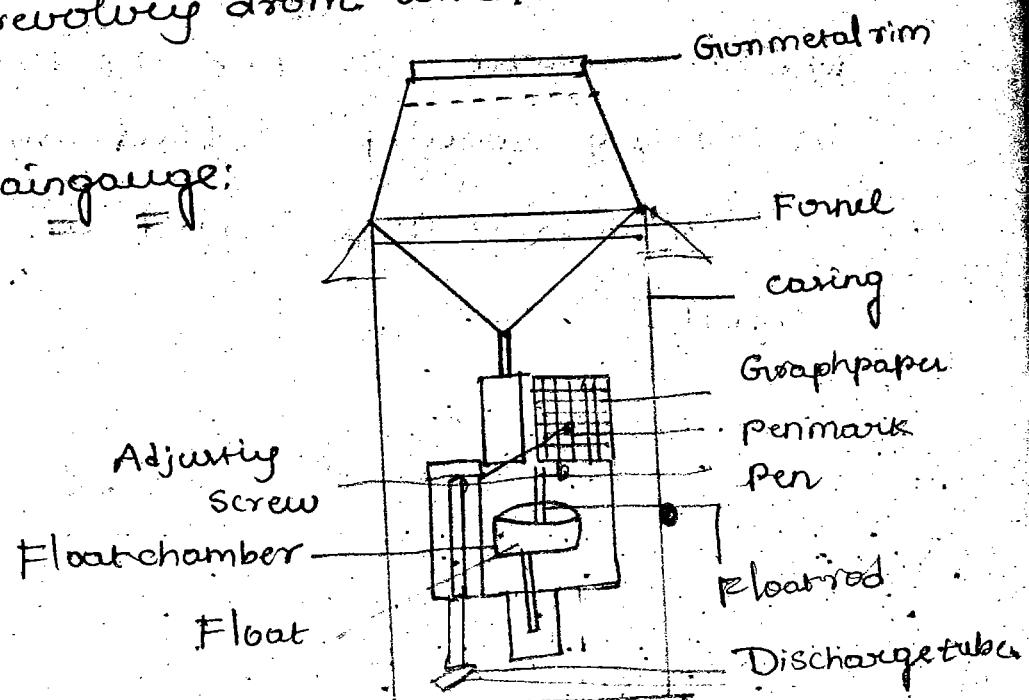


A Stevens tipping bucket type raingauge consist of 300mm diameter sharp edge receiver, at

the end of the receiver is provided in funnel.

A pair of buckets are pivoted under the funnel in such a way one bucket receives 0.25mm of precipitation it tips, discharging its contents into a container bringing the other bucket under the funnel. Tipping of the bucket completes an electric circuit causing the movement of pen to move on clock driven revolving drum which carries a graph sheet.

### \* Float Type Raingauge:



The working of a float type rain gauge is similar to the weighing bucket type rain gauge. A funnel receives the rainwater which is collected in a rectangular container. A float is provided at the bottom of the container. The float is raised as water level rises in the container, its movement being recorded by pen being moved on a recording drum actuated by a clock work.

### \* Advantages of Recording Type over Non-Recording Type Raingauges.

#### Advantage

- continuous record of rainfall.
- Intensity of rainfall can be measured.
- Installed in Remote areas.
- Elimination of manual errors.

#### Disadvantage

- These may costly.
- Mechanical & electrical errors may occur sometimes.

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### \* Rain gauge Network:

It is defined as the ratio of total area of catchment to the total no. of gauges in the catchment.

Area ( $\text{km}^2$ )

0 - 80

80 - 160

160 - 320

320 - 560

560 - 800

800 - 1200

No. of gauges

2

3

4

5

6

## \* Optimum No. of Raingauges:

By using of statistical method.

$$N = \left[ \frac{EV}{P} \right]^2 \quad P = \text{percentage of error.}$$

$N$  = no. of gauges

$CV$  = coefficient of variance

$$CV = \frac{100\sigma}{\bar{P}}$$

$$\bar{P} = \frac{\sum P}{n}$$

$$\sigma = \sqrt{\frac{n}{(n-1)} \left[ \bar{P}^2 - [\bar{P}]^2 \right]}$$

- \* Four rain gauge stations are located in catchment area whose average precipitations are 100cm, 120cm, 150cm & 135cm. Determine optimum no. of rain gauges required in that catchment area if allowable  $\gamma$ , is 8. How many no. of additional gauges are required.

Sol: Total no. of readings  $n = 4$ ,

$$\begin{aligned} \bar{P} &= \frac{\sum P}{n} \\ &= \frac{100 + 120 + 150 + 135}{4} \\ &= 126.25. \end{aligned}$$

$$(\bar{P})^2 = 15939.06.$$

$$\bar{P}^2 = \frac{\sum P^2}{n} = \left[ \frac{100^2 + 120^2 + 150^2 + 135^2}{4} \right] = 16281.25,$$

$$\bar{P}^2 = 16281.25.$$

$$\sigma = \sqrt{\frac{n}{n-1} \left[ \bar{P}^2 - (\bar{P})^2 \right]}$$

$$= \sqrt{\frac{4}{4-1} \left[ 162812.25 - 159.3906 \right]}.$$

$$= \sqrt{456.25} = 21.36.$$

$$Cv = \frac{100\sigma}{\bar{P}} = \frac{100 \times 21.36}{126.25} = 16.91.$$

$$N = \left( \frac{16.91}{8} \right)^2 = 4.467 \approx 5 \text{ SNo's.}$$

Five number of additional rain gauges are required.

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\* The rainfall readings at 4雨量計 stations are located in river catchment of 800, 620, 400 & 540mm respectively. Determine optimum no. of rain gauges in catchment if it is design to measurement of mean rainfall in the catchment upto 10% of mean rainfall in the catchment upto 10%. How many more no. of rain gauges are to be required.

Sol: Total no. of readings  $n = 4$

$$\bar{P} = \frac{\sum P}{n} = \frac{800 + 620 + 400 + 540}{4} = \frac{2360}{4}$$

$$\bar{P} = 590$$

$$(\bar{P})^2 = 348100$$

$$\bar{P}^2 = \frac{\sum P^2}{n} = \frac{800^2 + 620^2 + 400^2 + 540^2}{4} = 3,69,000$$

$$\bar{P}^2 = 3,69,000$$

$$\sigma = \sqrt{\frac{n}{n-1} [P^2 - (\bar{P})^2]}$$

$$= \sqrt{\frac{4}{4-1} \times [3,69,000 - 3,48,100]}$$

$$= 166.933.$$

$$CV = \frac{100\sigma}{\bar{P}} = \frac{166.933 \times 100}{590} = 28.29$$

$$N = \left( \frac{28.29}{10} \right)^2 = 8.00$$

Eight number of additional raingauges are required

### Missing Data Interpretation of Rainfall

The interpretation of missing rainfall data is

estimated by using two methods.

1. Arithmetic average method.

collecting the average rainfall values at  
3 different locations near to place where data  
is missing

Average annual rainfalls can be obtained from  
old records.

$$P_x = \frac{P_1 + P_2 + P_3 + \dots + P_n}{N}$$

This method is adopted only corresponding  
change b/w any two locations rainfall record is less than 10%.

## Normal Ratio Method:

If the corresponding change b/w any two locations rainfall record is more than 10%, the normal ratio method is to be adopted.

$$P_x = \frac{N_x}{N} \left( \frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} + \dots + \frac{P_n}{N_n} \right)$$

- \* Precipitation station X was in operative for a part of month in which a storm occur the respective storms totals at the surrounding stations a, b & c 107, 89, 122mm. The normal average precipitation x, a, b & c are respectively 978, 1120, 935 and 1200mm. Estimate the storm precipitation at station X.

Sol: Normal annual Rainfall  $N_x = 978$

$$N_x + 10\% \text{ of } N_x = 978 + 97.8 = 1075.8$$

$$\begin{aligned} P_x &= \frac{N_x}{N} \left[ \frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} \right] \\ 10\% &= \frac{978}{3} \left[ \frac{107}{1120} + \frac{89}{935} + \frac{122}{1200} \right] \\ &= 95.31 \text{ mm} \end{aligned}$$

\* Presentation of rainfall data:

~~rainfall for various areas~~

The data set by different types of gauges

are plotted by some methods

And parameters some required for the analysis  
are 1. Intensity • 2. Duration and 3. Frequency

\* Intensity:

~~rainfall~~

The rate at which the rain is falling

\* Duration:

~~rainfall~~

The time for which it is falling with a  
given intensity

\* Frequency

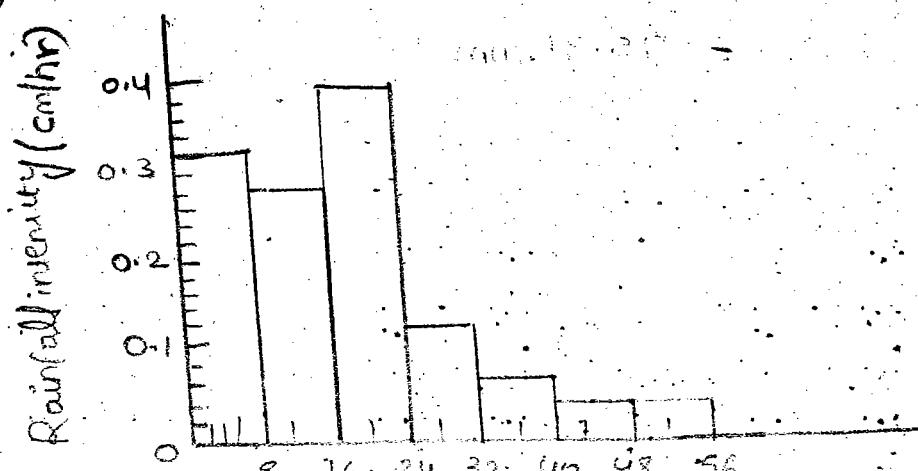
~~rainfall~~

How many times does it occur

## Hyetograph / Hydrograph.

A Hyetograph is plot of the intensity  
of the rainfall against the time interval and  
is represented as a bar chart is known as a

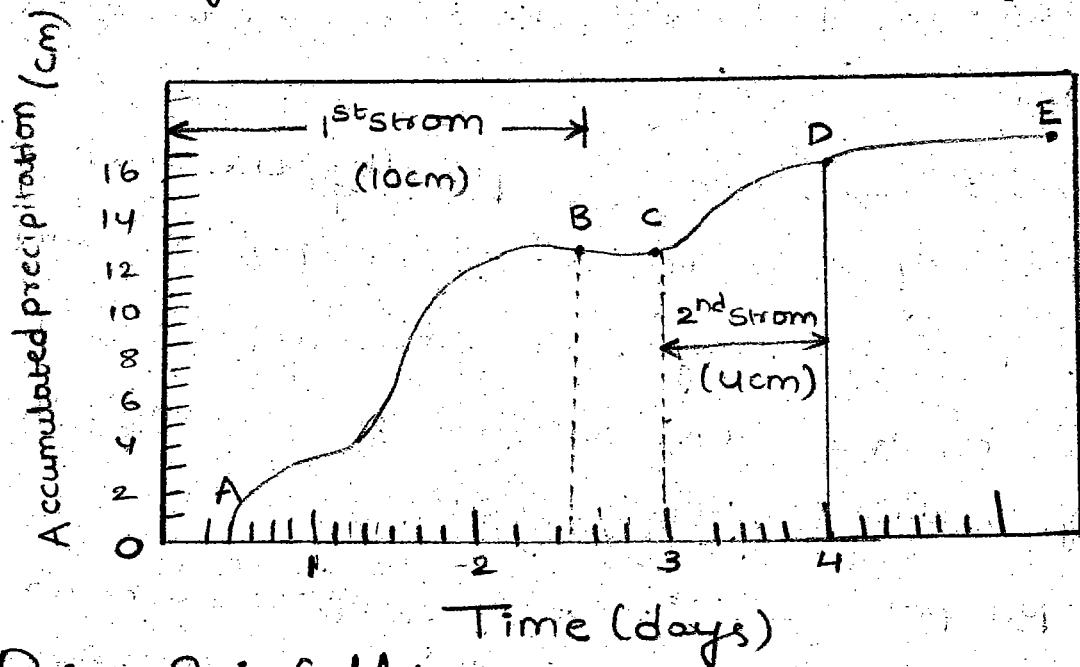
"Hydrograph."



## \* Mass Curve of Rainfall

The mass curve of Rainfall is plot after the accumulated precipitation against the time in chronological order. Mass curve of rainfall are very useful in (estab) extracting information on the duration and magnitude of the storm.

- The graph is obtained from a recording type raingauge and it is always a rising curve.



## \* Point Rainfall:

The rainfall during a given time interval measured in a raingauge the amount which might have been measured at given point.

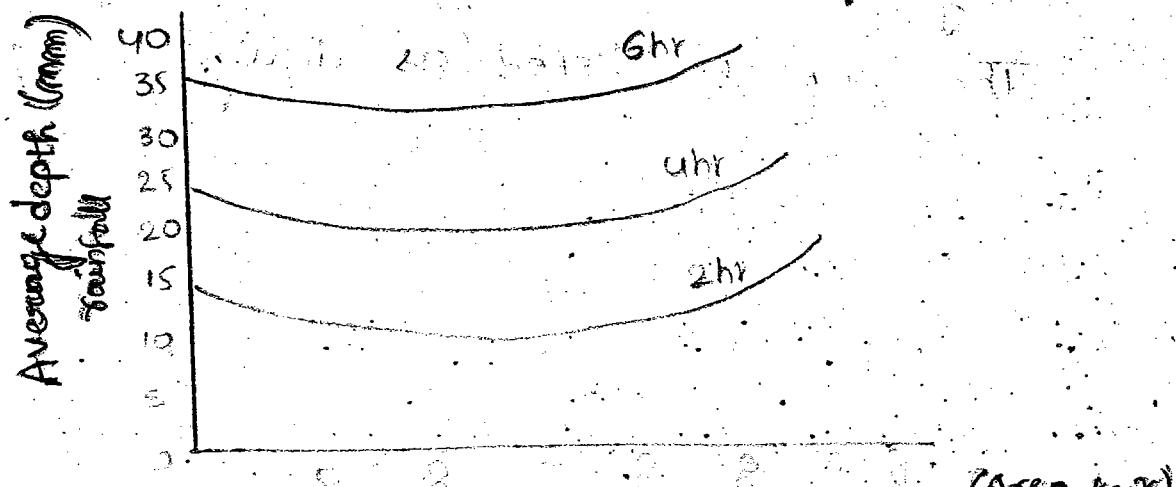
The can be listed as daily, weekly etc....

7/12/18  
= = =

## Depth Area Duration (DAD) and Curve relationship

The rainfall rarely occurs uniformly over the whole area of the catchment.

- A Rain gauge station gives the point rainfall which don't actually represent the rainfall in that area.
- To find out how much of rainfall will occur in an area converting the point rainfall data to areal rainfall data, depth area duration curve used.
- A DAD curve expresses graphically the relation b/w progressively decreasing average depth of rainfall over a progressively increasing area from the centre of the storm outward to its edges for a given duration of rainfall.
- The purpose of DAD analysis of a particular storm is to determine the largest average depth of rainfall that fall over various sizes of area during the standard passage of time.



To make the DAD curve the following steps are to be taken.

- 1) From the rainfall data prepare the Isohyets
- 2) Pbt the catchment area on paper with the help of planimeter. find the area b/w the Isohytes.
- 3) The volume of rainfall is calculated b/w the Isohytes by taking average of Isohytes multiplied with the area b/w the Isohytes.
- 4) calculate volume of rainfall of all area b/w the Isohytes.
- 5) calculate the cumulative volume and cumulative area
- 6) This cumulative volume is divided by cumulative area and average depth of rainfall over the area for that storm is foundout
- 7) same procedure is applied for other storm also.
- 8) The graph b/w average depth and cumulative area is plotted i.e. is called Depth area Duration curve for that storm.

Isohyets.

= = = A line (or) on a map which is connecting the points having the same amount of rainfall in a given duration is called "Isohytes".

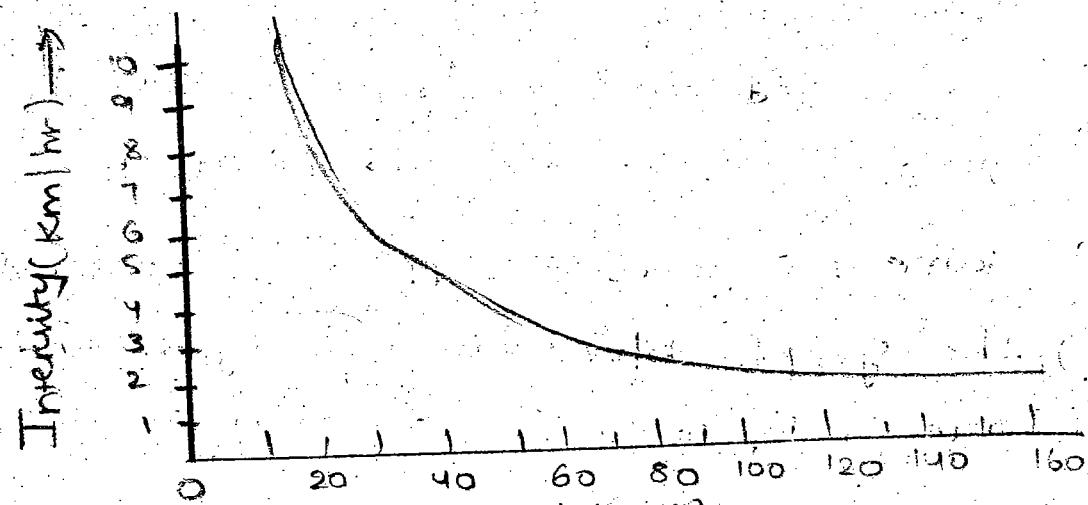
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## Intensity Duration Frequency curves (IDF) & Relationships

For the design of any hydraulic structure we should know about the peak flood what will be its frequency so this can be easily computed from intensity duration frequency curve. It is a plot b/w average rainfall intensity and that duration.

- It has generally been observed that greater the intensity of rainfall, shorter is the length of time it continues. As the duration of storm increases the max. intensity of storm decreases.

$$\text{Intensity} = \frac{\text{Rainfall depth}}{\text{Duration}}$$



- For plotting the curve the following steps are to be taken

- Arrange the data in descending order of magnitude of all time interval which has to be taken
- For finding the intensity of particular frequency the precipitation which is given for a particular time period.

