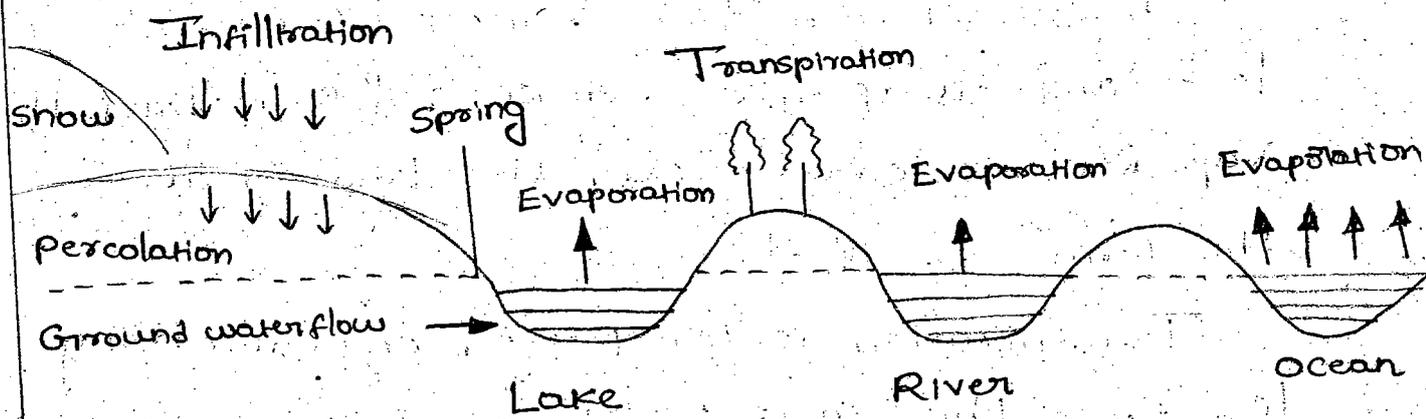
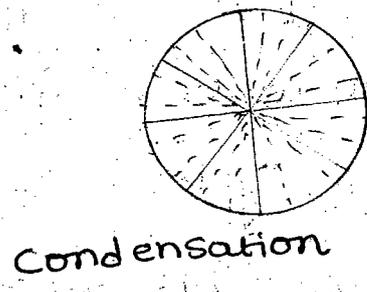
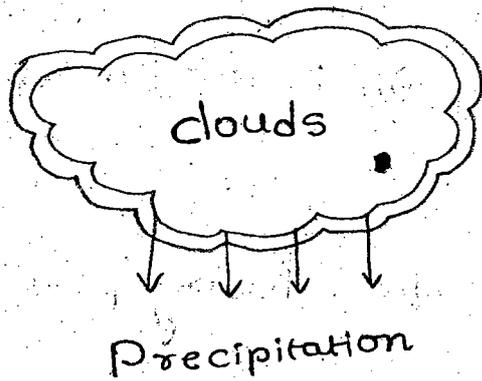


22/11/2018.

UNIT - 1 Introduction



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:

1. 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
 - (a) From river surface.
 - (b) From oceans
- (iii) Evaporation from plants and leaves (Transpiration)
- (iv) Atmospheric evaporation

* Precipitation:

Precipitation may be defined as the fall of moisture from the atmosphere to the earth's 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's surface, as precipitation a 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 (or) 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 water flow (or) 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 reservoirs 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 kilometers 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. km. Normal annual rainfall varies from 100mm in western Rajasthan to over 11000mm at Chirapurji in Meghalaya. In annual average rainfall over the country is of the order of 1170mm depth which is nearly 4000 km³.

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 to 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 run 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:

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:

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 ϕ 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 droplet is under 0.5mm & its intensity is less than 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 break up they fall through the air.

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

Sleet: It is frozen raindrops which cool 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 fused together forms snowflake

* 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.

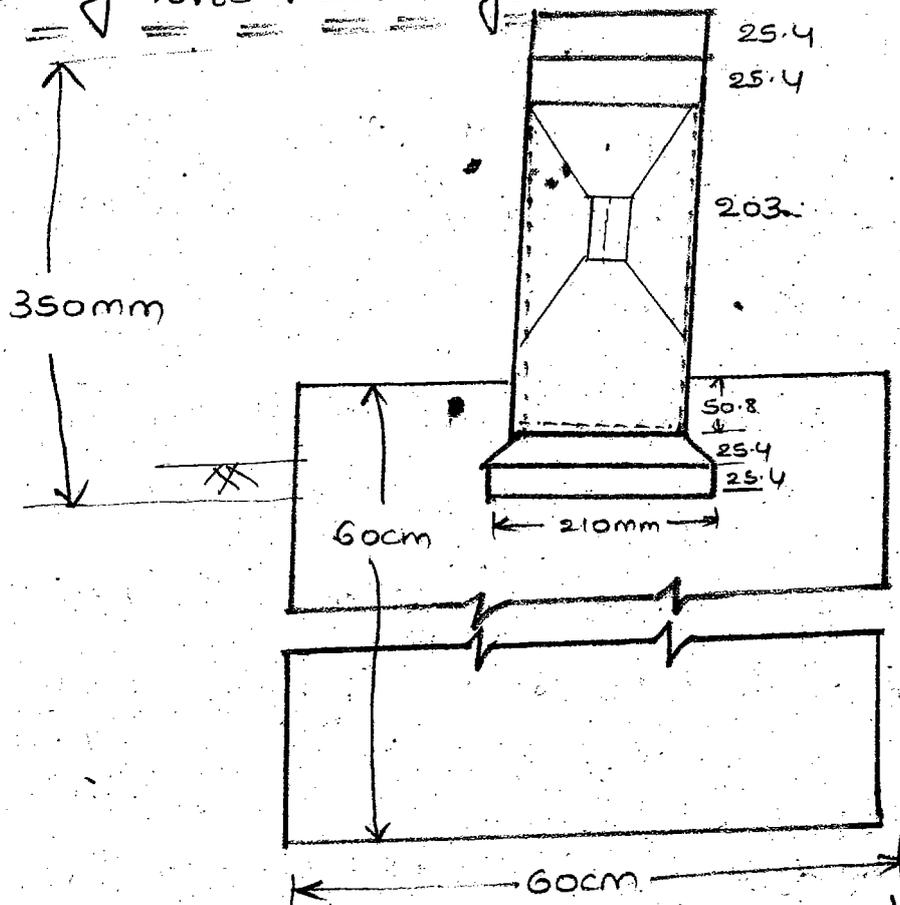
Symon's Rain gauge instrument prescribed by used at all Govt. rain gauge stations throughout India.