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## \* Consistency of rainfall data at a gauge station:

### \* Reasons for consistency:

If the change of station of gauge is unreported

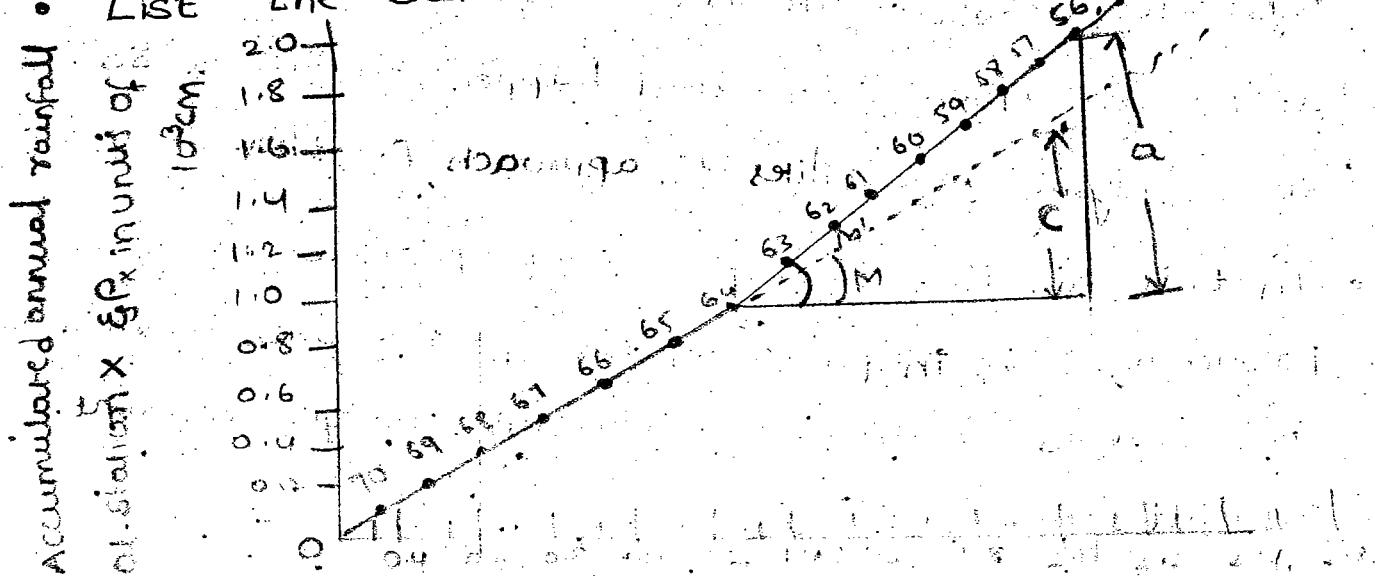
to IMD (Indian Meteorological Department)

or event

- Increased in built up area
- Change in environment around gauge station due to natural climates.
- Some extend due to manual errors.

### \* Elimination of Inconsistency by using of DMC Technique (Double Mass Curve)

- Select 8 to 6 gauge stations around the station where the station found is with inconsistent data.
- Collect and analyse the rainfall data of those selected 6 stations from a period of past 35 years calculate average rainfall for every year.
- Collect the data of inconsistent station for past 35 years
- Compare the rainfall data of inconsistent station with average rainfall of nearby stations.
- List the data from previous year to past years



- \* Calculate cumulative rainfall of 6 stations (Avg. rainfall and also at station X).
- \* The graph plotted b/w cumulative rainfall would be a straight line for consistent data. If there is a change in linear curve data found inconsistent.
- \* If inconsistent period is greater than 5 years previous data is to be collected with that of U.

$$\text{Corrected rainfall, } P' = P \times \frac{M'}{M}$$

$M'$  - New slope

$M$  - old slope

### 11/12/18. Frequency of Point Rainfall:

- When we design hydraulic structures we design for a particular hydraulic structure also and design for a particular lifespan. If the flow value doesn't exceed from the design value in b/w the design life of hydraulic structure than our structure will be fine.
- As we not know what will happen in future so we applying probabilities to approach for this.
- In this we find the probability of occurrence of particular storm in particular time period such information is obtained from the frequency analysis of point rainfall data.

- In this method the following steps are to be taken
  - 1) Arrange all the rainfall data in chronological order constituting a time series.
  2. Arrange the series in descending order of magnitude of rainfall and provide a number to each position. The position - 1 is given to largest magnitude rainfall and N is given to least magnitude of rainfall.
  3. Now the probability of the rainfall can be find from following formula.

$$(i) \text{ Weibull's formula } P = \frac{m}{N+1}$$

$$(ii) \text{ Hazeen formula } P = \frac{m - 0.5}{N}$$

$$(iii) \text{ California formula } P = \frac{m}{N}$$

Here  $N$  = Total no. of years / Total no. of record.

$m$  = Position of that rainfall.

### \* Probable Maximum Precipitation (PMP)

The probable Maximum Precipitation (PMP) is the max. possible precipitation that can reasonably be expected at a given location.

PMP is defined as the greatest (or) extreme rainfall for a given duration i.e. physically possible over a station (or) Basin.

PMP can be statically estimated as

$$\boxed{\text{PMP} = \bar{P} + K \cdot \sigma}$$

$\sigma$  = standard deviation.

$K$  = frequency factor which depends upon the statistical distribution

Here  $\bar{P}$  = Mean of angular rainfall series

- In the design of hydraulic structures the study of PMP is very much important.

### \* World's Greatest Observed Rainfall Data:

A list of world's greatest rainfall is made with the available data and plotted on logarithmic scale. The data seems to be in line can be used for other data also.

$$P_m = 42.16 D^{0.475}$$

Where  $P_m$  = extreme rainfall depth in cm

$D$  = Duration in hours.

### \* Index of Wetness:

The ratio of the actual rainfall in a particular year at a given place to the average annual rainfall of the place is known as "Index of wetness".

Index of wetness =  $\frac{\text{Actual rainfall in a given year at a given place}}{\text{Average annual rainfall of that place}} \times 100$

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## UNIT - II

## Abstractions from Precipitation.

When precipitation comes to the earth surface it produces runoff. The runoff is important for study & to design the hydraulic structures and estimating floods. All the precipitation that comes to the earth surface does not contribute the runoff. Some part of it disappears. The loss of it occurs due to evaporation, Transpiration, Interception, depression storage and Infiltration, these are called as Abstractions from Precipitation.

## Interception.

When a rain falls it is firstly intercepted by trees, plants, buildings etc.... When they become completely wet the water comes down to the earth surface.

- The initial water intercepted by trees, buildings and plants etc... is required to wet them and after that the water intercepted by equals evaporation rate. So this complete amount of water is called "Interception Loss", and it is denoted by

$$x = a + bt$$

$x$  = Total interception

$a$  = water required for wetting

$b$  = evaporation rate from the intercepting surface ( $\text{cm}/\text{hr}$ )

$t$  = Duration in hours

- Vegetation to cover on the ground, buildings roads and pavements intercept part of the fall in precipitation and temporarily stored on their respective surface. This intercepted water is either evaporated back into the atmosphere or mostly falls down to the ground.

- Normally water from the roof of a building is let into a drainage system (or) into the subsoil via sewers and storm drains.

#### \* Depression Storage:

When the precipitation reaches to the ground

Primarily it must fill all the depressions before it can flow over the surface. The volume of water trapped in these depression does not contribute to the runoff so there are called "depression storage".

- These depression storage depends on many factors such as
  1. The type of soil
  - 2 Condition of surface
  3. Nature of depression
  4. Slope of catchment
- From the experiment on different soil we are able to take some values for depression storage loss during intensive storms.

1. Sand - 0.5cm

2. Loam - 0.4cm

3. Clay - 0.25cm

### \* Watershed Leakage:

Adjacent basins are separated by ridge lines so that rainfall falling over a basin flows towards the drainage lines (Ex: Streams of the basin).

Watershed leakage may be defined as flow of water from one basin to another basin (or) from one basin to the sea through major faults (or) other geographical features.

### \* Evaporation:

Evaporation is the process in which a liquid changes to the gaseous state at the free surface below the boiling point through the transfer of heat energy. It is a continuous natural process by which substance changes from liquid to gaseous state.

The main source of evaporation is the solar radiation.

The rate of evaporation is depended on the

following factors.

1. Vapour pressure

7. Temperature of air

2. Nature of evaporating surface

8. Atmospheric pressure

3. Area of water surface

9. Quality of water

4. Depth of water bodies

10. Nature & size of

5. humidity

evaporating surface

6. Wind velocity

14/12/18

### \* Nature of evaporating surface:

Different evaporating surfaces like soil, forest area, houses and lakes effect evaporation to the extend they have the potential. Black cotton soils help to evaporate the soil water faster than red soil because such soils have the potential to absorb incoming radiation more effectively. Evaporation from wet soil is faster and it reduces gradually as soil becomes dryer.

### \* Area of water surface:

In evaporation loss directly depends upon the area of the water surface, greater the area greater will be the water loss due to evaporation.

### \* Depth of water in waterbody:

Deep water bodies evaporates slower than shallow water bodies in summer while in winter season their evaporation is faster.

### \* Humidity

Evaporation is inversely proportional to the humidity. If the humidity in the atmosphere is more evaporation will be less.

### \* Wind Speed | Velocity

Wind removes the overlaying member vapour from an evaporating body thereby increase the rate of evaporation. However high wind speed may not

necessarily remove water vapour from a small waterbody.

There is a relation between the wind speed & size of the waterbodies' area evaporating surfaces.

#### \* Temperature:

= = = =

Increase in air temperature increases the evaporation rate so not always proportionately for the same temperature colder ones have less evaporation than summer ones due to combined effect of other environmental parameters.

#### \* Atmospheric pressure:

= = = = =

The evaporation will be less if the atmospheric pressure is more. Thus <sup>at</sup> higher altitudes evaporation loss is more while in deep valleys evaporation is less.

#### \* Quality of water:

= = = = =

The presence of dissolved salts in water reduces the saturation water pressure of water which consequently reduces the rate of evaporation. For example the Bay of Bengal has salt concentration of 3.15% and its evaporation rate is nearly 3% less than the evaporation from freshwater.

1/12/18.

## Measurement of Evaporation:

Estimation of evaporation is of very much importance in many hydrologic problems like planning and operation of reservoirs and irrigation systems. The amount of water is estimated from a watershed by the following methods

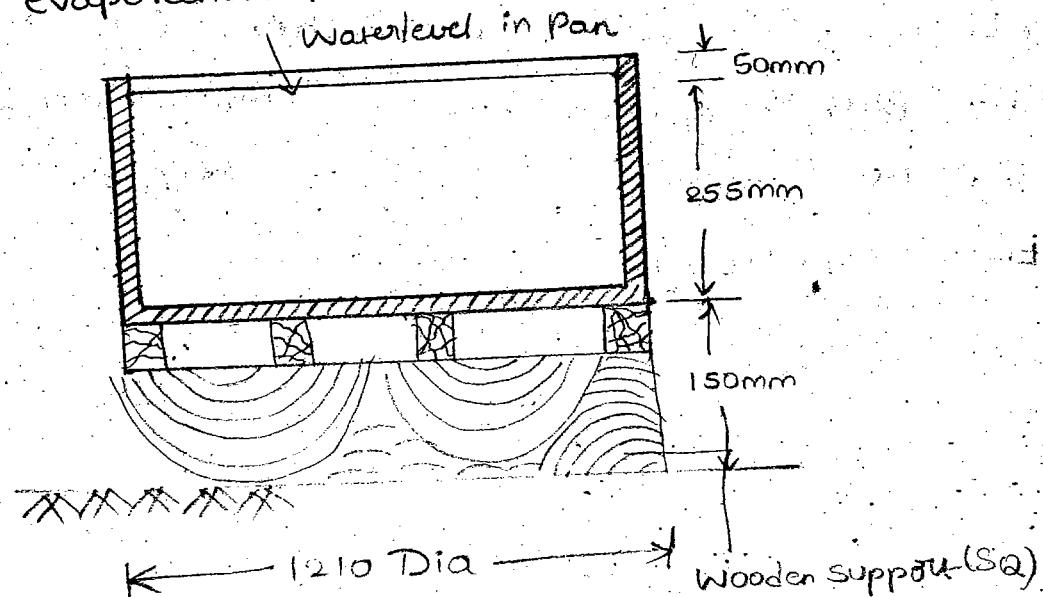
1. Evapometer Data
2. Empirical evaporation equation
3. Analytical method

### \* Evapometer Data:

Evapometer Data are water containing pans which are exposed to atmosphere and the loss of water by evaporation in them is measured. In practice

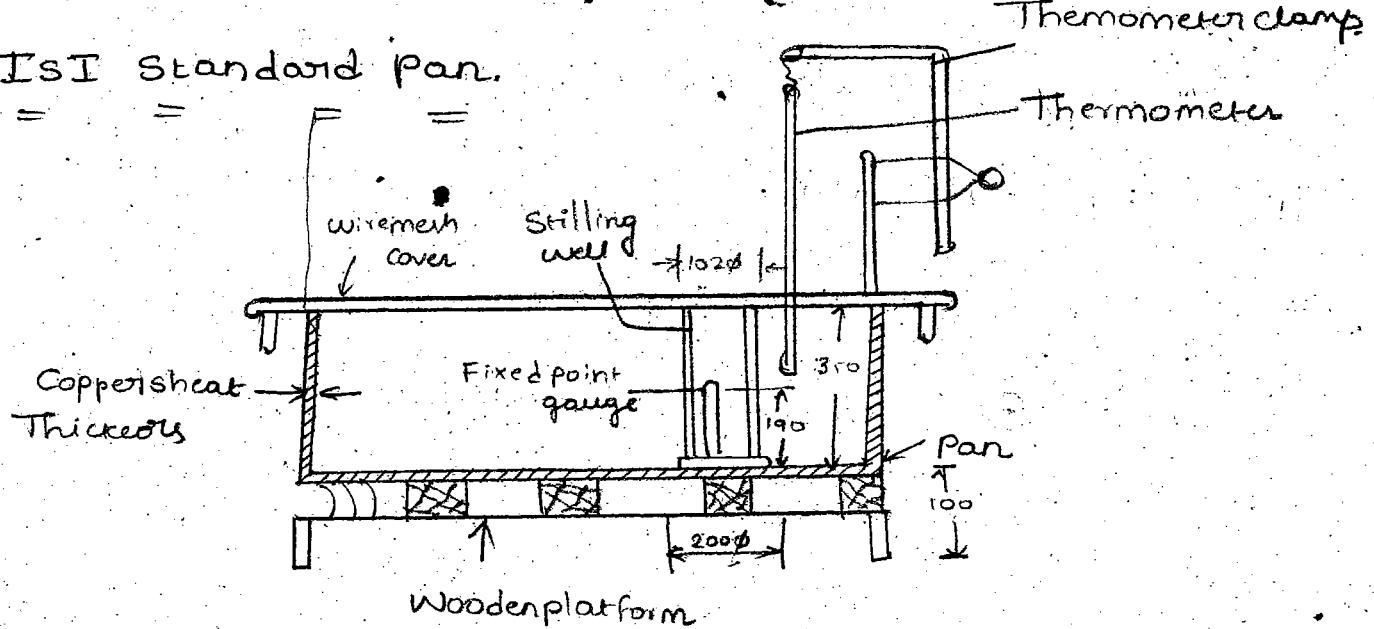
many evapometers are used some of them are

#### 1. Class-A evaporation pan



The pan is made up of unpainted galvanized iron sheet and the metal is used where corrosion poses a problem. It is mainly used by US weather Bureau.

#### \* ISI Standard Pan.



This pan evapometer is also known as modified class A pan. This pan is made of copper sheet, tinned inside and painted white outside. The top of the pan is covered fully with a hexagonal wire netting of galvanized iron to protect the water in the pan from birds.

The presence of a wire mesh makes the water temperature more uniform during day and night. The evaporation from this pan is 14% less than class A evaporation.

## \* Empirical Equations

A large number of empirical equations are obtained by substitution using

A rough estimate of the total evaporation using available data to estimate the

commonly available meteorological data. using Empirical formula:

Formula:

1. Meyer's formula:

$$E = km(\epsilon_s - \epsilon_a) \left(1 + \frac{V_q}{16}\right)$$

Where  $E = \text{evaporation from body water body in mm/day}$

$E = \text{Saturation vapour pressure at the water surface}$

CS = saturation  
Temperature in mm of hg

$e_a$  = Actual vapour pressure of overlying there in

$e_a$  = Actual vapor pressure  
mm of hg at specified height (9m)

$k_m$  = coefficient having value of 0.36 for large deeper shallow water bodies

$K_m$  = coefficient having value 1 for deep water bodies  
water bodies and 0.5 for shallow water bodies  
at a specified height  $z_m$

$V_q$  = Velocity of air at there specified height am  
water bodies and 0.5 for g.

Rohwer's formula:

$$= 0.000732 \text{ Pa}) \times$$

$$E = 0.771 (1.465 - 0.000) \\ (0.44 + 0.0783 V_{0.6}) (e_s - e_a)$$

$E$  = Evaporation from water body in mm/day

$P_a$  = Mean atmospheric pressure i.e Barometric reading

in mm of hg

$V_{10m}$  = Mean wind velocity in km/hr at ground level  
 in mm of hg

Mean wind velocity which can be considered as 0.6m above

ground

### One-Seventh Rule:

To estimate wind velocity at any height  $Z_2$  from known wind velocity at  $Z_1$ , is as follows

$$\left( \frac{V_1}{V_2} = \frac{Z_1}{Z_2} \right)^{1/7}$$

### (ii) Water budget Method:

$$P + Q_i \pm Q_u = E + Q_o \pm \Delta Q_s$$

$P$  = Total precipitation on the water surface

$Q_i$  = Total surface inflow

$Q_u$  = Total underground inflow (outflow)

$E$  = Evaporation

$Q_o$  = Surface outflow

$\Delta Q_s$  = Change in storage.

### \* Methods to reduce evaporation losses:

There are various methods to reduce the evaporation from surface of water bodies

#### 1. \* Reduction of surface area.

The volume of evaporated water is directly proportional to the surface area of the waterbody. So we try to reduce the surface by making the water body more deeper.

#### 2. Mechanical power:

Evaporation occurs when the sunlight reach to the

surface of waterbody so by providing the mechanical work will move the surface of waterbody

from direct sunlight.

### 3 Chemical cover:

This method consist of applying a thin film on the water surface to reduce the evaporation. This film reduces moment of water particles which leaves the <sup>surface</sup> after settling energy.

### 4 Increase Salinity

As we know if the salinity is more then evaporation is less so by increasing salinity we can reduce the evaporation.

18/12/18.

### \* Transpiration

Transpiration is the process by which the water leaves the body of a living plant and reaches the atmosphere as water vapour. The water leads the plant from its leaves and stomata. The transpiration occurs when the process of photosynthesis is run. As this process occurs in daytime only. The maximum transpiration occurs only on daytime (around 95%).