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 rain gauge has a capacity of about 75 to 100mm of rainfall and as during in heavy rainfall this quantity is frequently exceeded, the rain should be measured in a 3 (or) 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 $60\text{cm} \times 60\text{cm} \times 60\text{cm}$

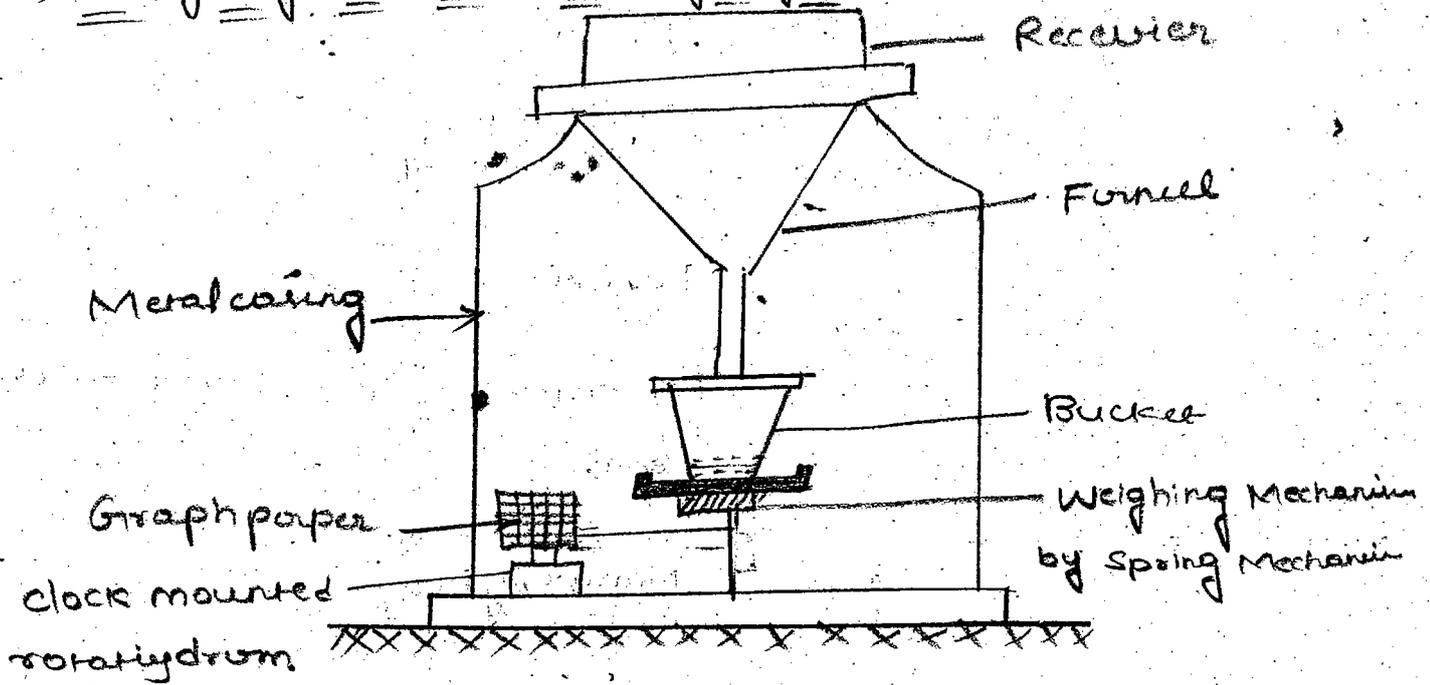
The following important points should be kept in mind while selecting site for a rain gauge station. [common for all type of RG]

- 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 (or) top of a hill if a suitable site on a level ground can be found.
- In the hills where it is difficult to find level space, this site for the gauge should be chosen where it is best shaded from high winds and where the wind does not cause eddy's.
- A fence is 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:



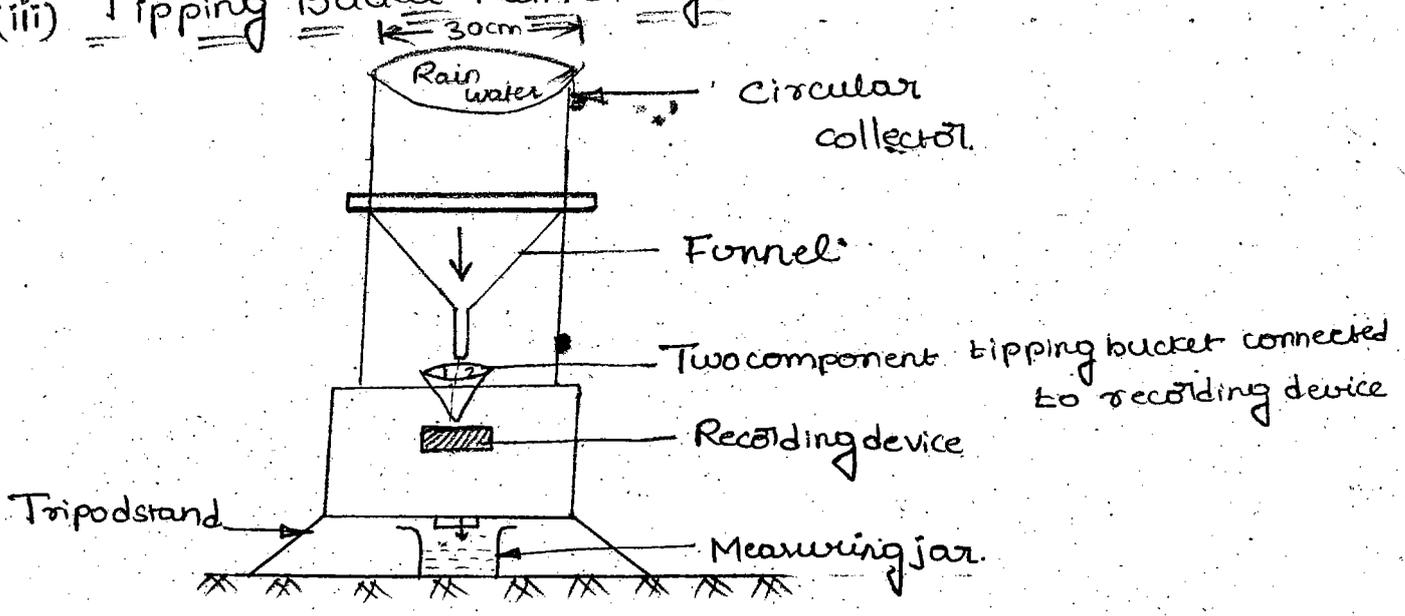
Weighing bucket rain gauge

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.

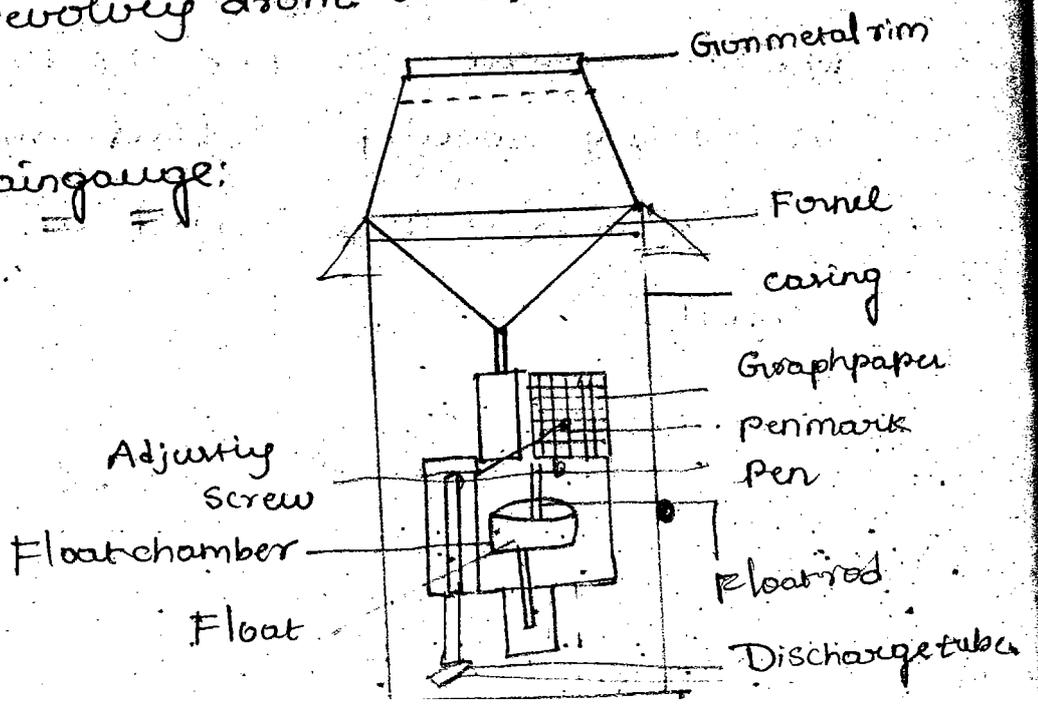
This rain gauge essentially consists of a receiver bucket supported by a spring (or) lever balance (or) any other weighing mechanism. The movement of the bucket due to increasing weight is transmitted to a pen which traces the record on a clock driven chart.

(iii) Tipping Bucket Rain Gauge:



A Stevens tipping bucket type rain gauge consist of 300mm diameter sharp edge, receiver, 1 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 make on clock driven revolving drum which carries a record sheet.

* Float Type Rain gauge:



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 moving on a recording drum actuated by a clock work.

* Advantages of Recording type over Non-Recording type Rain gauges.

Advantage

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

Disadvantage

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

05/12/18.

* Rain gauge Network:

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

<u>Area (km²)</u>	<u>NO. of gauges</u>
0-80	1
80-160	2
160-320	3
320-560	4
560-800	5
800-1200	6

* Optimum No. of Raingauges:

By using of statistical method.

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

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 % is 8. How many no. of additional gauges are required.

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

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

$$= \frac{100 + 120 + 150 + 135}{4}$$

$$= 126.25$$

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

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

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

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

$$= \sqrt{\frac{4}{4-1} [162812.5 - 152,39.06]}$$

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

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

$$N = \left(\frac{16.91}{8} \right)^2 = 4.467 \approx 5 \text{ No's.}$$

Five number of additional rain gauges are required.

* The rainfall readings at 4 rain gauge stations are located in river catchement of 800, 620, 400 & 540mm respectively. Determine optimum no. of rain gauges in catchement if it is design to measurement of mean rainfall in the catchement upto 10%.

How many more no. of rain gauges are to be required,

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

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

$$\bar{P} = 590$$

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

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

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

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

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

$$= 166.933.$$

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

$$N = \left[\frac{28.29}{10} \right]^2 = 8.00$$

Eight number of additional raingauges are required

06/12/18.

* 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 $< 10\%$.

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 inoperative for a part of month in which a storm occur. The respective storms totals at the ³ 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 $N_x = 978$

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

$$P_x = \frac{N_x}{N} \left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} \right]$$

$$= \frac{978}{3} \left[\frac{107}{1120} + \frac{89}{935} + \frac{122}{1200} \right]$$

$$= 95.31 \text{ mm}$$

* Presentation of rainfall data:

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:

The rate at which the rain is falling

* Duration:

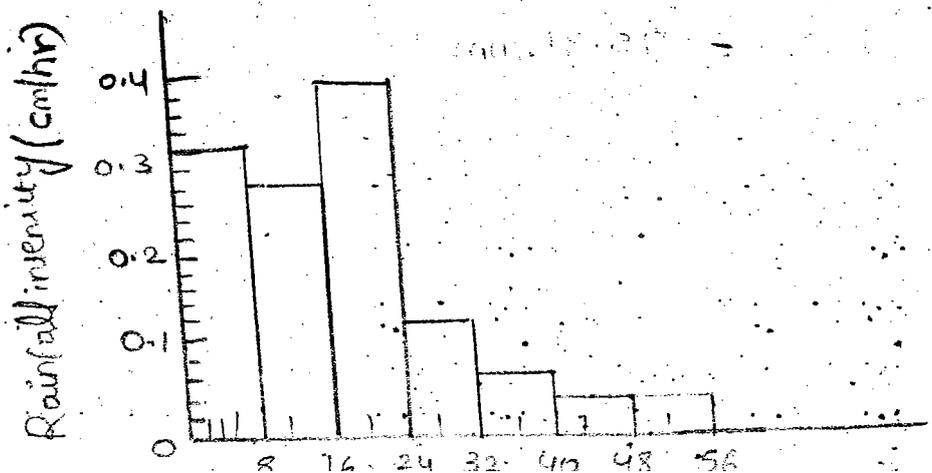
The time for which it is falling with a given intensity

* Frequency

How many times does it occur

Hyetograph / Hydrograph.