The important factors which effect the transpiration are as follows:

1. Atmospheric Vapour pressure

3. Wind

4. Light intensity

5. Characteristic of plant

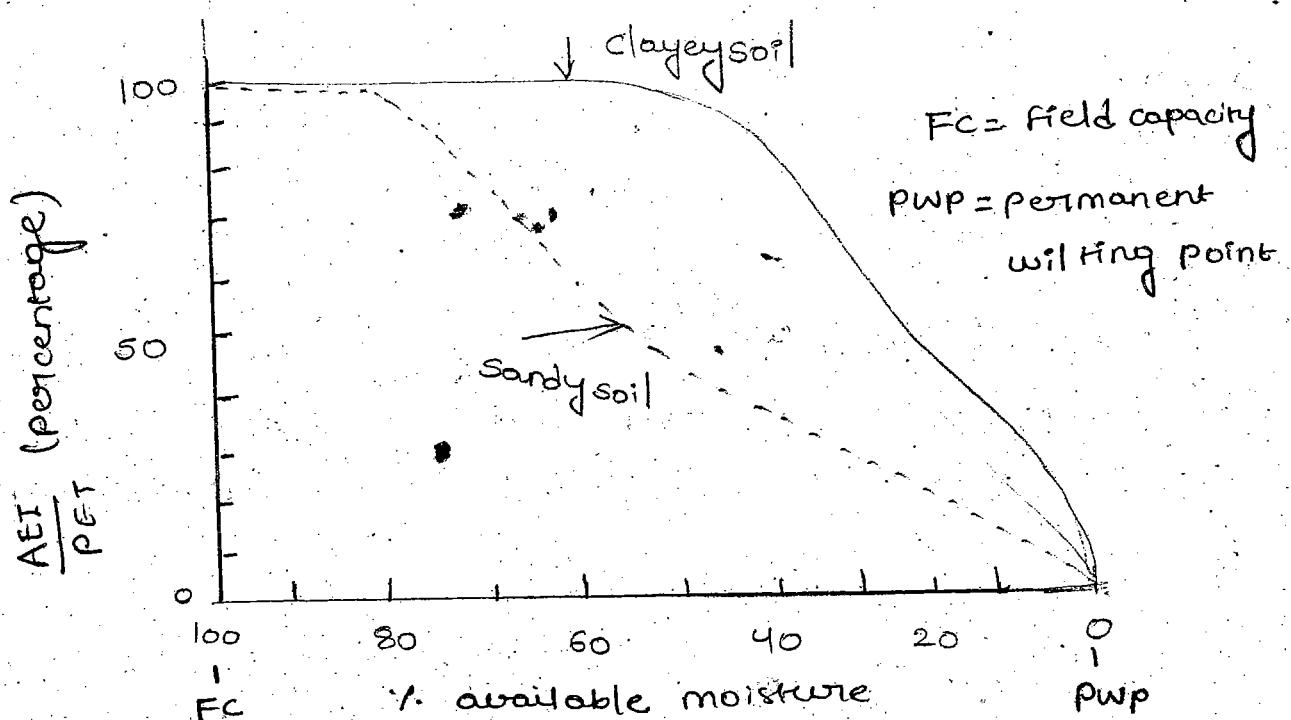
- \* Different plants will abidently transpire different amount of water and their water consuming characteristics are compared by the transpiration ratio.

$$\text{Transpiration ratio} = \frac{\text{Total mass of water transpired by the plant during its full growth}}{\text{Mass of dry matter produced}}$$

- Transpiration ratio will increase if the water requirement of a crop increases. Transpiration ratio for wheat is 300-600 and for rice is 600-800

### \* Evapotranspiration

When the transpiration takes place the land area in which plants stand also loose moisture by the evaporation of water. Since in the process of vegetation growth it is not possible to separate the transpiration and connected evaporation from the plants surrounding. So the evaporation and transpiration are considered under one head called as "Evapotranspiration."



- For a given set of atmospheric condition evapotranspiration mainly depends on the availability of water.
- When sufficient moisture is freely available to completely meet the needs of the vegetation fully covering the area, the result in evapotranspiration is called Potential evapotranspiration (PET)
- The real evapotranspiration occurs in a specific situation in the field is called Actual evapotranspiration (AEP)
- PET mainly depends upon climatological factors rather than on characteristics of plants and soil while AEP is largely effected by the characteristics of soil and vegetation.
- The water supply is adequate for plant soil moisture at field capacity at the stage AEP will be equal to PET. If the soil moisture is reduced then

AET by PET ratio will be less than unity.

$$\frac{AET}{PET} = 1$$

- For clayey soils AET/PET ratio will be nearly to unity when the available moisture is depleted upto 50%.
- In hydrology we use PET as a basic parameter in various estimation related to water utilization connected with evapotranspiration process.

### \* Definitions

Field capacity:

Field capacity is the maximum quantity of water that the soil can retain against the force of gravity.

Permanent wilting point:

It is that moisture content of a soil at which moisture is no longer available in sufficient quantity to sustain the plants.

The moisture in soil is tightly bonded with soil grain such that the plant cannot extract the water from it.

## \* Available Moisture:

The difference b/w the moisture content of field capacity & pwp is called available moisture which can be easily extracted by the plant.

## \* Measurement of Evapotranspiration:

The measurement of Evapotranspiration is

Very much important in hydrology. The measurement can be done by

1. Makkie Model
2. Evapotranspiration equation
3. Empirical equation.

## \* Makkie Model:

It can be found out by two model methods

### 1. Lysimeter

A lysimeter is a special water tight tank containing a block of soil and set in a field of growing plants. The plants grow in the lysimeter (or) same as the surrounding field. The evaporation is estimated in terms of the amount of water required to maintain constant moisture conditions within the tank, and is measured by an arrangement made in Lysimeter.

- A Lysimeter should be design to accurately reproduce the soil condition, moisture content, type & size of the vegetation of the surrounding area
- Lysimeter studies are time consuming & expensive.

## 2. Field plots:

A plot is chosen and all the elements like precipitation, irrigation input, surface runoff, soil moisture, and percolation is measured.

$$\text{Evapotranspiration} = \frac{\text{Precipitation} + \text{Irrigation input} - \text{runoff}}{-\text{Increase in soil storage}}$$

- As the measurement of percolation is a very difficult task in actual field problem so we keep the moisture level of soil at field capacity.

## \* Evapotranspiration equations

In the Evapotranspiration equations, the most used equation is Penman's equation.

### Penman's equation.

This equation is based on sound theoretical reason and is obtained by combination of energy balance and transfer approach.

A Hnt Eak

$$PET = \frac{\text{Air}}{\text{A Hnt Eak}}$$

Where PET = Daily Potential Evaporation Transpiration

in mm/day

A = Slope of the saturation vapour pressure vs  
Temperature curve at the mean air temperature  
(in mm of Hg per degree centigrade).

$H_n$  = Net radiation (in mm of evaporable water per day)

$E_a$  = Parameter including wind velocity & saturation  
deficit.

$r$  = Psychometric constant (0.49 mm of Hg  $^{\circ}\text{C}$ )

20/12/18.

\* A Reservoir with a surface area of 300 hectares  
has the following average meteorological values during

a given week. R.H = 50% at temperature of  $30^{\circ}\text{C}$ .

Wind velocity at 1mt above ground is 12 km/hour

Mean barometric reading 750mm of Hg. Saturation

Vapour pressure at  $30^{\circ}\text{C}$  is 31.82 mm of Hg

Estimate the average daily evaporation from

this reservoir and volume of water evaporate

during this week (use Meyer's & Rehse's formula).

So far: Given data:

$R.H = 50\%$   
Reservoir surface area = 300 hectares

$T = 30^{\circ}\text{C}$

$R.H = 50\%$

$e_s = 31.82 \text{ mm of Hg}$

$V_i = 12 \text{ km/hour}$

Mean Barometric reading  $P_0 = 750 \text{ mm of Hg}$

$K_m = 0.86$

Meyer's formula:

$$E = km(es - ea) \left( 1 + \frac{v_9}{16} \right)$$

$$ea = R.H \times e_s = 0.5 \times 31.82 = 15.91 \text{ mm of Hg}$$

$$v_9 \geq \frac{v_1}{v_9} = \left( \frac{1}{9} \right)^{1/7} = \frac{1.2}{v_9} = 0.730,$$

$$v_9 = 16.42$$

$$E = 0.36(31.82 - 15.92) \left( 1 + \frac{16.42}{16} \right)$$

$$E = 11.60 \text{ mm/day}$$

Total quantity of water evaporated

$$Q = \frac{11.60}{1000} \times 300 \times 10^4 = 34800 \times 7$$

$$Q = 243600 \text{ m}^3$$

\* Rohwer's formula:

$$E = 0.771(1.465 - 0.000732)(0.44 + 0.0733 V_{0.6})(e_s - ea)$$

$$V_{0.6} = \left( \frac{V_{0.6}}{v_1} \right) = \left( \frac{0.6}{1} \right)^{1/7} = 0.929$$

$$\frac{V_{0.6}}{T_2} = \left[ \frac{0.6}{1} \right]^{1/7}$$

$$V_{0.6} = 11.15 \text{ cm/hr}$$

$$E = 0.771 \left[ 1.465 - 0.000732 \right] \left[ 0.44 + 0.0733 \times 11.15 \right] \left[ 31.82 - 15.91 \right]$$

$$E = 14.1 \text{ mm/day}$$

$$Q = \frac{14.12}{1000} \times 300 \times 10^4 = 42360$$

$$Q_1 = 42360 \text{ m}^3 \text{ (per day)}$$

$$\therefore Q_1 = 42360 \times 7 = 2,96,520 \text{ m}^3 \text{ (per week)}$$

Total quantity of water per day =  $42360 \text{ m}^3$

Total quantity of water per week =  $2,96,520 \text{ m}^3$

### \* Infiltration:

It may be defined as the downward movement of water from soil surface into the

soil mass through the pores of the soil.

In simple terms infiltration is the entry (or) passage

of water into the soil through soil surface. Once

water enters into the soil the process of transmission

of water in the soil known as "Percolation."

Infiltration is a major process continually affecting

the magnitude, timing & distribution of surface runoff

of a basin

### \* Infiltration Capacity:

The capacity of any soil to absorb water

from rainfall continuously at an excessive rate

goes on decreasing with time until a minimum rate

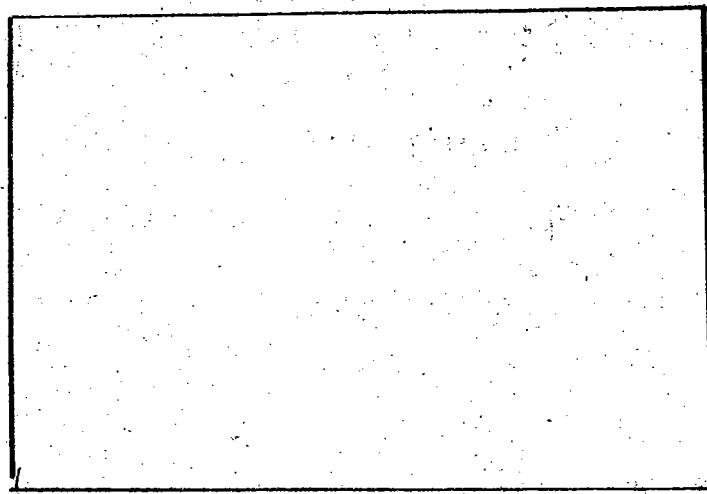
of infiltration is reached. At any instant the

infiltration capacity of a soil is the max. rate at which water can infiltrate the soil in a given condition.

## \* Effects of Infiltration:

- It reduces the magnitude of the flood.
- It delays the time of arrival of water to the channel.
- It recharges the ground water reservoir.
- It reduces soil erosion.
- It fills the soil pores to its field capacity thus making water available to plants.
- It sustains green vegetation cover on the ground surface thus helps in reducing dust storms.

24/12/18



## \* Factors affecting Infiltration:

Condition of entry surface (Vegetation cover for Bareland)

If the area is covered by grass, vegetation & bushy plants the infiltration capacity will be more.

→ Retarding surface flow and thus allowing more time for water to drain under the soil.

→ Shielding the soil surface from direct impact of raindrops because raindrop causes compaction and reducing infiltration capacity.

→ The root system of the vegetation makes the soil more permeable and thus encourage more rapid passage of infiltrating water.

\* Spreading of building and paved surface in urban areas effectively reduces the infiltration.

## 2. Permeability (or) Percolation characteristics of soil formation

The infiltration will continue only when percolation continues. The infiltrated water must be transmitted down by the force of gravity and capillary action.

The percolation however depends upon several factors such as soil & its composition, permeability, porosity, stratification presence of organic matter and presence of salts.

## \* Moisture conditions in soil:

The infiltration rate will depend on initial moisture conditions of soil. When the soil moisture is high the infiltration rate will be low. When water falls on a dry surface the upper surface becomes wet while the lower parts of the soil remain comparatively dry initially. This results in a large difference of capillary potential due to which a downward force will act on the water in addition to the normal force of gravity.

## Temperature

The viscosity of water changes with temperature.

The flow of water within the body of the soil is laminar and the flow is directly related to viscosity. In summer the infiltration will be higher due to less viscous water, in comparison to winter.

## Intensity and duration of rainfall:

When the precipitation takes place with heavy intensity the impact of water causes mechanical compaction of fine particles, resulting in faster decrease in the rate of infiltration. However rainfall of lesser intensity result in higher infiltration rate. The rainfall with higher duration will result in lower infiltration in comparison to the same quantity of rain falling as 'n' number of isolated stones.

## Movement of Man and Animals:

When there is heavy movement of man (or) animals the soil gets compacted resulting in reduction in the infiltration rate.

## Change due to human activities:

Cultivation of barren land by growing crops and grass cover results in increasing rate of infiltration.

On the other hand construction of roads, houses, factories, playgrounds results in reduction in infiltration capacity.

## Quality of water

Silts and other impurities present in incoming water result in retardation of infiltration rate due to clogging of soil pores. The salts present in water affect the viscosity of water and may react with soil to form complexes that reduce the porosity of soil.

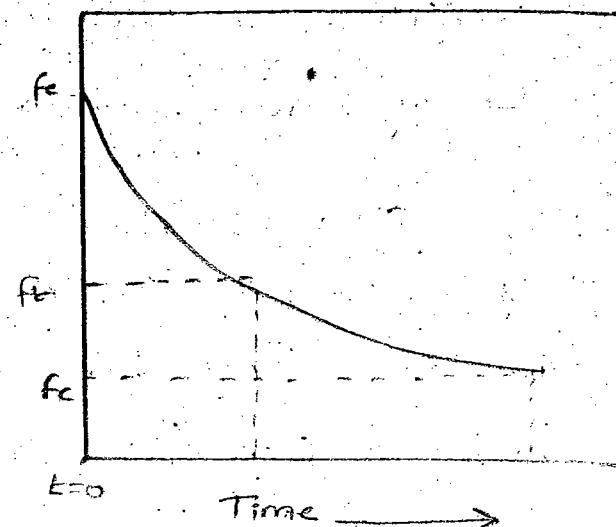
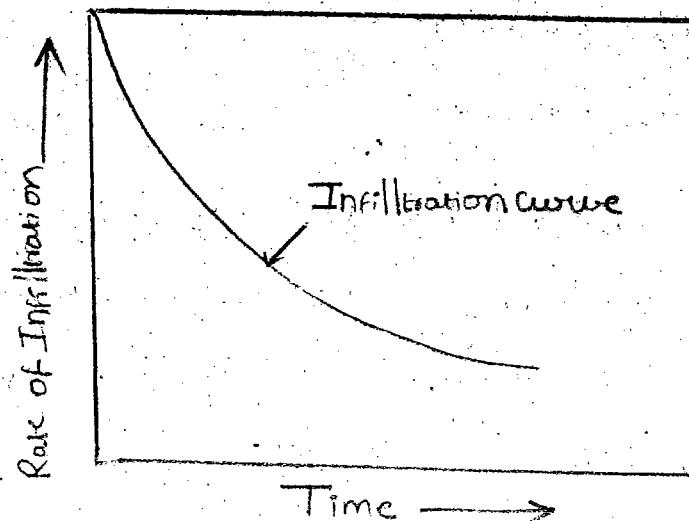
## Presence Of Ground water Table

In presence of GW Table reduces infiltration. For infiltration to continue in position of GWT should not be very close.

## Size and characteristics of soil particles

The infiltration rate is directly proportional to the grain size (or) diameter for granular soil. However if the soil has swelling minerals like illite, the infiltration rate may reduce drastically.

## \* Infiltration Capacity Curves



26/12/18.

## \* Field measurement of Infiltration rate:

It can be measured with two types of Infiltrometers

1. single tube infiltrometer
2. Double tube Infiltrometer

### 1. Single tube Infiltrometer

It consists of a hollow metal cylinder of 30cm diameter, 60cm length with both ends open. The cylinder is driven in the ground such that 10cm of it projects above the ground. The cylinder is filled with water such that a head of 7cm within the infiltrometer is maintained above ground level. Due to infiltration of water the water level in the cylinder will hope on decreasing.

Water is added to the cylinder through graduated

jars (81) Burette so as to maintain constant level

The volume of water added over a pre determined time interval gives

the infiltration rate for that time interval.

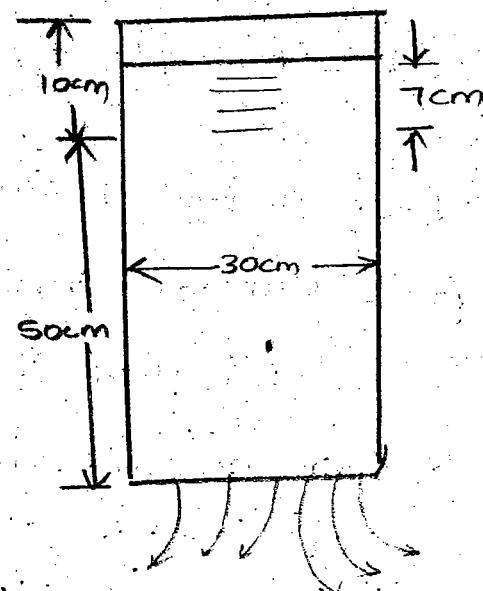
The observations are

continued till almost

uniform infiltration rate is

obtained, which may take about 3-6 hrs depending

on the type of a soil.



## 2. Double tube Infiltrometer:

This infiltrometer consists of two concentric hollow rings driven into the soil uniformly without any tilt and disturbing the soil to the least depth of 15cm. The diameter of the rings may vary from 25-60cm.

Water is applied in both inner & outer rings to maintain a constant depth of about 5cm. The water depth in the inner & outer rings should be kept the same during the observation period.

By using of Empirical Equations:

Horn ton's equation:

$$f_t = f_c + (f_0 - f_c) e^{-RT}$$

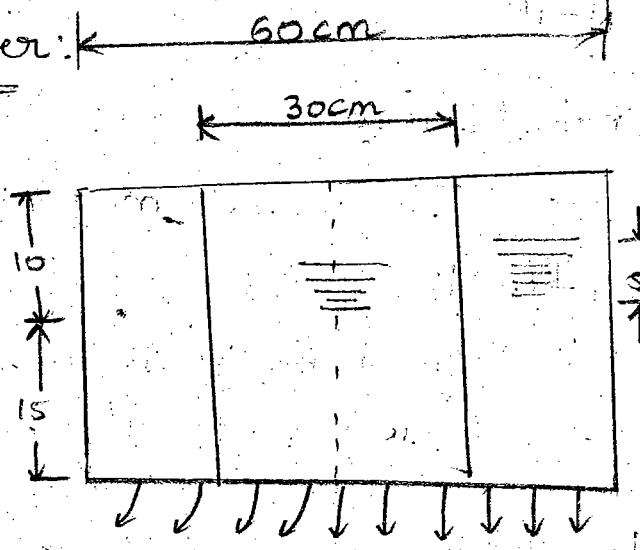
Where

$f_t$  = infiltration rate at any time  $t$

$f_c$  = constant infiltration rate at time  $t = T$  (say)

$f_0$  = Infiltration rate in the beginning ( $t=0$ )

$K$  = a constant which depends on the soil and Vaporation.



31/12/18.

### 3. RUN-OFF

Runoff means the draining of precipitation from a catchment area through the surface channels. It is normally expressed as volume per unit time for a given area, represents the output from the catchment in a given unit of time.

#### \* Characteristics of Runoff:

The total runoff from a typical catchment area may be divided into 4 parts

1. Direct precipitation | stream channels.
2. Surface runoff
3. Interflow
4. Groundwater flow.

#### \* Direct precipitation | stream channels:

The precipitation on the water surface will normally go into the stream channels. This portion of runoff represents only a small percentage of total volume of water flowing in the stream.

#### \* Surface runoff:

The precipitation over the land surface moves as sheet flow, this portion of runoff is called overland flow. Normally the length & depth of overland flow is small, and flow is laminar after travelling this small length. Over the ground they join a channel and become

Eulerian due to high velocity in channel. The flow from several small channels join to make bigger channel and these bigger channel join to form large stream till the overall flow reaches the catchment outlet.

### \* Interflow

The part of precipitation that infiltrate into the soil moves gradually laterally and return to the surface at some location away from the point of entry to the soil, is called Interflow.

### \* Ground Water Flow

Sometime infiltrated water is to undergo deep percolation and reach the ground water storage in the soil. The ground water follow a complicated path ultimately reaches the surface.

### \* Classification of Runoff

Based on the time delay b/w the precipitation & the runoff, the runoff is classified as

1. Direct runoff
2. Base flow.

## \* Direct runoff

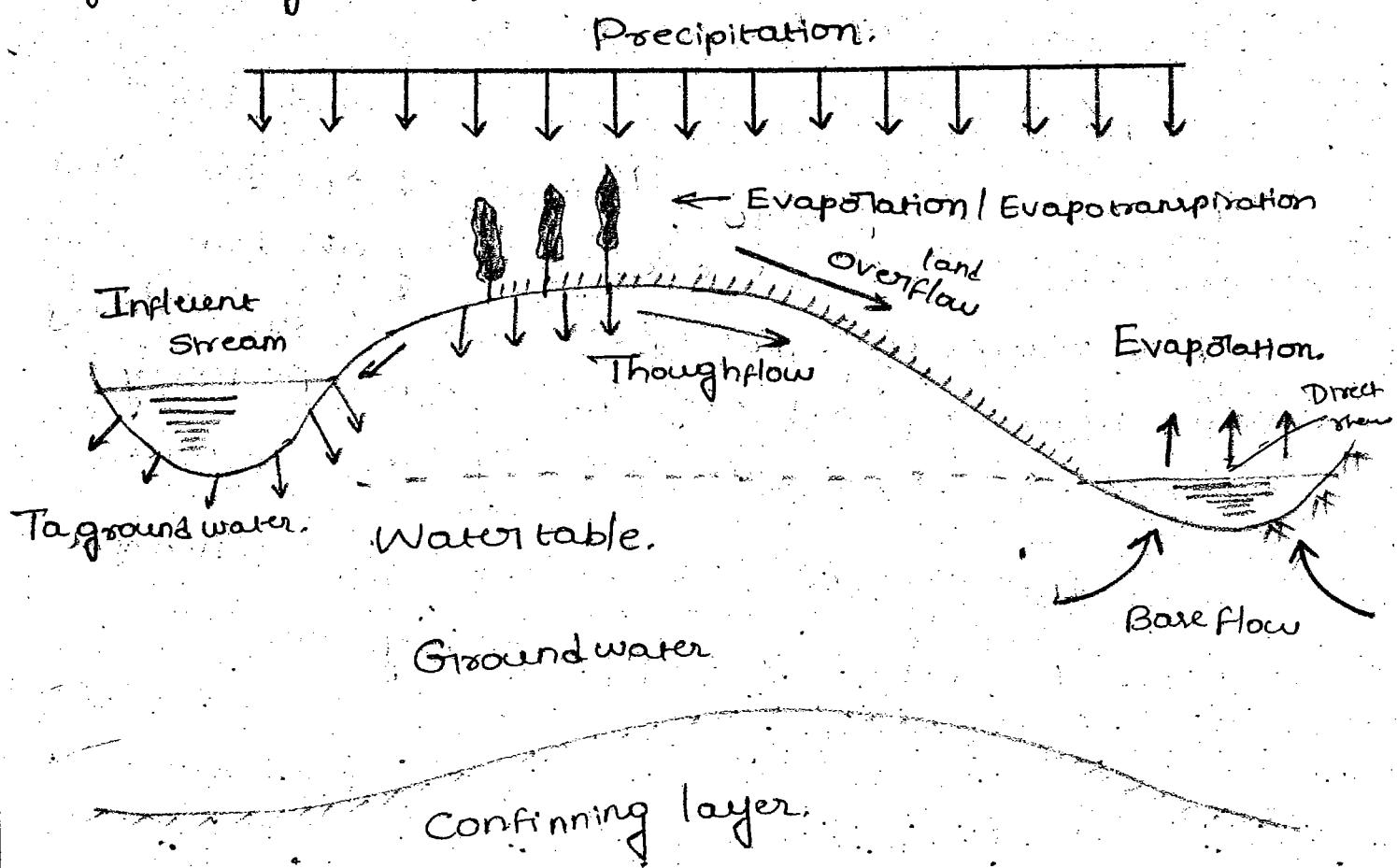
It is the part of runoff which enters the stream immediately just after the rainfall.

It includes

1. Surface runoff
  2. Prompt inflow
  3. Rainfall on surface of stream
- Resulting inflow due to snow melt into stream is called "Direct runoff."

## \* Base flow

The delayed flow that reaches a stream generally as groundwater is called "Base flow."



## Objectives

### \* Factors effecting Runoff

The principal factors effecting the flow from a catchment area are

#### 1. Precipitation characteristics.

This is the most important factor on which runoff depends. Important precipitation characteristics are

1. Intensity 2. duration 3. Areal distribution

4. Direction of stream movement 5. Form of precipitation

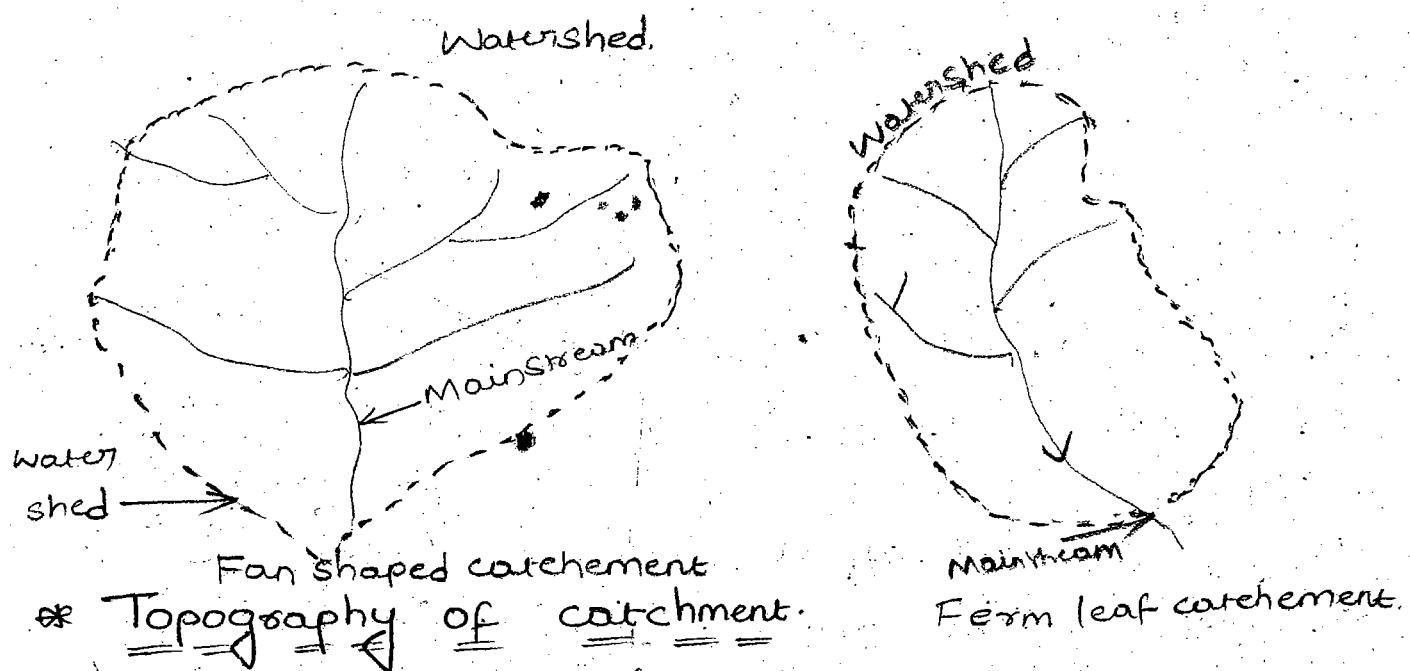
6. Evapotranspiration

The runoff depends on the type of the stream carrying precipitation and also upon its duration. Runoff also increases with the intensity of rainfall.

#### 2. Shape and size of the catchment:

The runoff from a catchment also depends upon the size, shape and location of the catchment. More intense rainfalls are generally distributed over a relatively smaller area. A stream collecting water from a small catchment area is likely to give greater runoff intensity per unit area.

In the case of fan(δ) shaped catchment all the tributaries are approximately of the same size. Such catchment gives greater runoff since the peak flood from the tributaries is likely to reach the mainstream approximately at the same time.



The runoff depends upon whether the surface of the catchment is smooth (or) rugged. If the surface slope is steep, water will flow quickly, and absorption, evaporation losses will be less. Resulting in greater runoff. If catchment lies on the windward side of the mountains the intensity of rainfall will be more, and hence runoff will also be more.

#### \* Orientation of watershed

In orientation of watershed effects the evaporation and transpiration loss by influencing the amount of heat received from the sun. The N-S. orientation of watershed effects the melting time of collected snow and hence the runoff. Similarly in mountainous watershed the windward side of the mountain receives comparatively higher intense rainfall than the leeward side.

## \* Geological characteristics of building basin

This is an important factor effecting the runoff there include the type of surface soil and subsoil, type of rock and their permeability characteristics. If the soil and subsoil is pervious seepage will be more and this is term reduces the peak flood. If the surface is rocky and the absorption will be practically nil, so the runoff will be more.

## \* Meteorological characteristics

Temperature, wind and humidity also effects the runoff. If the temperature is low the ground is saturated & frozen, It gives rise to greater runoff. However if the whole of the steel freezes the peak floods will be reduced. On the other hand high temperature and greater wind velocity give rise to greater evaporation loss and reduce the runoff.

\* The peak flood depends upon the direction of movement of the storm causing rainfall with relation to the direction of the stream.

## \* Character of the catchment surface

The runoff depends upon the surface condition whether the surface is drained (or) undrained, natural (or) ~~ultimate~~ cultivated (or) it is covered with vegetation etc.... If the surface has enough natural drainage, absorption loss will be more. If more area of a catchment is cultivated surface runoff will be less.

## \* Storage characteristics of catchment

The artificial storage such as dams, reservoirs etc... and natural storage such as lakes, ponds etc... tend to reduce the peak flow. They also give rise to greater evaporation losses.

04/01/2019

### Important definitions:

#### Stream density:

If  $N$  is the no. of streams in the basin and  $A$  is the total area of the basin, then

#### Stream density

$$D_s = \frac{N}{A} \cdot \left[ \frac{\text{No. of streams}}{\text{Km}^2} \right]$$

#### Drainage Density:

It is defined as length of streams per unit area.

$$\text{Drainage density (Dd)} = \frac{L}{A} \left[ \frac{\text{L}}{\text{Km}^2} \right]$$

### \* Time of Concentration

= = = = = =

It is a drainage basin time required by water to reach the outlet from the remote point on the basin.

### \* Time of overland flow

= = = = = =

Excess rainfall passes it's weight overland to the rivers stream and appears as surface runoff but only after some delay.

In other words there exist a lag time and when excess rainfall occurs and the time when it appears as runoff at the outlet.

This lag is time for which water has flowed through the basin before entering into a definite drain known as "Time of overland flow."

### \* Isochromes:

It is the line joining points of equal total time overland flow on a drainage basin.

It is the line joining points of equal total time overland flow on a drainage basin.

It is the line joining points of equal total time overland flow on a drainage basin.

## \* Competition of Runoff

=====

The using methods are

1. Using runoff coefficients
2. Using infiltration capacity curves
3. Using infiltration indices
4. Using empirical equations
5. Using tables and curves.
6. Using unit hydrograph method.

22/01/2019

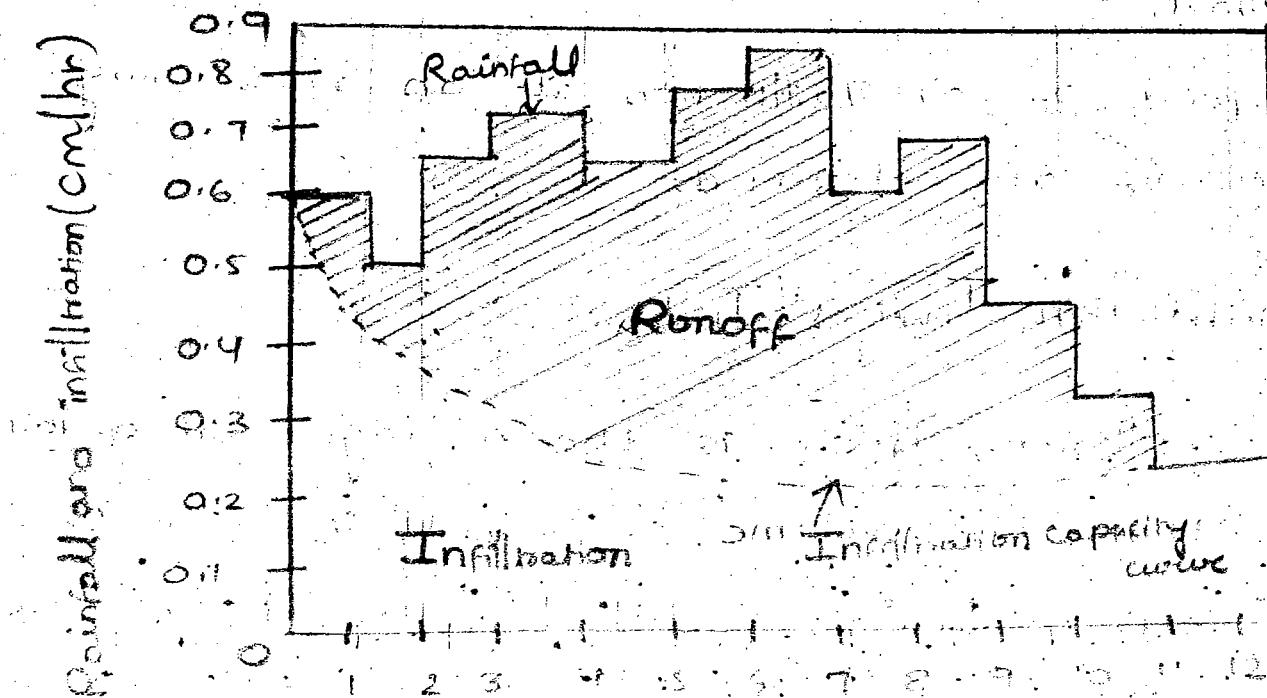
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## \* Runoff coefficients

$$R = K \cdot P$$

$K$  = Coefficient,  $P$  = Precipitation,  $R$  = Runoff.  
in cm              in cm              in cm

## Runoff by Infiltration capacity curve Method.



The infiltration is defined as the movement of water to the soil surface and into the soil.

The capacity of any soil to absorb water from rainfall falling continuously at an excessive rate goes on decreasing with time until a minimum rate infiltration is reached.

The infiltration rate is the rate at which water actually enters the soil during a storm and is equal to the infiltration capacity ( $I_C$ ) if the rainfall rate whichever is less.

### $I_C$ curve limitations

$R = K$   
It is applicable for small areas with

homogenous soil condition and uniform rainfall

→ and it cannot be applicable for large areas because the soil having heterogeneous conditions & non-uniform rainfall.

→ Some part of an infiltration at an area may be runoff at other area.

### \* Infiltration Indices (Index)

$= = = = = = = =$

Infiltration Index is the average rate of loss such that the volume of rainfall in excess of that rate will be equal to the direct runoff

Estimate of runoff volume from large areas having heterogeneous infiltration loss and rainfall characteristics are made by use of infiltration Indices

\* Average Infiltration Rate ( $\bar{\delta}$ ) W-Index &  $\phi$ -Index

$\phi$ -Index

It is defined as the average rate of rainfall above which the rainfall volume equal to the runoff volume. Alternatively it is defined as the average rate of loss such that the volume of rainfall in excess of that rate will be equal to direct runoff. The  $\phi$  index is usually known as excess of rainfall (or) effective rainfall.

$$\phi_i = \frac{P - R}{t_{ex}}$$

Thus we find that W-index is essentially equal to  $\phi$ -index minus average rate of retention by interception and depression storage.

$$\phi_i = \frac{\text{Total infiltration during excess rainfall}}{\text{Duration of excess rainfall}}$$

$$\phi \text{ index equal to } \frac{A_2 + A_3 + A_4 + A_5}{P}$$

$$\phi_i = \frac{A_2 + A_3 + A_4 + A_5}{t_{e1} + t_{e2} + t_{e3}}$$

Where.

$A_2, A_3, A_4, A_5$  = Infiltration during excess rainfall

$t_{e1}, t_{e2}, t_{e3}$  = Individual periods of excess rainfall;

\* W-index

$$W_i = \frac{A_2 + A_3 + A_4 + A_5}{t_{01} + t_{02} + t_{03}}$$

Where  $t_{0i}$  = Total period of Rainfall.

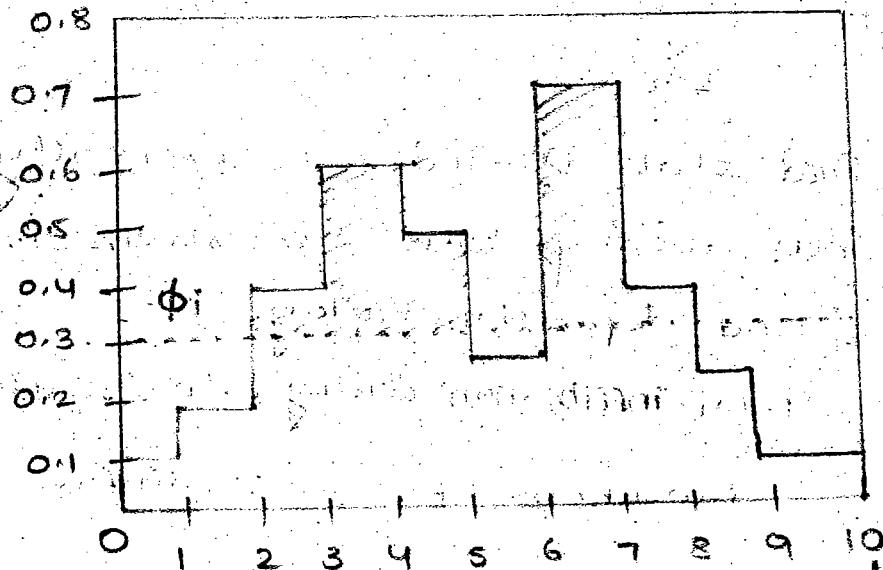
The W-index is calculated from the expression is

$$W_i = \frac{P - R - S_R}{t_{0i}} \text{ cm/hr.}$$

Where  $S_R$  = Surface Retention

$t_{0i}$  = Duration of rainfall in hours.