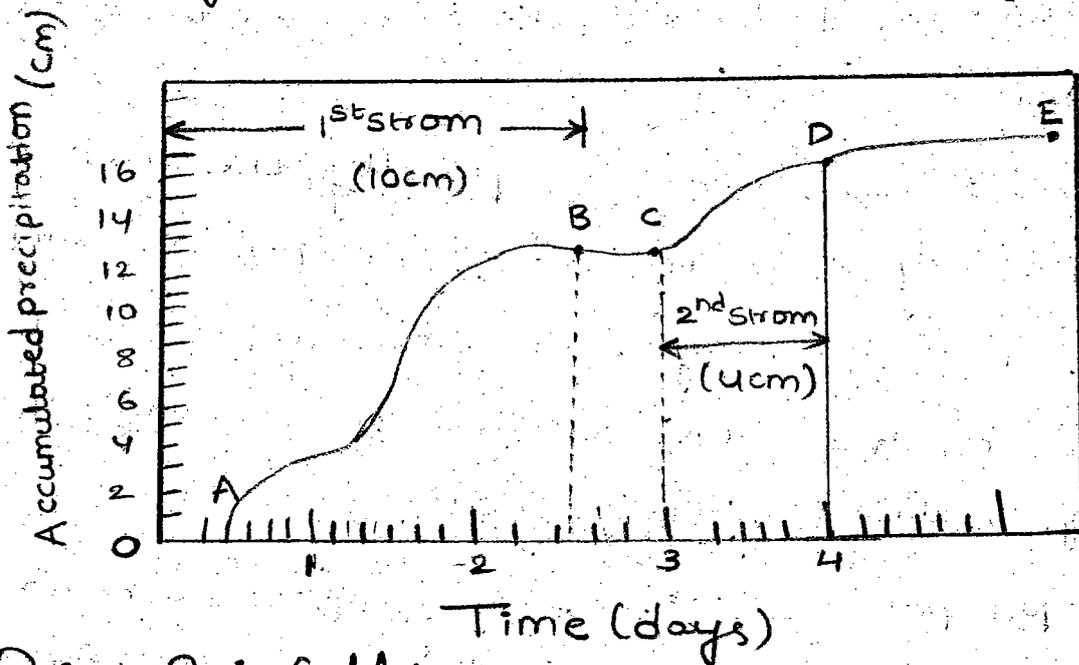
A Hyetograph is plot of the intensity of the rainfall against the time interval and is represented as a bar chart. For is known as a "Hydrograph."



* 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 (extra) extracting information on the duration and magnitude of the storm.

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



* Point Rainfall:

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

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

17/12/18.
==

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 does not 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 is 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 depths 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) Plot the catchment area on paper with the help of planimeter. find the area b/w the isohyets.
- 3) The volume of rainfall is calculated b/w the isohyets by taking average of isohyets multiplied with the area b/w the isohyets.
- 4) Calculate volume of rainfall of all area b/w the isohyets.
- 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 found out
- 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 "Isohyets".

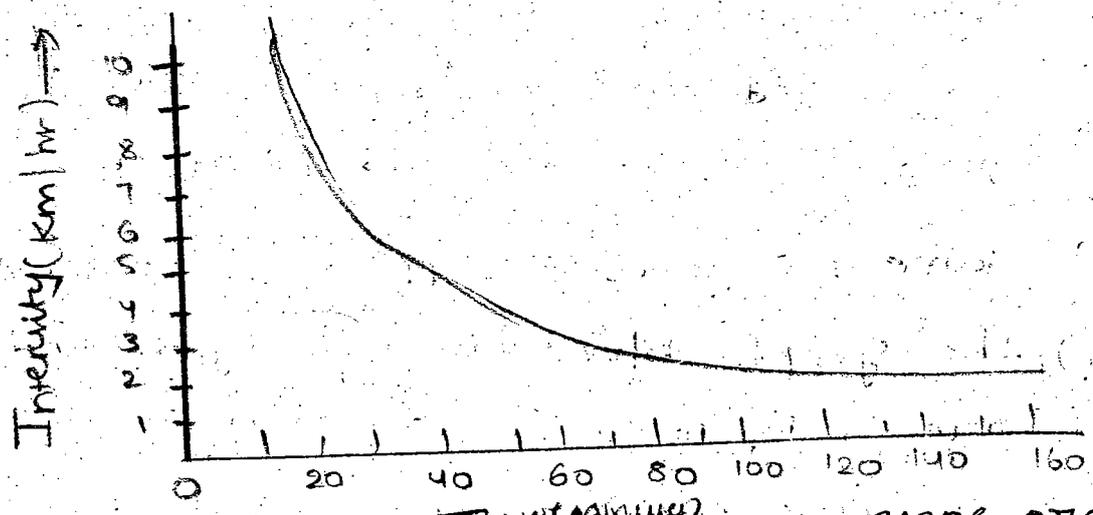
3/12/18.

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

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

10/12/18.

* Consistency of rainfall data at a gauge station:

• Reasons for consistency:

If the change of station of gauge is unreported

to ^{IMD} (Indian Metrological Department)

• ^{if area} Increased in built up area

• ^{dist} 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.

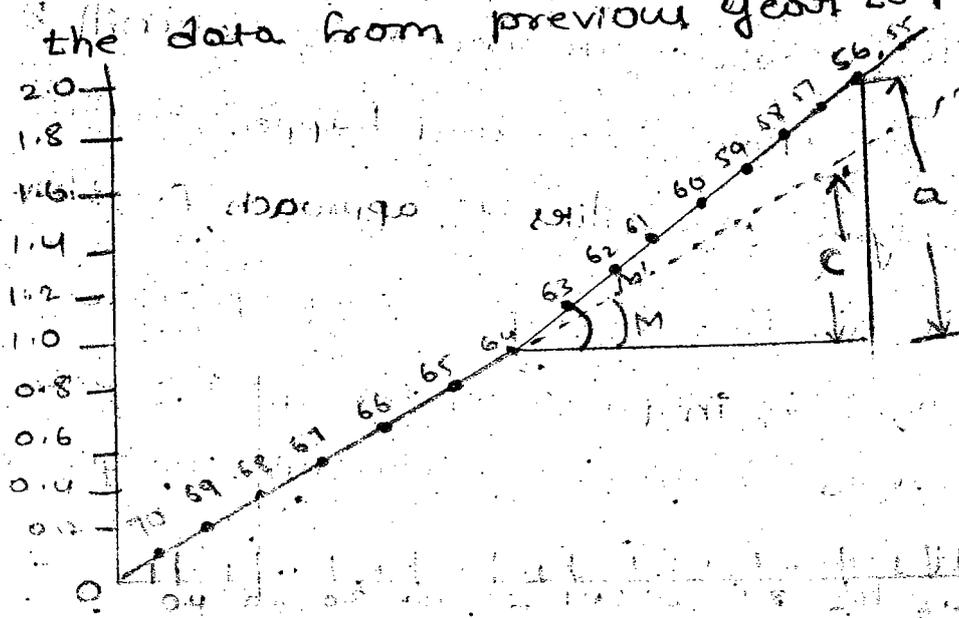
• Collect and analyse the rainfall data of those selected 6 stations from a period of past 35 years. Calculate average rainfall for every year.

• Collect the data of inconsistent station for past 35 years

• Compare the rainfall data of inconsistent station with average rainfall of near by stations.

• List the data from previous year to past years

Accumulated rainfall from year prepared rainfall of station X & P in units of 10³cm.



* 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 found from following formula.

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

(ii) Hazen formula $p = \frac{m - 0.5}{N}$

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

Here $N = \text{Total no. of years} / \text{Total no. of records}$.

$m = \text{Position of that rainfall}$.