Q<sub>i</sub> Curve:



24/01/16

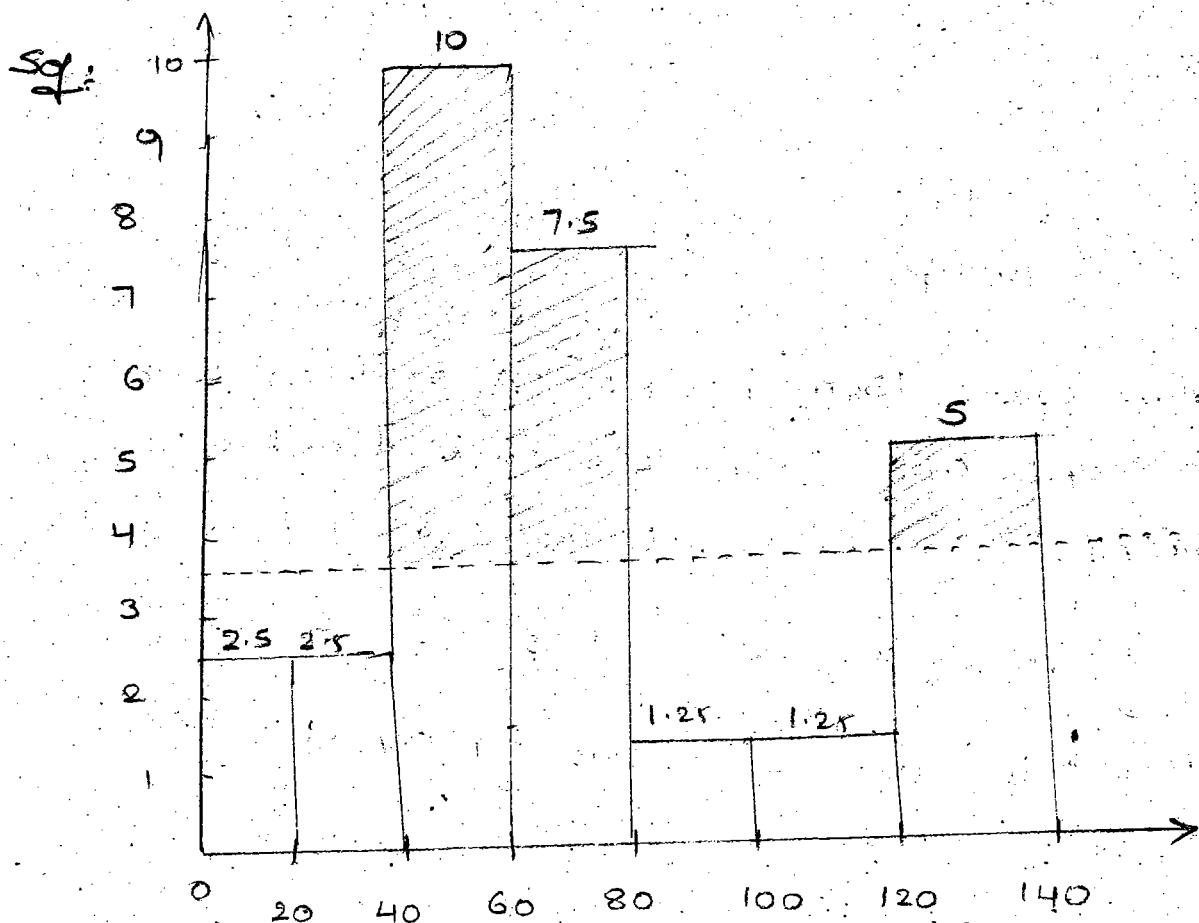
1. The following are the rate of rainfall for successive 20min period for a rainfall of 140 minutes duration.

Time	20	40	60	80	100	120
Duration (Rate of rainfall)	2.5	2.5	10	7.5	1.25	1.25
Time	140					
Duration		5.0				

Taking  $\phi_i$  as 3.2 cm/hr

Find out net runoff in cm

Total runoff & value of W-Index.



Step 1:

$$\text{Net runoff } R = \sum (i - \phi_i) t$$

$$= \left[ (10-3.2) \frac{20}{60} + (7.5-3.2) \frac{20}{60} + (5-3.2) \frac{20}{60} \right] \\ = 4.8 \text{ cm/hr}$$

Step 2

$$\text{Total Rainfall } = (2.5+2.5+10+7.5+1.25+1.25+5) \frac{20}{60} \\ = 30 \text{ cm/hr}$$

Step 3:

Windex

$$W_i = \frac{P-R-Sg}{Eg} \\ = \frac{10 - 4.3 - 0}{146/60} = 2.44 \text{ cm/hr}$$

2. A storm with 15cm precipitation produces a direct runoff of 8.7cm. The time distribution of storm is as follows. Estimate  $\phi$  index of a storm

Time	1	2	3	4	5	6	7	8
Excess Rainfall in each hour (cm)	0.6	1.35	2.25	3.45	2.7	2.4	1.5	0.75

28/01/19.

2. Sol: Given data:

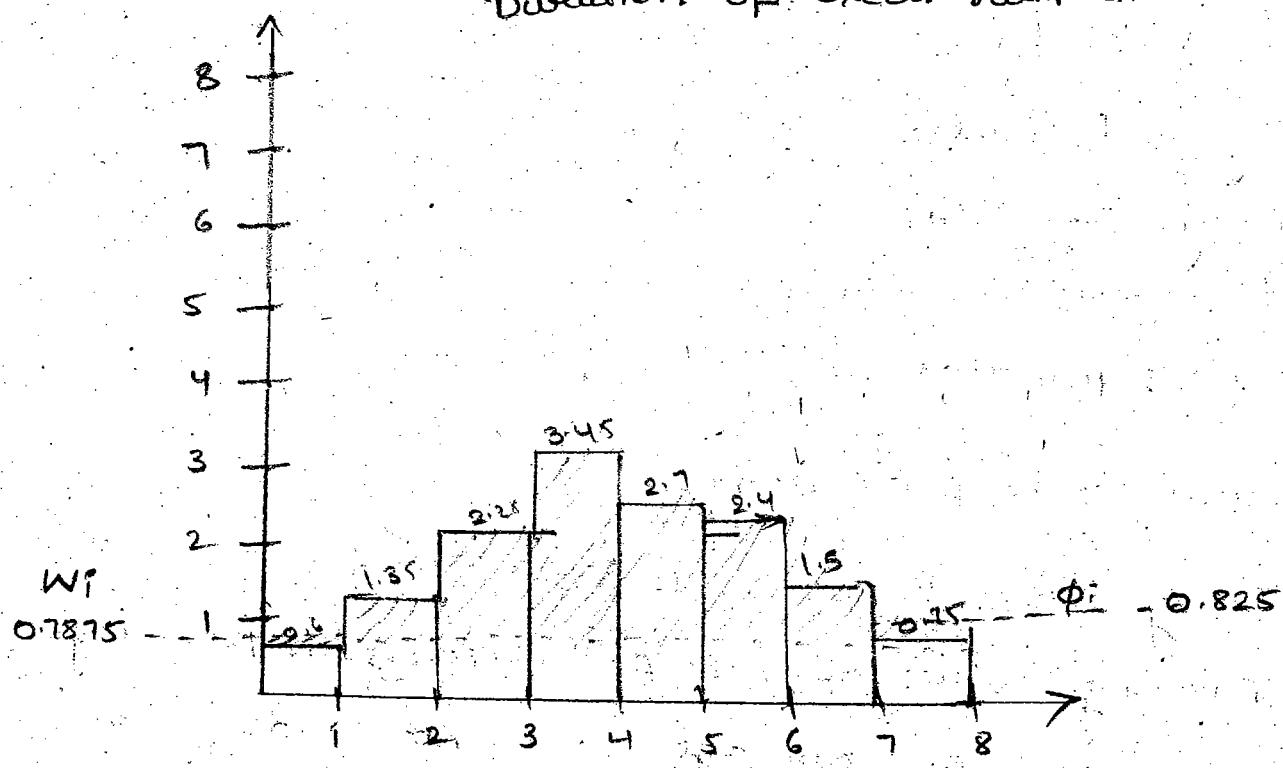
$$\text{Precipitation (P)} = 15 \text{ cm}$$

$$\text{Direct Runoff (R)} = 8.7 \text{ cm}$$

As we know that  $\phi$  index  $\geq W_i$

$$W_i = \frac{P - R - S_{91}}{t_{91}} = \frac{15 - 8.7 - 0}{8} = 0.7875 \text{ cm/hr}$$

$$\phi_i = \frac{\text{Total infiltration during excess rainfall} - (\text{Infiltration at start}) - (\text{Infiltration at end})}{\text{Duration of excess rainfall}}$$



As 1st and last hour rainfall is less than W-index so they do not give any excess rainfall i.e. Runoff

∴ The excess rainfall may be occur in b/w (Infiltration & Runoff)

$$\phi_i = \frac{\text{Total infiltration during excess rainfall} - (\text{Infiltration at start}) - (\text{Infiltration at end})}{\text{Duration of excess rainfall}}$$

$$\frac{(15 - 8.7) - (0.6) - (0.75)}{6} = 0.825$$

Check:

$$\begin{aligned} \text{Runoff} &= (1.35 - 0.825) + (2.25 - 0.825) + (3.45 - 0.825) \\ &\quad + (2.7 - 0.825) + (2.4 - 0.825) + (1.8 - 0.825) \\ &= 8.7 \text{ cm} \end{aligned}$$

Q9/01/19.

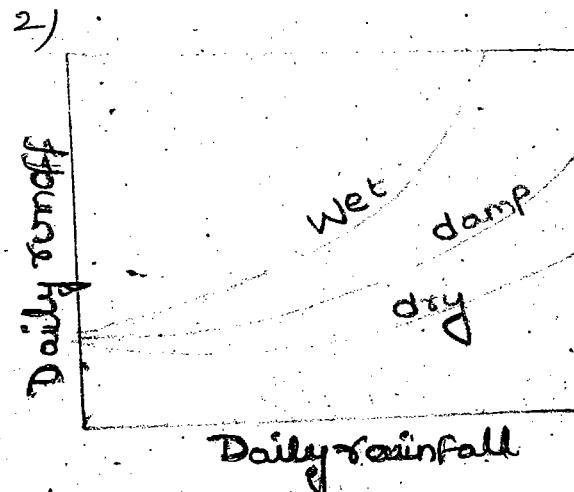
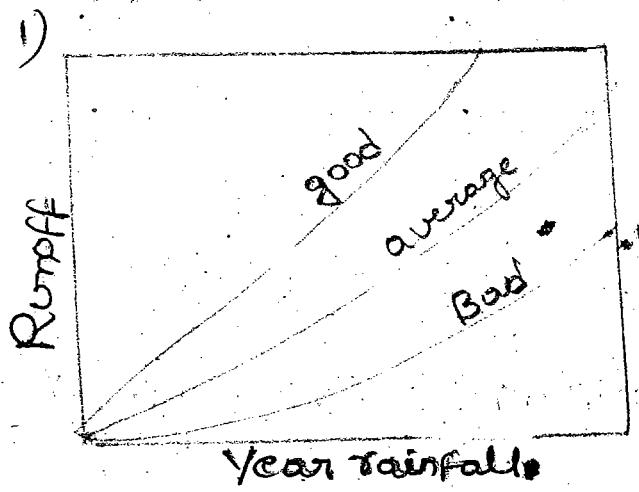
### \* Empirical Formulae and Charts.

1. Burrow's runoff coefficient
2. Stranigan's charts and tables
3. Inglis' Formulae
4. Lacey's Formulas
5. Khosla's formulas
6. Pakers formulas.

### \* Burrow's runoff coefficient:

This is Study 140 km<sup>2</sup> catchment in United province and give following values of runoff coefficients in percentages. The values are for average coefficient and to be multiplied with constants according to seasons.

Burrow's catchments	K(%)
A Flat, cultivated, Black cotton soils	10%
B Flat partly cultivated various soils	15%
C Average soils	20%
D Hills and planes with cultivation	35%
E Very hilly and steep area with hard soil cultivation	45%



### \* Stranger's Tables and charts

He proposed tables & charts for computation of runoff in planes of south India. These charts & tables gives information about yearly and daily runoff based on corresponding rainfalls and take into account of 3 types of catchments.

1. Good 2. Average 3. Bad (Rainfalls)

2. Dry, Damp, Wet → (surface conditions).

### \* Tingli's Formula:

For Bombay presidency, Western Ghats and plains of Maharashtra

$$\text{Ghats : } R = 0.85P - 30.5$$

$$\text{Non Ghats : } R = \left( \frac{P-17.8}{2.54} \right) P \quad [P, R \text{ in cm}]$$

### Indo-gangetic plain:

$$R = \frac{!}{1 + \frac{304.8F}{P.S}} \quad (P, R \text{ in cm})$$

$F \rightarrow$  Type of Monsoon for certain period.

F → 0.5 short  
 F → 1.0 Standard  
 F → 1.5 Long

S value: Depending upon classification of catchment  
 by Below

$$A \rightarrow 0.25$$

$$B \rightarrow 0.6$$

$$C \rightarrow 1.0$$

$$D \rightarrow 1.7$$

$$E \rightarrow 345$$

#### 4. Khosla's Formula

$$\text{Runoff } R = P - \frac{T-32}{3.74}$$

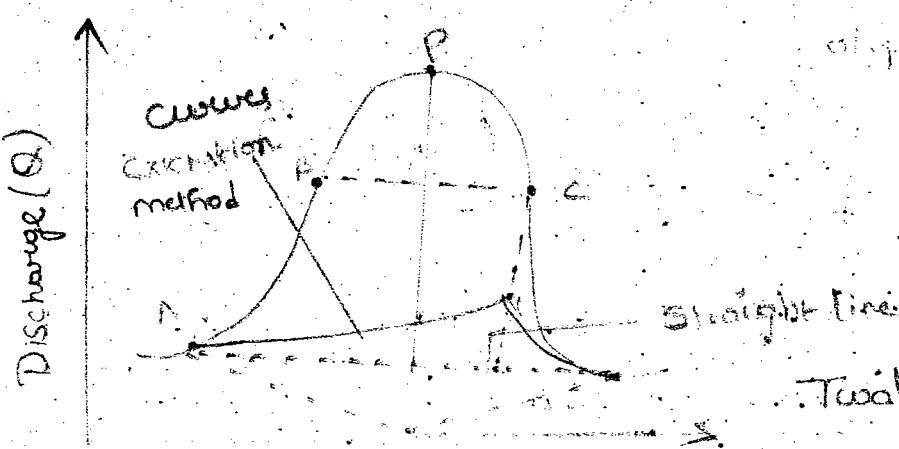
#### 5. Parker's Formula

$$R = 0.94P - 1.4 \rightarrow \text{British}$$

$$= 0.94P - 1.6 \rightarrow \text{Germany}$$

$$= 0.84P - 16.5 \rightarrow \text{East U.S.A.}$$

#### Bate flow Graph



straight line

Two line method

08/02/19:

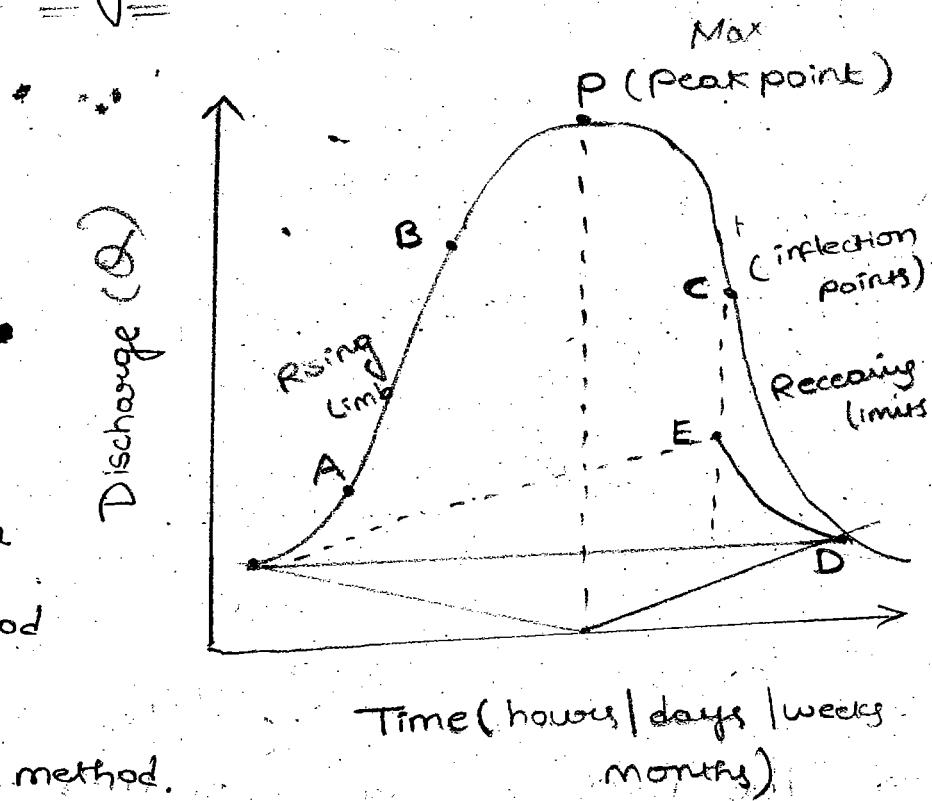
## \* Hydrograph Analyses:

components:

1. Rising limb
2. Peak point
3. Inflection point
4. Receding limb

Bare flow separation

1. Straight line method
2. Two line method
3. Curve extension method.



The following are the ordinates of a runoff hydrograph  
3 hours storms runoff readings are measured at  
3 hour intervals

(Time) Hour	0	3	6	9	12	15	18	21	24
ordinates	10	25	40	60	75	35	20	5	10

Assume Bareflow  $10 \text{ m}^3 \text{ per second}$ . Find out Ordinates  
of direct runoff hydrograph & runoff depth in cm  
if area of catchment is  $20 \text{ km}^2$ .

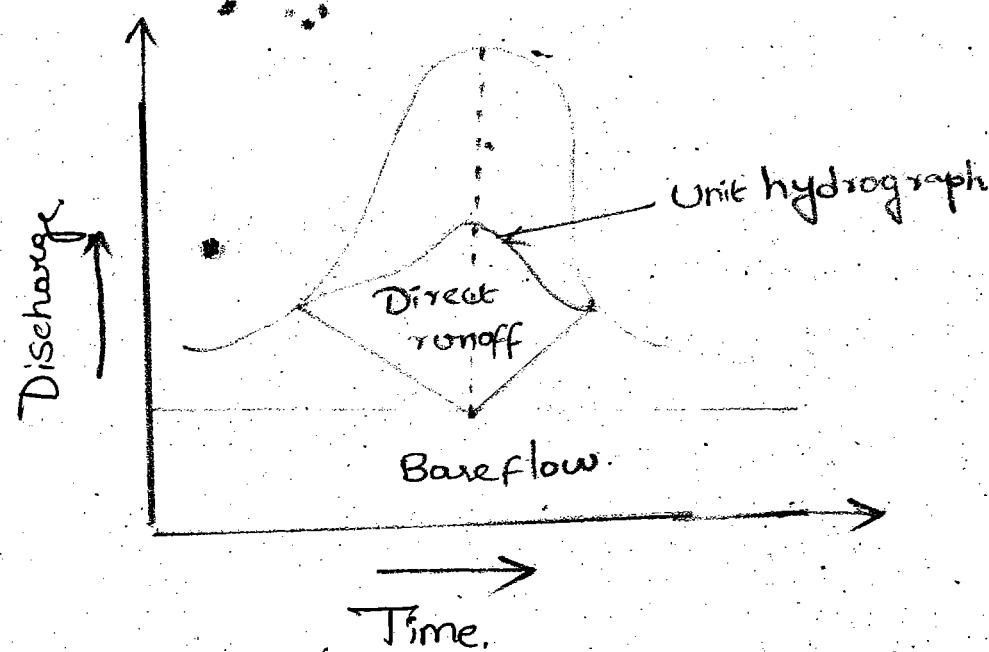
Sol: Direct runoff =  $\frac{0.36(\Sigma O)t}{A}$

$$D.R. = \frac{0.36(10+25+40+60+75+35+20+15+10)}{20}$$

$$= 15.66 \text{ cm}$$

14/02/19  
=====

## Unit Hydrograph Method



\* The following Runoff values are available for outlet for 4 hour rainfall over a catchment.