* 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

$$\text{PMP} = \bar{p} + k \cdot \sigma$$

Here \bar{p} = Mean of annual rainfall series

σ = standard deviation.

k = Frequency factor which depends upon the statistical distribution

• 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 and 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".

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

13/12/18.

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. T*

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

$$x = a + bE$$

x = Total interception

a = water required for wetting

b = evaporation rate from the intercepting surface (cm/hr)

E = 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 do not contribute to the runoff so these 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 - 0.5 cm
2. Loam - 0.4 cm
3. Clay - 0.25 cm

* 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
2. Nature of evaporating surface
3. Area of water surface
4. Depth of water bodies
5. Humidity
6. Wind velocity
7. Temperature of air
8. Atmospheric pressure
9. Quality of water
10. Nature & size of evaporating surface

14/12/18

* Nature of evaporating surface:

Different evaporating surfaces like soil, forest area, houses and lakes effect evaporation to the extent 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 waterbodies in summer. while in winter season they evaporates 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 overlying moisture vapour from an evaporating body there by 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' are evaporating surfaces.

* Temperature:

= = = = =

Increase in air temperature increases the evaporation rate so not always proportionately for the same temperature cooler 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 ^{at} higher altitudes evaporation ^{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.

11/12/18.

Measurement of Evaporation:

Estimation of evaporation is of very much importance in many hydrologic problems like planning and operation of reservoirs and irrigation systems.

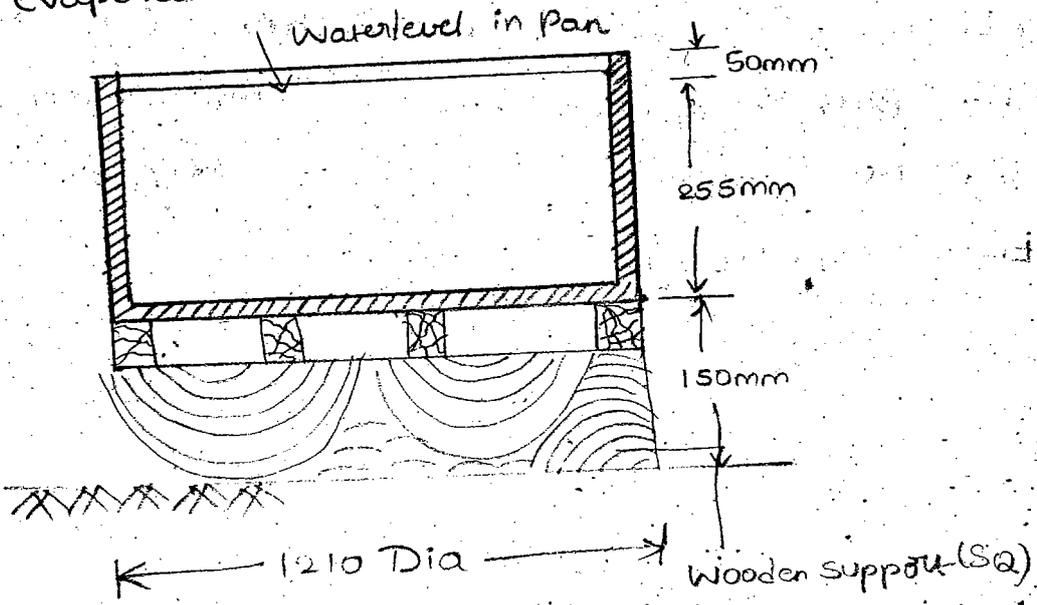
The amount of water is estimated from a water surface by the following methods.

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

* Evapormeter Data:

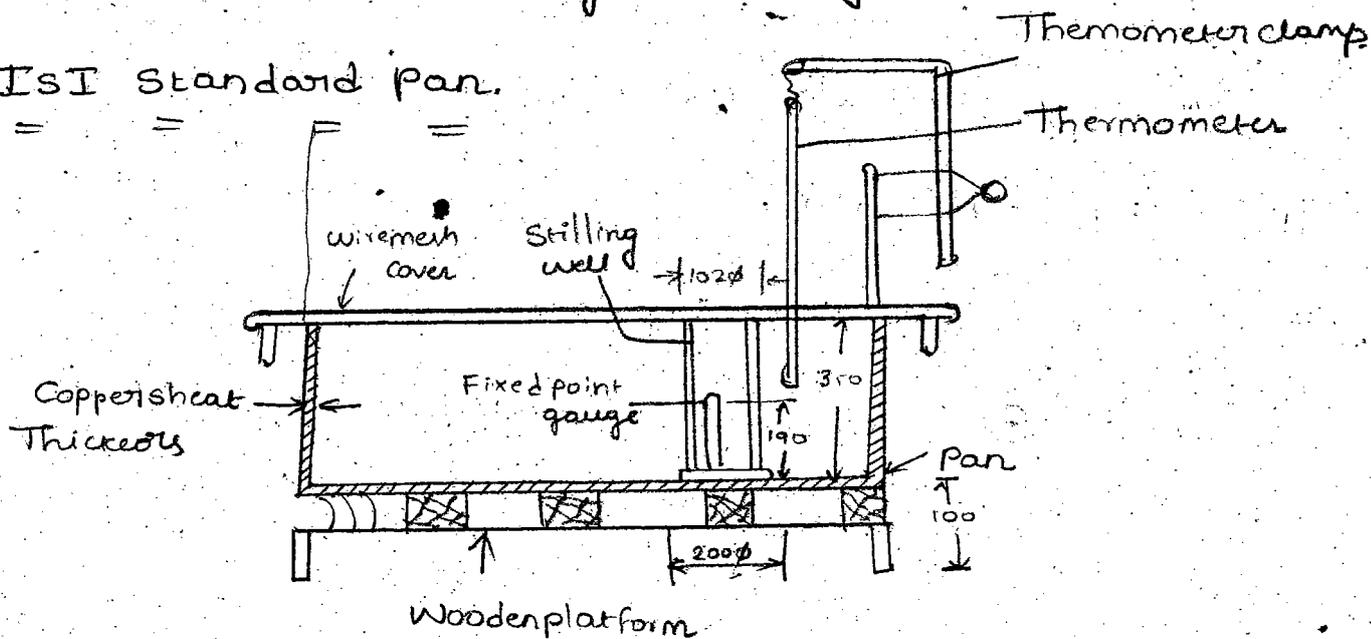
Evapormeter Data are water containing pans which are exposed to atmosphere and the loss of water by evaporation in them is measured. In practice many evapormeter are used. Some of them are

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 evaporimeter 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 Equation

A large number of empirical equations are available to estimate the lake evaporation using commonly available meteorological data. using Empirical Formula:

1. Meyer's formula:

$$E = k_m (e_s - e_a) \left(1 + \frac{V_q}{16} \right)$$

Where E = evaporation from body water body in mm/day

e_s = Saturation vapour pressure at the water surface temperature in mm of hg

e_a = Actual vapour pressure of overlying there in mm of hg at specified height (q_m)

k_m = coefficient having value of 0.36 for large deeper water bodies and 0.5 for shallow water bodies

V_q = Velocity of air at there specified height q_m

2. Rohwer's formula:

$$E = 0.771 (1.465 - 0.000732 P_a) \times$$

$$(0.44 + 0.0733 V_{0.6}) (e_s - e_a)$$

E = Evaporation from waterbody in mm/day

P_a = Mean atmospheric pressure i.e. Barometric reading in mm of hg

$V_{0.6}$ = Mean wind velocity in km/hr at ground level which can be considered at 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

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

(iii) 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

ΔQ_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 water body. So we try to reduce the surface by making the water body more deeper.