Derive 4 hour unit hydrograph for a catchment

Assuming bare flow is uniform at  $20 \text{ m}^3/\text{s}$  -

Area of catchment is  $200 \text{ km}^2$ .

Time (hours)	ordinates of flood Hydrograph	Bareflow
0	20	20
4	35	20
8	60	20
12	220	20
16	430	20
20	450	20
24	250	20
28	180	20
32	80	20
36	20	20

Time (hours)	ordinates of flood hydro. graph	Bareflow	ordinates of DRH	unit hydrograph
0	20	20	0	0
4	35	20	15	1.348
8	60	20	40	3.595
12	220	20	200	17.979
16	430	20	410	36.853
20	450	20	480	38.665
24	250	20	230	20.676
28	180	20	160	14.313
32	80	20	60	5.393
36	20	20	0	0

$$\text{Depth of runoff} = \frac{0.36(1545)4}{200}$$

$$= 11.124 \text{ cm}$$

ordinates of unit hydrograph. ( $\frac{\text{DRH ord}}{\text{Runoff}}$ )

$$\frac{15}{11.124} = 1.348$$

$$\frac{40}{11.124} = 3.595$$

$$\frac{200}{11.124} = 17.979$$

$$\frac{40}{11.124} = 36.853$$

$$\underline{430} = 38.655$$

$$\frac{230}{11.124} = 20.676$$

$$\frac{160}{11.124} = 14.383$$

$$\frac{60}{11.124} = 5.393$$

$$\Sigma O = 138.882$$

Check: Depth of runoff for U.H = 1cm

$$\rightarrow \frac{(0.36 \times 138.82) \times 4}{200} = 1\text{cm.}$$

\* Expt

Derive a 2-hr unit hydrograph from following total runoff hydrograph resulting from rainfall of effective duration 2hrs.

Drainage basin area is 104 km<sup>2</sup>.

Date	Time(hr)	Runoff (m <sup>3</sup> )	Baseflow (m <sup>3</sup> )
------	----------	--------------------------	----------------------------

July 10	06	14.2	14.2
	08	958.5	14.7
	10	260	15.2
	12	286	15.7
	14	221	16.2
	16	186.5	16.7
	18	157	17.2
	20	133	17.3
	22	113	17.7

July 11

2	76.4	19.2
4	65.0	19.7
6	55.2	20.2
8	46.7	20.7
10	39.6	21.2
12	34	21.7
14	28.3	22.2
16	22.7	22.7

Sol: Depth of run off =  $\frac{0.36(\Sigma O) \times t}{A}$

$$= \frac{0.36(1659.3) \times 2}{104}$$

$$= 11.48 \text{ cm}$$

Date	Time	Runoff	Baseflow	ordinates of DRH	ordinates of shg hydrograph
July 10	06	14.2	14.2	0	0
	08	158.5	14.7	143.8	12.52
	10	260	15.2	244.8	21.32
	12	286	15.7	209.8	23.54
	14	221	16.2	204.8	17.83
	18	186.5	16.7	160.8	14.79
	20	157	17.2	130.8	12.17
	22	133	17.3	115.7	10.07
	24	113	17.7	95.3	8.30
	July 11	2	76.4	19.2	6.50
	4	65.0	19.7	57.2	4.98
	6	55.2	20.2	45.3	3.945
	8	46.7	20.7	35.0	3.048
	10	39.6	21.2	26.0	2.264
	12	34	21.7	18.4	1.602
	14	28.3	22.2	12.3	1.071
	16	22.7	22.7	6.1	0.531

$\Sigma$  ordinates of unit hydrograph = 144.481.

Check:

$$\frac{(\Sigma O) \times 36 \times 2}{104} = \frac{144.481 \times 0.36 \times 2}{104} = 1.00 \text{ cm.}$$

14/10/2019.

\* Application of unit hydrograph for the construction of flood hydrograph resulting from the rainfall of unit duration.

$$DRH = \text{Runoff (cm)} \times \text{ordinates of unit hydrograph}$$

2. Ordinate of flood hydrograph = ordinates of DRH + Bareflow

The following data of 2h unit hydrograph. If rainfall exceeds 8cm for an intense rainfall of 2 hours on some catchment. Determine the ordinates of flood hydrograph. Bare flow of ordinates are given below.

Sol:

Date	Time	Ordinates of unit hydrograph	ordinates of DR	Bareflow	ordinates of flood hydrograph
	6	0	0	4.0	4
	9	0.12	0.96	3.5	4.46
	12	0.35	2.80	3.0	5.80
	15	0.88	7.04	2.5	9.84
	18	1.50	12.0	2.0	14.00
	21	2.80	22.40	1.5	23.90
	24	2.00	16	1.8	17.80
Day - 2	3	1.85	14.80	2.1	16.90
	6	1.53	12.24	2.4	14.64
	9	1.26	10.08	2.7	12.78
	12	0.84	6.72	3.0	9.72
	15	0.50	4.00	3.3	7.30
	18	0.35	2.80	3.6	6.40
	21	0.12	0.96	3.8	4.76
	24	0.00	0	4.0	4.0

\* Application of unit hydrograph to construct flood hydrograph resulting from 2(00) more rainfall of same duration.

Find the ordinates of a storm hydrograph resulting from  $\Delta t = 3h$  with rainfalls of  $2, 6.75, 37.5$  mm respectively during subsequent 3 hours intervals. The ordinates of unit hydrograph are given in the following table. Assume an initial loss of 5mm and  $\phi$  index of  $2.5 \text{ mm/hr}$  and a constant base flow of  $10 \text{ m}^3/\text{sec}$ .

Time	ordinates of UH.	Rainfall Excess.	Surface Runoff due to excess rainfall in 3hr dur				Base flow
			0.75	6	3	Total	
3	0	0.75	0	0	0	0	
6	110	6	82.5	660	330	1072.5	
9	365	3	213.7	2190	1095		
12	500		37.5	3000	1500		
15	390		292.5	2340	1170		
18	350		232.5	1860	930		
21	250		187.5	1500	750		
24	235		176.25	1410	705		
3	175		131.25	1050	525		
6	130		97.5	780	390		
9	95		71.25	570	285		
12	65		48.75	390	195		
15	40		30	240	120		
18	22		16.5	132	66		
21	10		7.5	60	30		
24	0		0	0	0		

Rainfall excess during 1st 3 hours

$$\Rightarrow 20 - (2.5 \times 3) = 12.5 - 5 = 7.5 \text{ mm} = 0.75 \text{ cm.}$$

Rainfall excess during 2nd 3 hours,

$$67.5 - (2.5 \times 3) = 60 \text{ mm} = 6 \text{ cm.}$$

Rainfall excess during 3rd 3 hours and last 3 hours,

$$37.5 - (2.5 \times 3) = 30 \text{ mm} = 3 \text{ cm.}$$

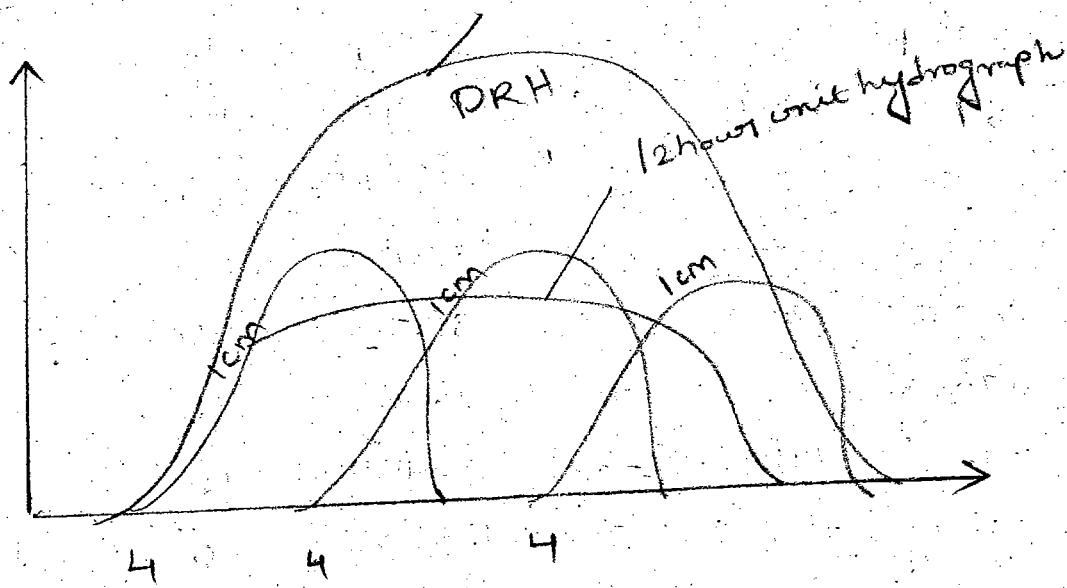
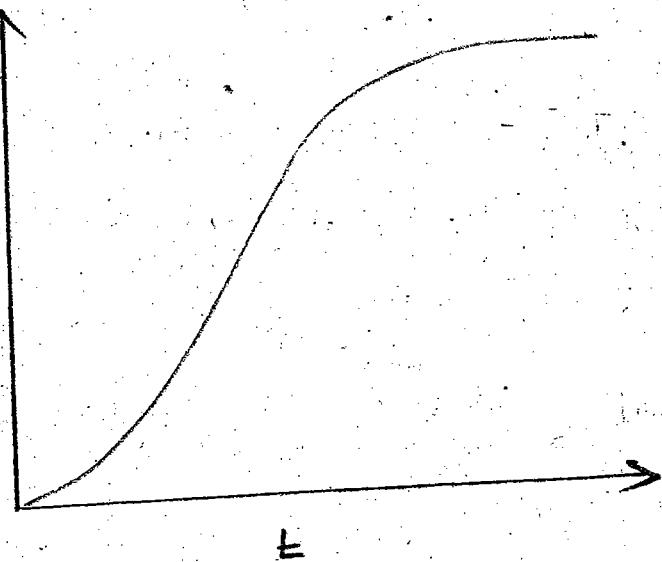
Rainfall excess.	Surface run-off from rainfall excess during successive unit periods			Baseflow	Total Discharge
	0.75	6.00	3.00		
0.75	0			0	10
6.00	82.5	0		82.5	10
3.00	27.5	660	0	934	10
	375	2190	330	2895.	10
	292.5	3000	1095	4887.5.	10
	232.5	2340	1500	4072.5	10
	187.5	1860	1170	3217.5.	10
	176.25	1500	930	2606.25	10
	131.25	1410	750	2291.25	10
	97.5	1050	705	1852.5	10
	71.25	780	525	1376.25	10
	48.75	570	40890	1008.7	10
	30	390	285	705.	10
	16.5	240	195	451.5.	10
	7.5	132	120	259.5	10
	0.	60	66	126.	10
		0	30	30	10
			0	0	40

14/02/19.

S - Hydrograph.  
in straight

S = summation

It is mainly imp  
for 1 unit hydrograph  
to many hydrographs

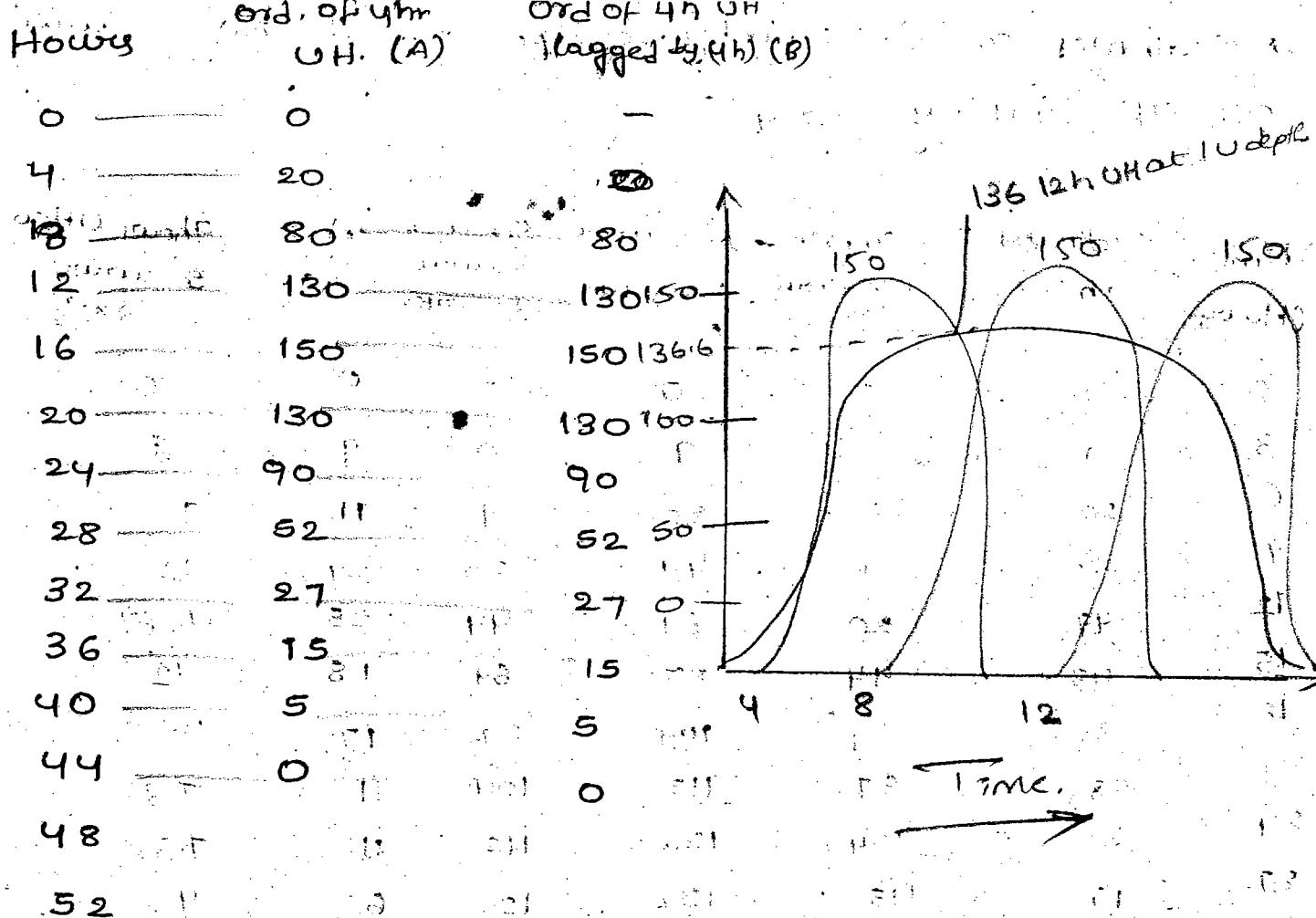


15/02/19.

\* Given the ordinates of 4-hour UH below. Derive the

ordinates of 12-hr for the same catchment.

Ordinates of 12-hr for



Hours	Ord. of 4h-UH (A)	Ord. of UH lagged by 4h (B)	Ord. of UH lagged by 4h (C)	Ord. 12h UH with 3cm : 1	Ord. of 12h with $\frac{20}{3}$ 10 depth.
0	0	-	-	0	0
4	20	0	-	20	6.67
8	80	20	0	100	33.3
12	130	80	20	230	76.67
16	150	130	80	360	120
20	130	150	130	410	136.6
24	90	130	150	370	123.3
28	52	90	130	272	90.6
32	27	52	90	169	56.3
36	15	27	52	94	31.0
40	5	15	27	47	15.6
44	0	5	15	20	6.6
48	0	0	5	5	1.6
52	0	0	0	0	0

\* Ordinates of 6H unit hydrograph are derive S-curve  
of 9H unit hydrograph.

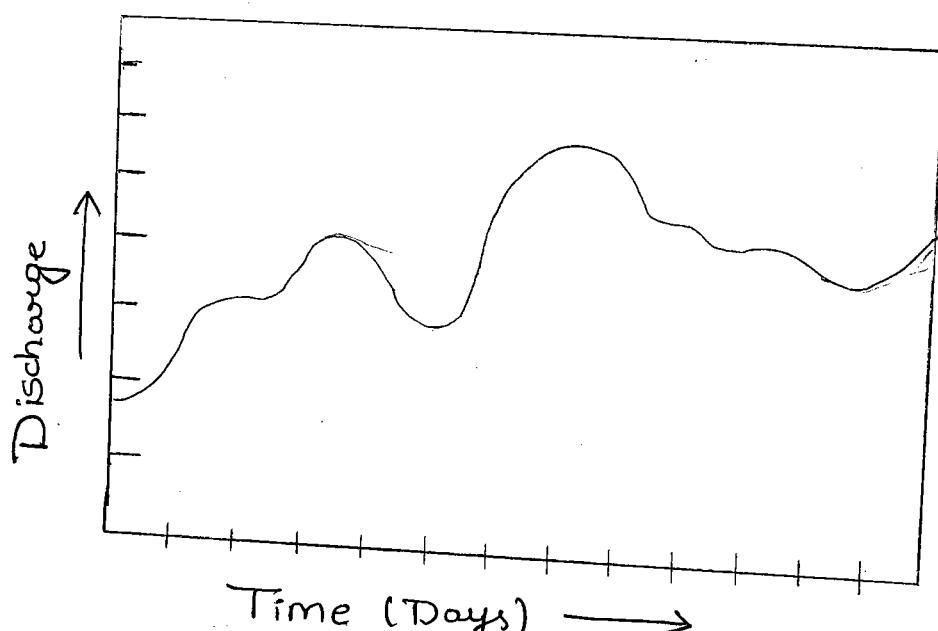
Time (Hours)	ordinates of 6h UH	Offset ordinates	S-curve ordinates	offset of s-curve ordinates	$\Delta$ of old	9hour UH with s-curve ( $\Delta \times \frac{2}{3}$ )
0	0	-	0	-	0	0
3	9	-	9	0	9	6
6	20	0	20	9	11	7.3
9	35	9	44	20	24	16
12	49	20	69	44	25	16.67
15	43	44	87	69	18	12
18	35	69	104	87	17	11.33
21	28	87	115	104	11	7.33
24	22	104	126	115	11	7.33
27	17	115	132	126	6	4
30	12	126	138	132	6	4
33	9	132	144	138	3	2
36	6	138	144	141	3	2
39	3	141	144	144	0	0
42	0	144	144	144	0	0
45						
48.						

$$9h UH = \Delta \times \frac{2}{3} \text{ of each ordinate.}$$

## \* Hydrograph Analysis

A hydrograph is a graph showing variations of discharge with time, at a particular point of stream. It shows the time distribution of total runoff at the point of measurement.