2. * Mechanical power:

Evaporation occurs when the sunlight reaches to the surface of water body. So by providing the mechanical power, we will make the surface of water body

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 movement of water particles which leaves the ^{surface} 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 leaves the plant from its leaves and stomata. The transpiration occurs when the process of photosynthesis is running.

As this process occurs in daytime only. The maximum transpiration occurs only on 'daytime' (around 95%).

The important factors which affect the transpiration are as follows:

1. Atmospheric vapour pressure

3. Wind
4. Light intensity
5. Characteristic of plant

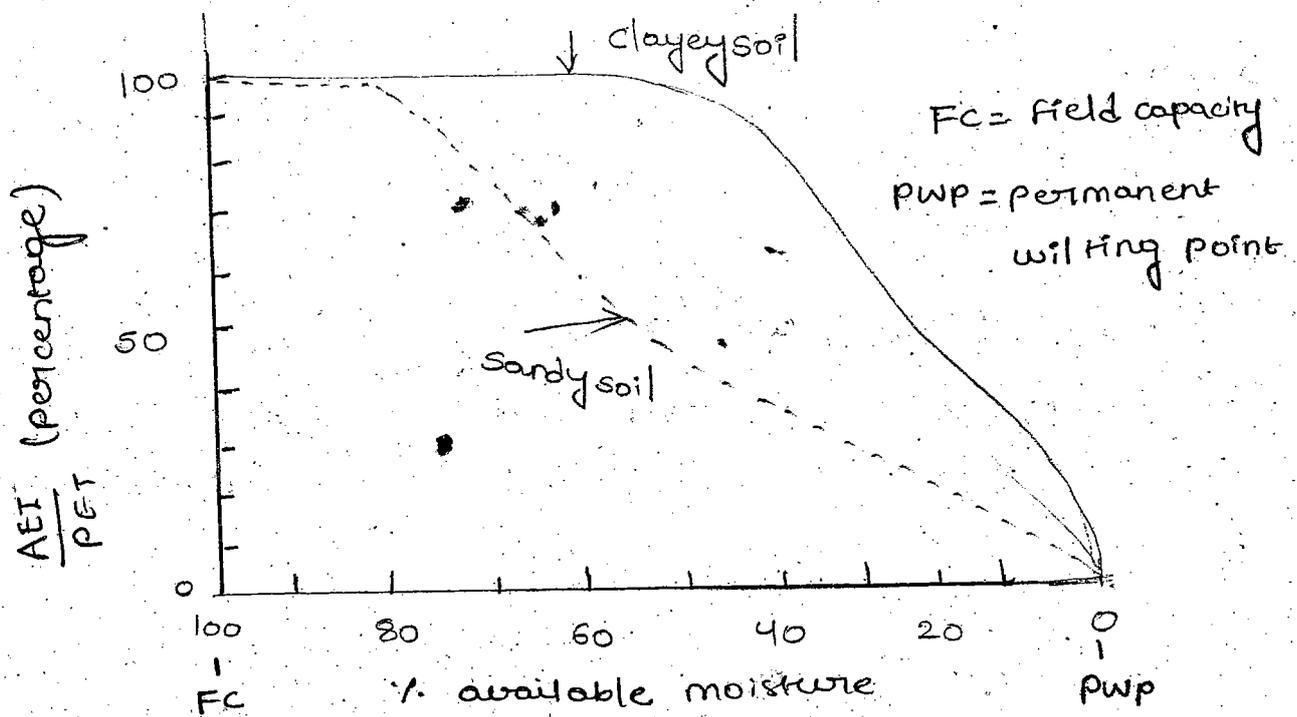
* Different plants will obviously transpire different amount of water and their water consuming characteristics are compared by the transpiration ratio.

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

- 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 occur in in a specific situation in the field is called Actual evapotranspiration (AET)
- PET mainly depends upon climatological factors rather than on characteristics of plants and soil while AET 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 AET 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 to 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. Making Model
2. Evapotranspiration equation
3. Empirical equations.

* Making 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 equation, 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 mass transfer approach

$$PET = \frac{A H_n + E_a r}{A r}$$

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 gradation (in mm of evaporable water per day)

E_a = Parameter including wind velocity & saturation deficit.

K = Psychrometric constant (0.49 mm of Hg / °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°C. Wind velocity at 1mt above ground is 12 km/hour. Mean barometric reading 750 mm of Hg. Saturation vapour pressure at 30°C is 31.82 mm of Hg. Estimate the average daily evaporation from this reservoir and volume of water evaporated during this week (use Meyer's & Rohwer's formula).

Soln: Given data:

Reservoir surface area = 300 hectares

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

R.H = 50%

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

$V_1 = 12 \text{ km/hour}$

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

$K_m = 0.86$

Meyer's formula:

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

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

$$V_g \approx \frac{v_1}{V_g} = \left(\frac{1}{9}\right)^{(1/7)} = \frac{12}{V_g} = 0.730$$

$$V_g = 16.42$$

$$E = 0.36(31.82 - 15.91) \left(1 + \frac{16.42}{16}\right)$$

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

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:

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

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

$$\frac{V_{0.6}}{12} = \left(\frac{0.6}{1}\right)^{1/7}$$

$$V_{0.6} = 11.15 \text{ km/hr.}$$

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

$$E = 14.12 \text{ mm/day}$$

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

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

$$Q_7 = 42360 \times 7 = 2,96,520 \text{ m}^3 \text{ (per week)}$$

Total quantity of water per day = 42360 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 controlling the magnitude, timing & distribution of surface runoff of a basin.

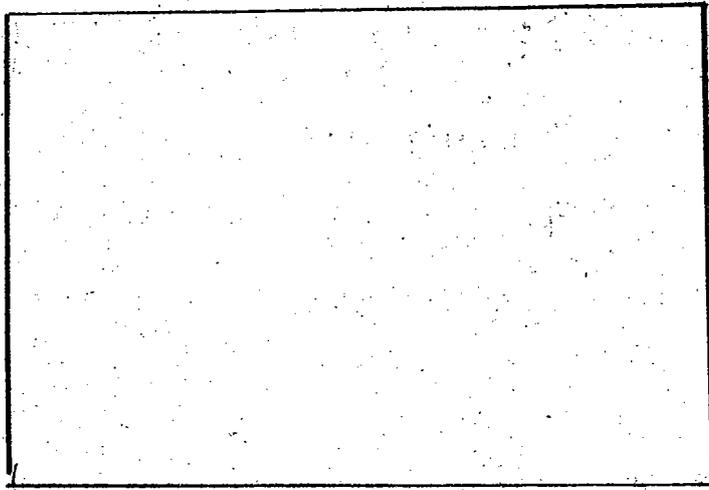
* Infiltration Capacity:

The capacity of any soil to absorb water from rainfall continuously at an excessive rate goes on decreasing with time until a minimum rate to infiltrate is reached. At any instant the infiltration capacity of a soil is the max. rate at which all water entering 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 groundwater 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 effecting Infiltration:

1. 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.

→ shield in the soil surface from direct impact of raindrops because rain drop 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 infill.

2. Permeability (or) Percolation characteristics of soil formation

The infiltration will continue only when percolation continue. 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's 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. The 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 result in increasing rate of infiltration. On the other hand construction of roads, houses, factories, playgrounds result 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.

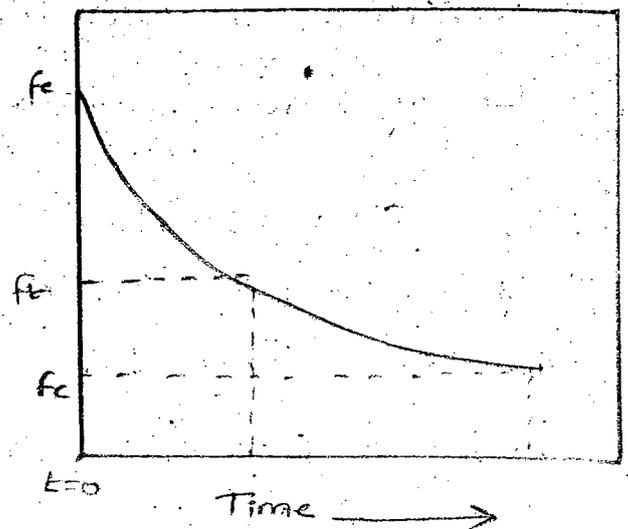
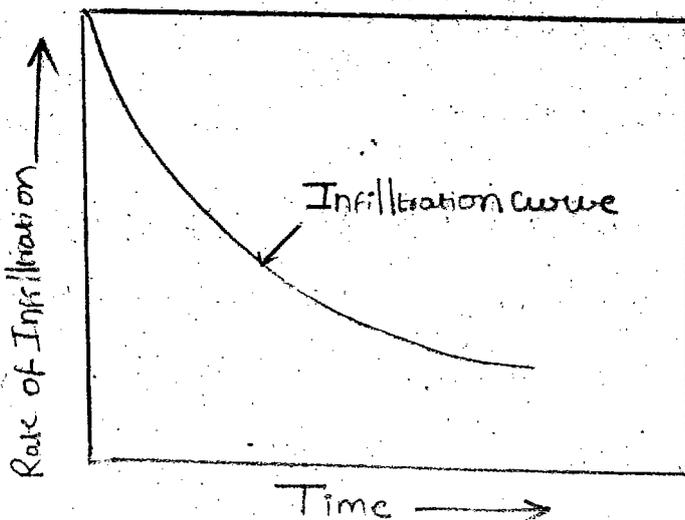
Presence of Groundwater Table

In presence of GW Table reduces infiltration. For infiltration to continue in position of GW Table 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.

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* Field measurement of Infiltration rate:

It can be measured with two types of Infiltrometers

1. Single tube infiltrometer
2. Double tube Infiltrometer

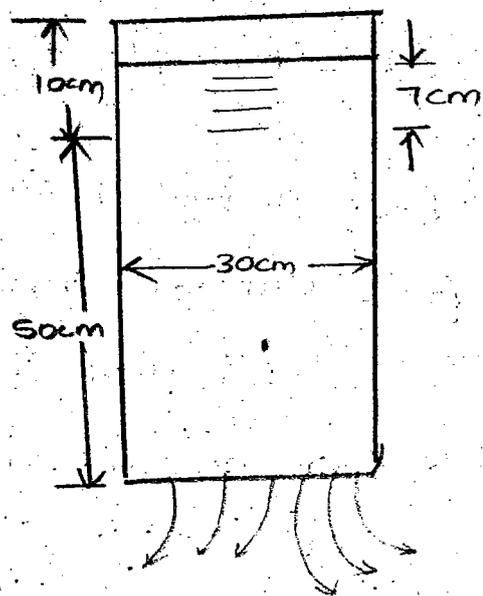
1. Single tube Infiltrometer

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 keep on decreasing.

Water is added to the cylinder through graduated jar (or) 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

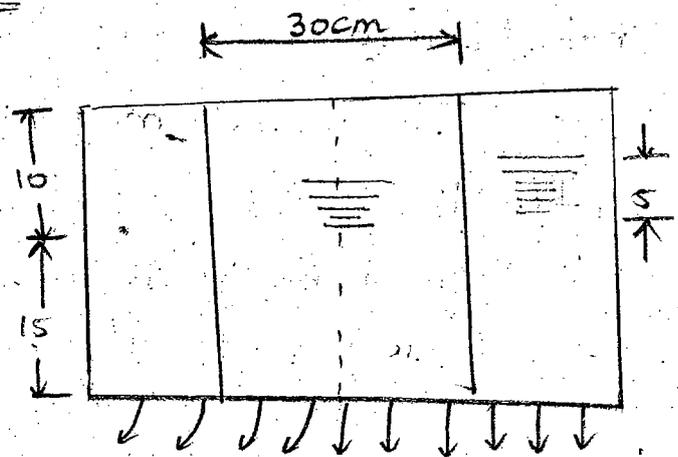
obtained, which may take about 3-6 hrs depending upon the type of a soil.



Infiltration rate

2. Double tube Infiltrometer: $\leftarrow 60\text{cm} \rightarrow$

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:

Horton's equation:

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

Where

f_t = infiltration rate at any time t

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

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

K = a constant which depends on the soil and evaporation.