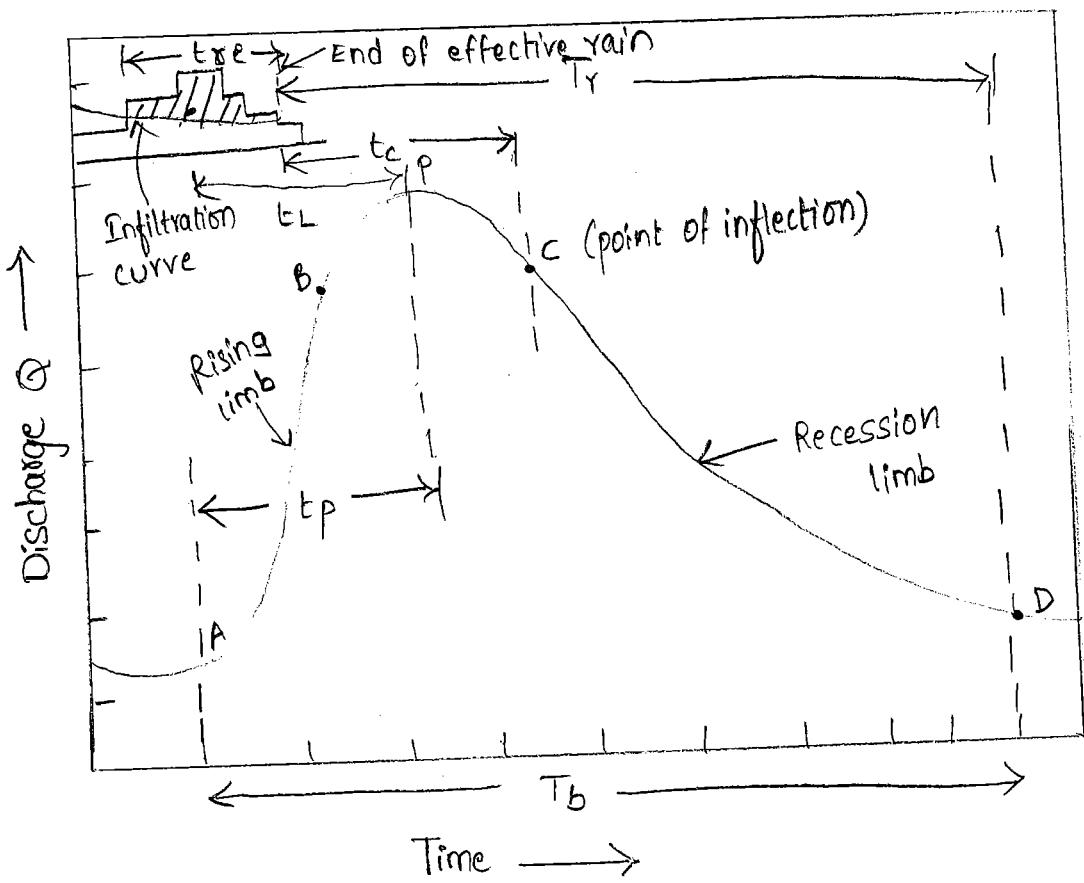
As the runoff includes the contributions from surface runoff, subsurface runoff (or interflow) and groundwater runoff. (or base flow).



STORM HYDROGRAPH

## \* Components of Hydrograph

The figure shows a single peaked hydrograph resulting from an isolated storm. The rainfall hyetograph, along with infiltration curve, is shown on the top of the diagram.



There are three essential components of a single peaked hydrograph resulting from an isolated storm:

- (i) The rising limb (AB)
- (ii) The peak or crest element (BPC)
- and (iii) The recession limb (CD).

### (i) Rising Limb:

The rising limb AB is the ascending portion of the hydrograph corresponding to the increase of discharge due to gradual formation of storage in the channels existing in the area and also over the watershed surface. The rising limb also known as the "concentration curve." In the early period of a storm, there are initial losses as well as high infiltration losses and hence the discharge rises slowly. As the time increases, the initial losses stop and the infiltration rate also decreases. Due to this, more and more discharge from the distant parts reach the basin outlet.

Point A is the starting point while B is the point of inflection. The shape of the rising limb is controlled by the characteristics of basin and duration, intensity and uniformity of the rain.

### (ii) The Peak (or) Crest Segment (BPC)

The peak or crest segment includes the part of the hydrograph from the inflection point (B) on the rising limb to an inflection point (C) on the recession limb. Crest Segment is one of the most important component of the hydrograph because

it indicates the peak flow rate.

### (iii) The recession limb (CD):

The recession limb extends from the point of inflection (point C) of the crest segment to the point D, the point of commencement of the natural ground water flow. The recession limb indicates the storage contribution from surface storage, interflow and ground water flow.

Time Parameters used in Hydrograph Analysis

#### 1. Effective time duration ( $t_{re}$ ):

It is the net duration of precipitation during which rainfall rates more than infiltration rates.

#### 2 Lag time or basin lag ( $t_l$ ):

It is the time interval between the centre of mass of net rainfall and centre of mass of runoff hydrograph. More commonly, it is also taken as the time lapse between the centre of mass of effective rainfall and the peak (P) of the hydrograph.

#### 3. Time to peak ( $t_p$ ):

It is the time interval between the starting of the rising limb (A) to the peak (P) of the hydrograph.

(3)

## \* Separation Of Base flow:

There are three methods.

1. Straight line Method
2. Two line Method
3. Curves extension method.

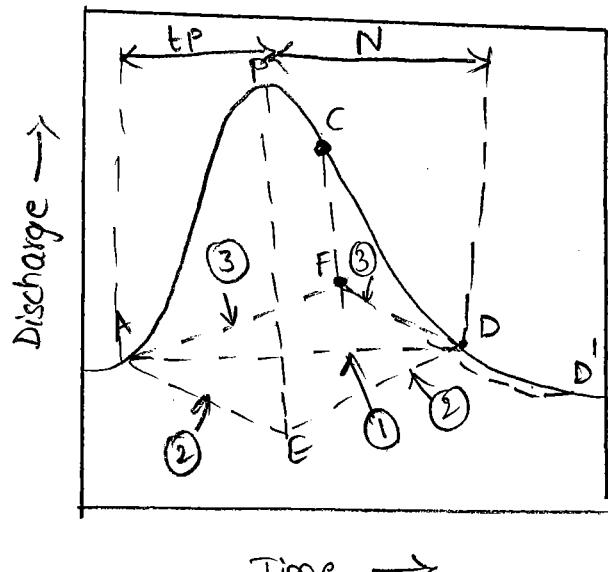
### 1. Straight line Method:

In a storm hydrograph direct runoff & base flow can be separated by joining point of rise and point of end by a simple straight line AC.

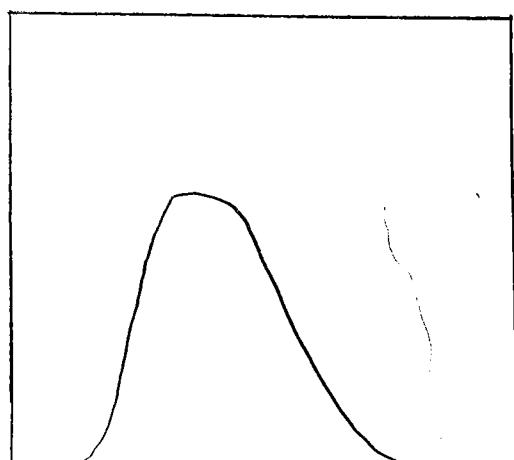
\* Portion above AC - Runoff

Below AC - Baseflow.

### \* Simplex Method.



(a) Three methods of  
Separation.



(b) Resulting DRH.

(3)

## 2. Two line Method:

= = = = -

Recession curve existing before A is extended to a point under peak of hydrograph (F).

From this point a straight line is drawn to C.

AFC = Base flow separation Line.

## 3. Curves extension Method:

= = = = = -

Base flow on recession is extended backside to point below P.O.I then it is connected to point of rise by a smooth curve (A GID)

This method is preferred when stream and ground water are hydraulically connected and flow from G.W storage quickly appears as runoff at outlet.

## \* UNIT HYDROGRAPH (UH)

====

A unit hydrograph is a hydrograph representing 1cm (or 1inch) of runoff from a rainfall of some unit duration and specific areal distribution. Unit duration refers to the duration of a run-off producing rainfall-excess, that results in a unit hydrograph. For example, if a unit hydrograph results from a 3 hours unit rainfall duration, it is known as a 3-hours unit hydrograph, meaning thereby a hydrograph produced by surface run-off from a storm lasting for 3 hours and yielding rainfall excess of 1cm.

### Assumptions Of Unit Hydrograph Theory

The assumptions of unit hydrograph theory must be properly understood before applying it to actual problems, as these assumptions impose certain limitations which must be carefully noted. The various assumptions are given below.

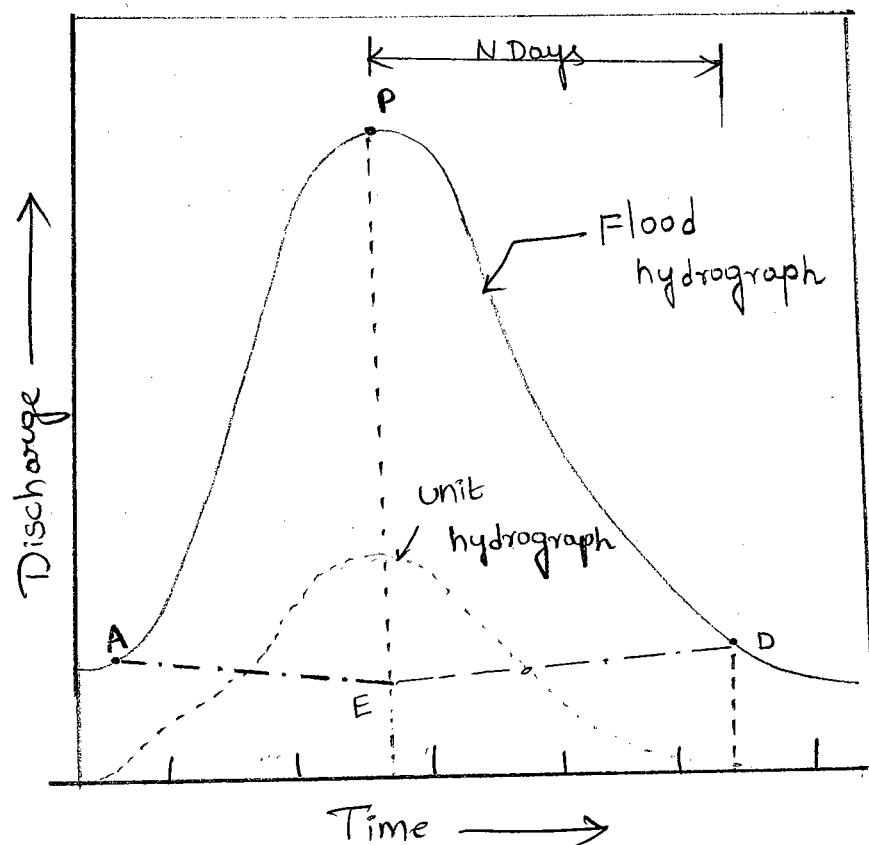
1. The effective rainfall is uniformly distributed within its duration of specified period of time.
2. The effective rainfall is uniformly distributed throughout the whole area of drainage basin
3. The base (or) time duration of the hydrograph

of direct run-off due to an effective rainfall of unit duration is constant.

#### CONSTRUCTION OF UNIT HYDROGRAPH.

The following are the steps for constructing a unit hydrograph of some unit duration from a storm hydrograph of the same unit duration.

1. From the past records, select some unit period of intense rainfall duration corresponding to an isolated storm uniformly distributed over the area.



#### CONSTRUCTION OF UNIT HYDROGRAPH.

(2)

(5)

2. From the past records of the river discharge for that stream, plot the stream hydrograph for some days before and after the period of rainfall of that unit duration.
3. By the method indicated in § 4.20, separate the ground water flow (base flow) from the direct run-off.
4. Subtracting the ordinates of base flow from the total ordinates, find the ordinates of direct run-off.
5. calculate direct run-off  $n$  (in centimeters) by the expression:

$$\text{Direct run-off, } n = 0.36 \frac{(\Sigma O) \times t}{A} \text{ cm.}$$

Where

$\Sigma O$  = sum of the discharge ordinates (direct run-off) in cumecs.

$t$  = Time interval between successive ordinates in hours.

$A$  = Area of drainage basin in Sq. Km

6. calculate the ordinates of unit hydrograph by the relation:

$$\text{Ordinate of unit hydrograph} = \frac{\text{Ordinate of direct run-off}}{\text{Direct run-off in cm}}$$



(6)

1. The following are the ordinates of a runoff hydrograph from 3 hours storm. Runoff readings are measured at 3 hr intervals.

Time (Hours)	0	3	6	9	12	15	18	21	24
Ord.of TRH (m³/s)	10	25	40	60	75	35	20	15	10

Assume baseflow to be 10 cumecs uniform. Find out ordinates of direct runoff hydrograph and Runoff depth in cm if Area of catchment is 20 km².

Sof:

Given data:

$$\text{Base flow} = 10 \text{ m}^3/\text{sec.}$$

$$\text{Area of catchment} = 20 \text{ km}^2$$

$$\text{Time } t = 3 \text{ hours}$$

$$\text{Runoff} = \frac{\left[ (\sum \text{ord.of TRH}) - (10 \times \text{baseflow}) \right] \times 0.36 \times 3}{A}$$

$$\text{Runoff} = \frac{216}{20} = 10.8 \text{ cm.}$$

2. The following runoff values are available for outlet for 4hr, rainfall over a catchment. Derive 4hour unit hydrograph for a catchment. Assuming baseflow is uniform at  $20 \text{ m}^3/\text{sec.}$ , Area of catchment is  $200 \text{ km}^2$ .

2  
sof.  
4

Time (hours)	ordinates of flood hydrograph	Bareflow	ordinates of DRH	Depth of Runoff	ordinates of unit hydrograph (DRH ord / Runoff)
0	20	20	0	11.124	$\frac{0}{11.124} = 0$
4	35	20	15	11.124	1.348
8	60	20	40	11.124	3.595
12	220	20	200	11.124	17.979
16	430	20	410	11.124	36.853
20	450	20	430	11.124	38.655
24	250	20	230	11.124	20.676
28	180	20	160	11.124	14.383
32	80	20	60	11.124	5.393
36	20	20	0	11.124.	0

$$\text{Direct runoff} = \frac{0.36(1545)4}{200}$$

$$= 11.124 \text{ cm.}$$

ordinates of unit hydrograph ( $\frac{\text{DRH ord}}{\text{runoff}}$ )

$$1. \frac{0}{11.124} = 0$$

$$5. \frac{410}{11.124} = 36.853$$

$$9. \frac{60}{11.124} = 5.393$$

$$2. \frac{15}{11.124} = 1.348$$

$$6. \frac{430}{11.124} = 38.655$$

$$10. \frac{0}{11.124} = 0.$$

$$3. \frac{40}{11.124} = 3.595$$

$$7. \frac{230}{11.124} = 20.676$$

$$4. \frac{200}{11.124} = 17.979.$$

$$8. \frac{160}{11.124} = 14.383$$

Check: Depth of runoff for U.H = 1cm

$$\Rightarrow \frac{(0.36 \times 1 \times 138.88)4}{200} = 1 \text{ cm.}$$

(7)

3. Derive a 2-hour unit hydrograph from following total runoff hydrograph resulting from rainfall of effective duration 2 hours. Drainage basin area is  $104 \text{ km}^2$ .

Date	Time (hour)	Runoff ( $\text{m}^3/\text{s}$ )	Baseflow ( $\text{m}^3/\text{s}$ )	ordinates of DRH	ordinates of 2hour hydrograph
July 10	6	14.2	14.2	0	0
	8	158.5	14.7	143.8	12.52
	10	260	15.2	244.8	23.32
	12	286	15.7	270.3	23.54
	14	221	16.2	204.8	17.83
	16	186.5	16.7	169.8	14.79
	18	157	17.2	139.8	12.17
	20	133	17.3	115.7	10.07
	22	113	17.7	95.3	8.30
	24	93.4	18.7	74.7	6.50
July 11	2	76.4	19.2	57.2	4.98
	4	65.0	19.7	45.3	3.945
	6	55.2	20.2	35.0	3.048
	8	46.7	20.7	26.0	2.264
	10	39.6	21.2	18.4	1.602
	12	34	21.7	12.3	1.071
	14	28.3	22.2	6.1	0.531
	16.	22.7	22.7	0	0

$$\begin{aligned}\text{Direct runoff depth} &= \frac{0.36(\Sigma O) \times t}{A} \\ &= \frac{0.36(1659.3)2}{104} \\ &= 11.48 \text{ cm.}\end{aligned}$$

$\Sigma$  ordinates of unit hydrograph = 144.481

Check:

$$\begin{aligned}\frac{(\Sigma O) \times 0.36 \times 2}{104} &= \frac{144.481 \times 0.36 \times 2}{104} \\ &= 1 \text{ cm.}\end{aligned}$$

(8)

## Application Of UH for the construction of

### flood hydrograph resulting from the rainfall of

#### unit duration.

1. Ordinates of Direct runoff hydrograph is calculated

$$DRH = (\text{runoff}) \text{cm} \times \text{ordinates of UH.}$$

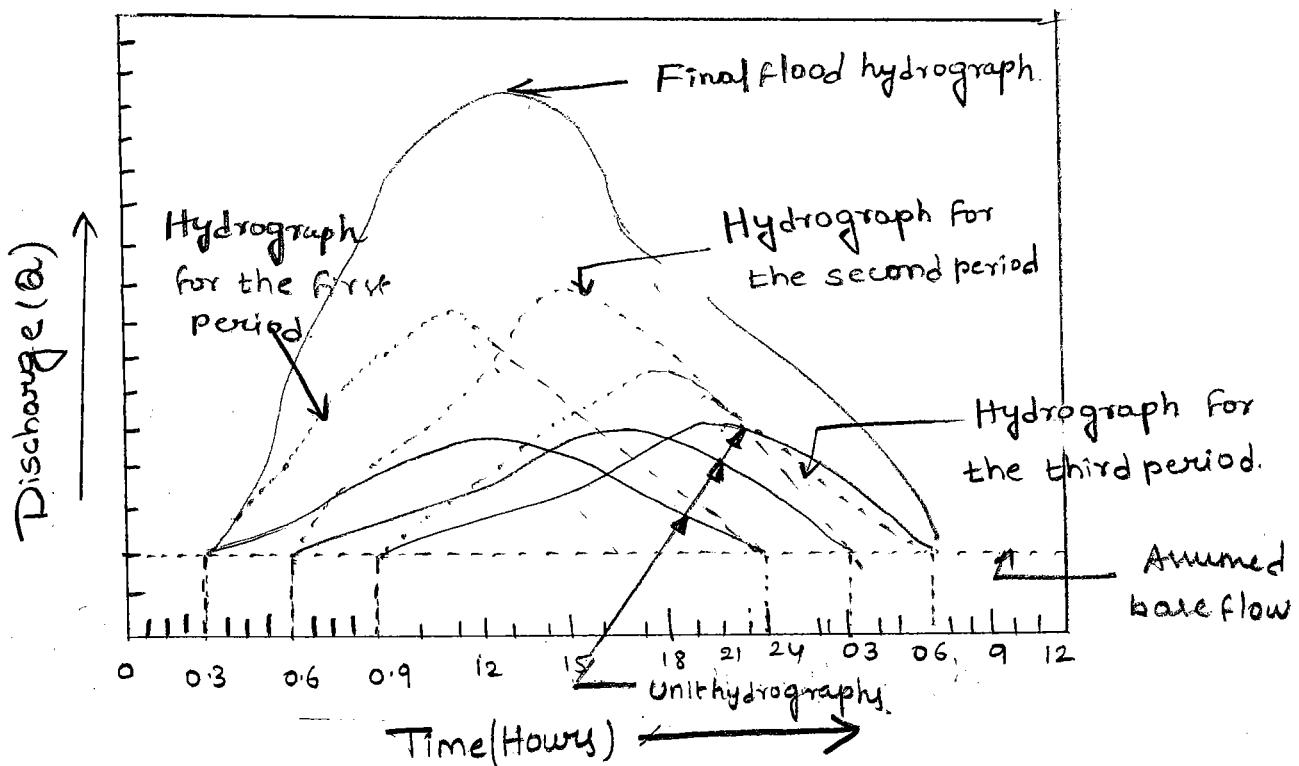
2. Ordinates of flood hydrograph = ord of DRH + Base flow.

4. Following is data of 2 hour unit hydrograph. If rainfall exceeds 8cm for an intense rainfall of 2hour on same catchment. Determine the ordinate of flood hydrograph.

Base flow of ordinates are given.

Date (1)	Time (hours) (2)	Ordinates of unit hydrogr. aph. (3)	Ordinates of D.R (4) = (3) × n	Base flow (5)	Total ordinates of FH (6) = (4) + (5)
22 July	6	0.00	0	4.0	4
	9	0.12	0.96	3.5	4.46
	12	0.35	2.80	3.0	5.80
	15	0.88	7.04	2.5	9.54
	18	1.50	12.00	2.0	14.00
	21	2.80	22.40	1.5	23.90
	24	2.00	16.00	1.8	17.80
	3	1.85	14.80	2.1	16.90
	6	1.53	12.24	2.4	14.64
	9	1.26	10.08	2.7	12.78
	12	0.84	6.72	3.0	9.72
	15	0.50	4.00	3.3	7.30
	18	0.35	2.80	3.6	6.40
	21	0.12	0.96	3.8	4.76
	24	0.00	0	4.0	4.0

Application of Unit hydrograph to Construction of a flood hydrograph resulting from Two (or) More Periods of Rainfall



Flood Hydrograph Resulting from a Storm of Longer duration

A unit hydrograph of some specific unit duration can also be utilised for construction of flood hydrograph resulting from the rainfall lasting for a long duration. The essential condition, however is that the storm pattern should be the same as that for the unit hydrograph. As an example, let us say that a 3-hour unit hydrograph is available and it is required to compute the flood hydrograph resulting from a rainfall lasting for 9 hours with variable intensities of rainfall - the intensity rates having  $n_1$  cm/3-hours for the first period of 3 hours,  $n_2$  cm/3-hours for 2nd 3 hours,

(9)

and  $n_3$  cm/3-hour for the last 3 hours. The storm is divided into 3 parts, and the flood hydrograph of the storm starts 3 hours later than that for the first part. Similarly, the hydrograph for the third part of the storm starts 6 hours later than that for the first, or 3 hours later than that for the second part.

5. Find the ordinates of a storm hydrograph resulting from a 3 hour storm with rainfall of 2, 6.75 & 3.75 cm. during subsequent 3 hours intervals. The ordinates of unit 3-hour hydrograph are given in the following data.

Hours	3	6	9	12	15	18	21	24	03	6	9	12	15	18	21	24
ordinates of UH (cm/sec)	0	110	365	500	390	310	250	235	175	130	95	65	40	22	10	0

Assume an initial loss of 5mm, infiltration index of 2.5 mm/hr and baseflow of 10 cmecs.

Sol: (i) Rainfall excess during the first three hours

$$= 20 - (2.5 \times 3) - 5 = 7.5 \text{ mm} = 0.75 \text{ cm}$$

(ii) Rainfall excess during the second three hours

$$= 67.5 - (3 \times 2.5) = 60 \text{ mm} = 6 \text{ cm.}$$

(iii) Rainfall excess during the last three hours.

$$= 37.5 - (3 \times 2.5) = 30 \text{ mm} = 3 \text{ cm.}$$

Time in hours	ordinates of 3-hour unit hydrograph (cumecs)	Rainfall excess cm/2 hours	Surface run-off from rainfall excess during successive unit periods				Baseflow (cumecs)	Total discharge (cumecs)
			0.75	6.0	3.0	sub Total		
3	0	0.75	0			0	10	10.0
6	110	6.00	82.5	0		82.5	10	92.5
9	365	3.00	214.0	660	0	934.0	10	944.0
12	500		375.0	2190	330	2895	10	2905.0
15	390		295.5	3000	1045	4331.5	10	4347.5
18	310		232.5	2340	1500	4072.5	10	4082.5
21	250		187.5	1860	1170	3217.5	10	3227.5
24	235		176.0	1500	930	2606.0	10	2616.0
3	175		131.5	1410	750	2291.5	10	2301.5
6	130		97.5	1050	705	1852.5	10	1862.5
9	95		71.3	780	525	1376.3	10	1386.0
12	65		48.6	570	390	1008.6	10	1018.6
15	40		30.0	390	285	705.0	10	715.0
18	22		16.5	240	195	451.5	10	461.5
21	10		7.5	132	120	259.5	10	269.5
24	0		0	60	66	126.0	10	136.0
30				0	30	30.0	10	40.0
86					0	0	10	100.0

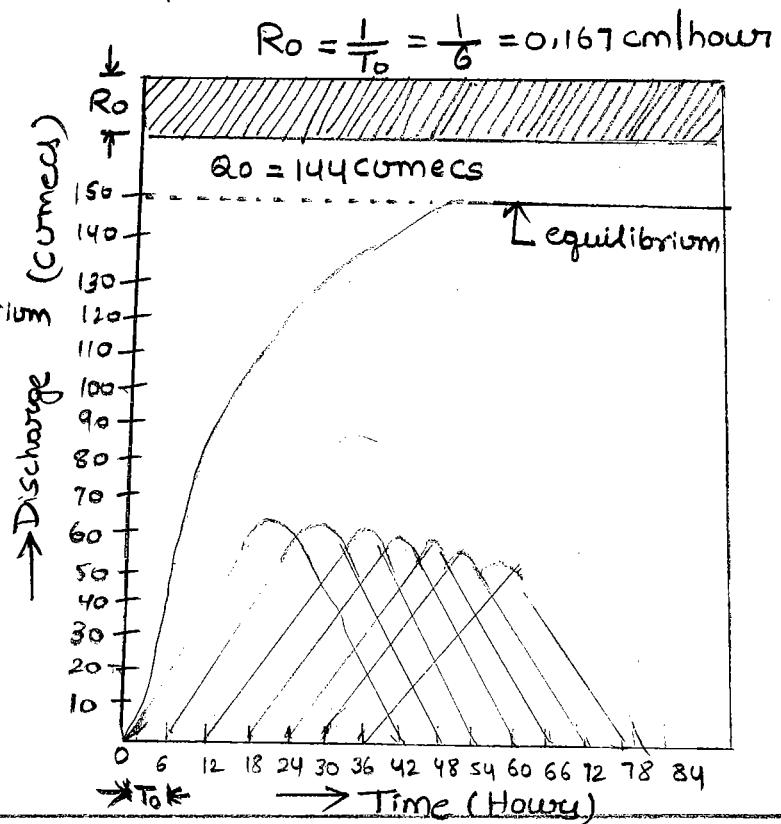
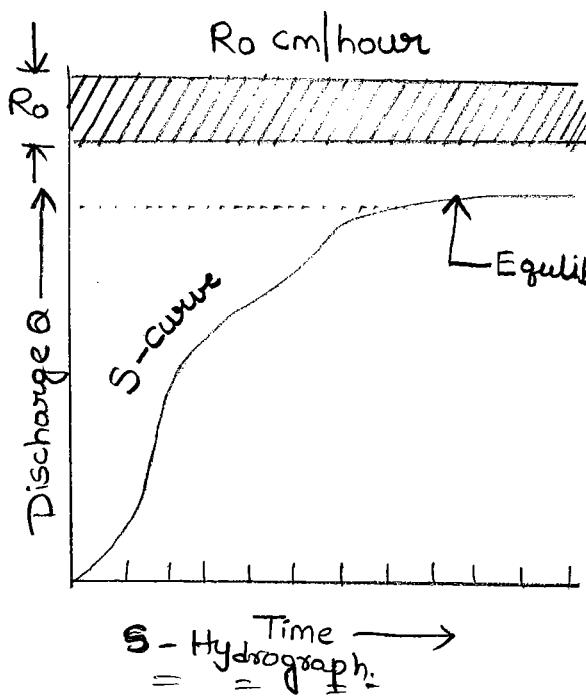
## (10)

### S-Hydrograph (Summation Hydrograph).

S-hydrograph (or) S-curve is a hydrograph that is produced by a continuous effective rainfall at a constant rate for indefinite period. It is a continuous rising curve, in the form of letter S, till equilibrium is reached. At the time of equilibrium it will represent a constant rate of continuous effective rainfall, say  $R_0$  cm per hour.

$$Q_0 = \frac{(A \times 1000 \times 1000) R_0}{100 \times 3600} = 2.778 A R_0 \text{ (cumecs)}$$

The S-hydrograph (or) S-curve is constructed by adding together a number of unit hydrographs of unit time duration ( $T_0$ ) spaced at a unit time duration  $T_0$ . (i.e. duration of effective rainfall).



I. Ordinates of 6 hour unit hydrograph are given.

Derive S-curve of 9 hour UH.

Time (Hours)	Ord of 6h UH.	Offset ordinates	S-curve ordinates	Offset of S-curve ordinates	Difference of ord ( $\Delta$ )	9h UH. of S-curve ( $\Delta \times 2/3$ )
0	0	-	0	-	0	0
3	9	-	9	0	9	6
6	20	0	20	9	11	7.3
9	35	9	44	20	24	16
12	49	20	69	44	25	16.67
15	43	44	87	69	18	12
18	35	69	104	87	17	11.33
21	28	87	115	104	11	7.33
24	22	104	126	115	11	7.33
27	17	115	132	126	6	4
30	12	126	138	132	6	4
33	9	132	141	138	3	2
36	6	138	144	141	3	2
39	3	141	144	144	0	0
42	0	144	144	144	0	0

$$9H \text{ UH} = \frac{2}{3} \text{ of each ordinate} \times \Delta.$$

## Unit hydrograph of different duration

There are two methods. can be plotted for

1. Longer duration
2. Shorter duration.

### \* Longer duration:

→ If the desired UH is integral multiple of given duration = superposition method.

→ If not integral method = S-curve.

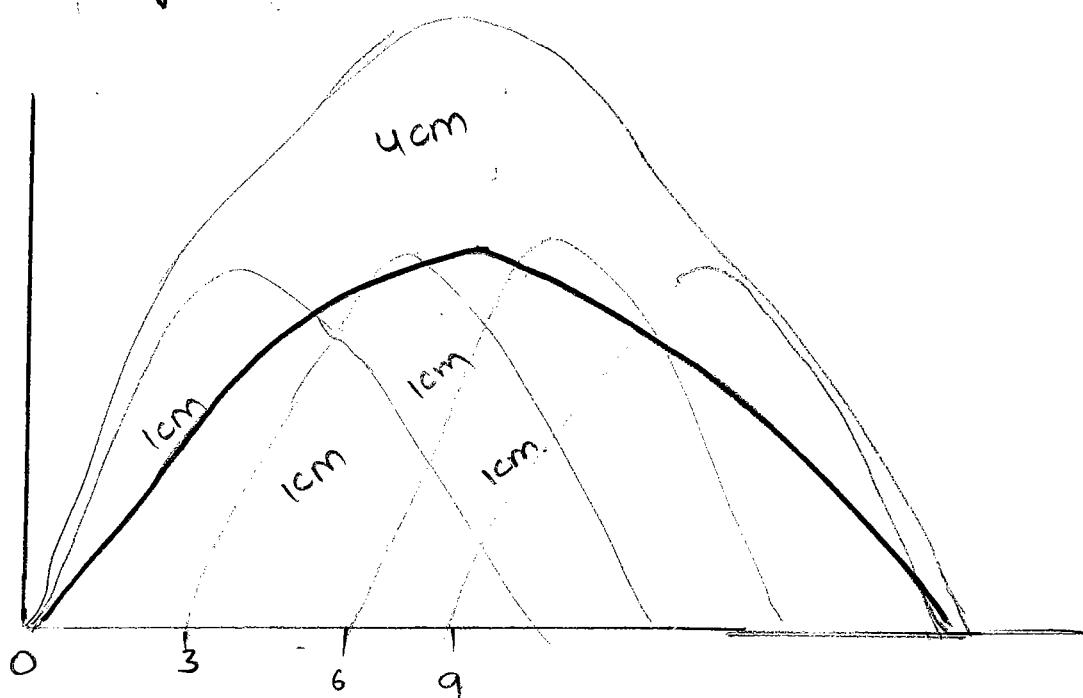
### \* Shorter duration: S-curve method.

#### Superposition method:

Given duration of UH =  $t_0$  hour.

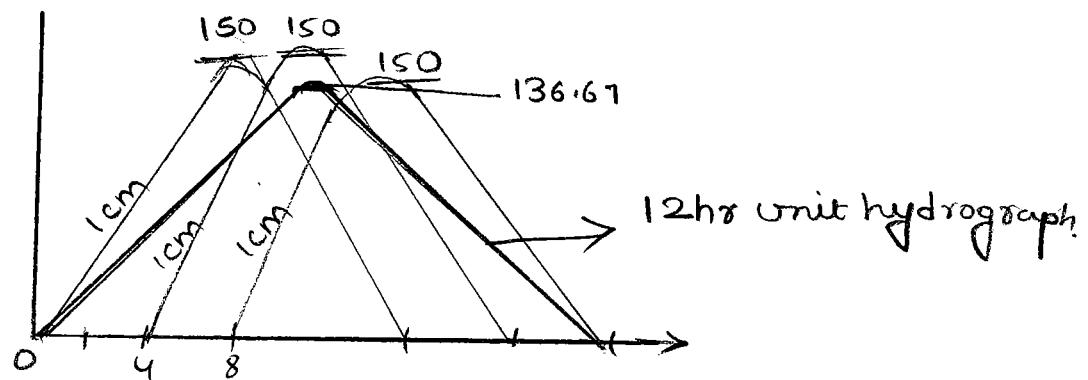
Required UH duration =  $T_0$  hour.

' $T_0$ ' is an integral multiple of ' $t_0$ '



2. Given the ordinates of a 4hour unit hydrograph  
 Derive the ordinates of 12hour unit hydrograph  
 for the same catchment.

Hours	ord of 4h UH (A)	ord of UH lagged by 4h (B)	ord of UH lagged by 4h (C)	ord of 12h UH with 3cm	Ord of 12h with 1U depth. (1/3)12h.
0	0	-	-	0	0
4	20	0	-	20	6.67
8	80	20	0	100	33.3
12	130	80	20	230	76.67
16	150	130	80	360	120
20	130	150	130	410	136.6
24	90	130	150	370	123.3
28	52	90	130	272	90.6
32	27	52	90	169	56.3
36	15	27	52	94	31.0
40	5	15	27	47	15.6
44	0	5	15	20	6.6
48		0	5	5	1.6
52			0	0	0.



## \* Uses of Unit Hydrographs:

This unit hydrograph establishes a relationship between effective rainfall and direct runoff for a catchment.

This relationship is very useful in study of the hydrology of catchment, as

- (i) In the development of flood hydrograph for extreme rainfall magnitude.
- (ii) In extension of flood-flow records based on rainfall records.
- (iii) In development of flood forecasting and warning system based on rainfall.

## \* Limitations of Unit Hydrograph

1. Unit hydrograph assumes uniform distribution of rainfall over the catchment, and the intensity of rainfall is assumed constant for the duration of rainfall excess. In practice these two conditions are never strictly satisfied.
2. Unit hydrograph method can not be used for a catchment area greater than  $5000 \text{ km}^2$  and less than  $2 \text{ km}^2$ .
3. Precipitation must be from rainfall only. Snowmelt runoff can not be satisfactorily represented by U.H.

4. The catchment should not have large storage  
(Ex: tank pond etc) which affects the linear relationship  
between storage and discharge.

In the use of unit hydrograph 20% variation in time base  
and 10% variation in peak are expected in reproduction  
of result.

#### \* Synthetic unit hydrograph - Snyder's Method

To develop unit hydrograph for a catchment, we  
need detailed information about the rainfall and  
resulting flood hydrograph. Majority of location in  
world, specially those which are at remote location,  
the data would normally be very scanty. For  
those area we construct the unit hydrograph with  
the help of empirical equation, such a unit hydrograph  
is called Synthetic unit hydrograph.

Snyder developed a set of empirical equation for  
construction of synthetic unit hydrograph, which is  
known as Snyder's synthetic unit hydrograph.

Snyder selected three important parameter for  
construction of SUH.

##### 1. Base time width ( $T$ )

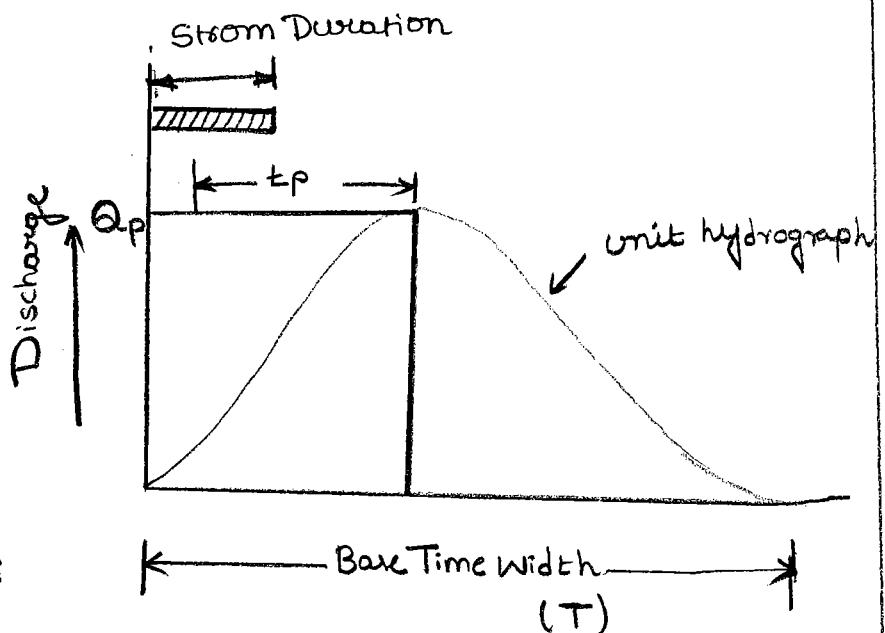
$$T = 0.32 + 3t_p \text{ (in hours)}$$

## (ii) Peak discharge ( $Q_p$ )

$$Q_p = 2.78 C_F \frac{A}{t_p}$$

## (iii) Lag time ( $t_p$ ):

Lagtime represents the meantime of travel of water from all parts of catchment to the outlet during a given storm.



$$t_p = C_F (L \cdot L_c)^{0.3}$$

Here

$L$  = Length of main stream in the catchment upto gauging site (in km).

$L_c$  = The distance along the main stream from the gauging site to a point on the stream which is nearest to the centroid of the basin (in km).

$C_F$  = Regional constant representing the watershed slope and storage ( $C_F$  varies from 0.3 to 6).

$W_{75}$  = Width of graph in hr at 75% of peak discharge.