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: (catchment)

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 & into the stream channels will normally represent only a small percentage of total volume of water flowing in the stream

* Surface runoff

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

Turbulent 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 until finally 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

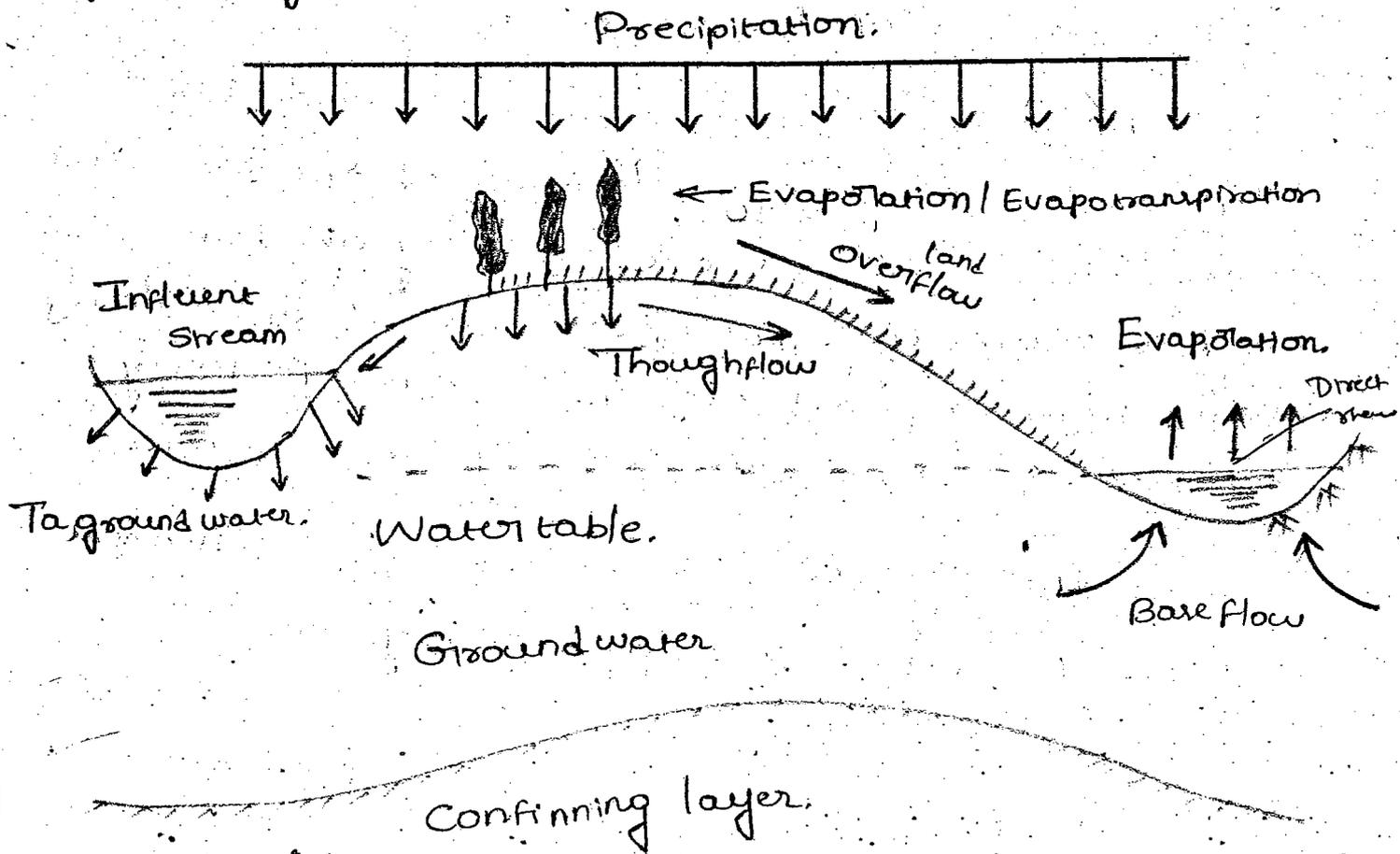
It is the part of runoff which enters the stream immediately just after the rainfall.

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."



03/01/19.

* Factors effecting Runoff

The principal factors affecting the flow from a catchment area are

1. Precipitation characteristics.

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

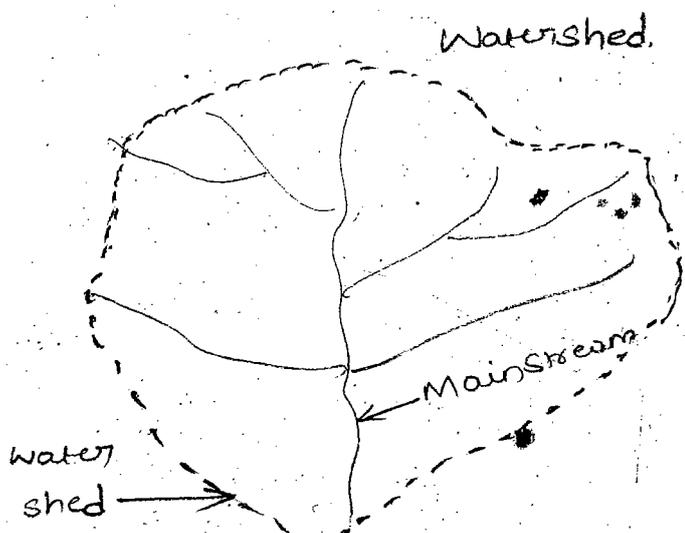
1. Intensity
2. duration
3. Areal distribution
4. Direction of storm movement
5. Form of precipitation
6. Evapotranspiration.

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

2. Shape and size of the catchment:

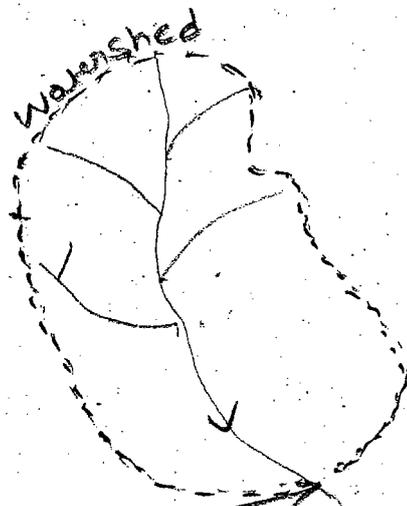
The runoff from a catchment also depends upon the size, shape and location of the catchment. More intense rainfalls are generally distributed over a relatively smaller area. A stream collecting water from a small catchment area is likely to give greater runoff intensity per unit area.

In the case of fan (or) sector shape 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.



Fan shaped catchment

* Topography of catchment.



Mainstream

Fern leaf catchment.

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 is mountainous and is 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 catchment basin

This is an important factor affecting the runoff. These 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 in turn 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 affects the runoff. If the temperature is low the ground is saturated & frozen, it gives rise to greater runoff. However if the whole of the stream 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 carrying 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) ~~planted~~ 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

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

Drainage Density:

It is defined as length of streams per unit area.

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

* 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 finds its weight overland to the rivers stream and appears as surface run but only after some delay.

In other words there exists a lag b/w 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 flow through the basin before entering into a definite drain known as "Time of overland flow."

* Isochrone:

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.

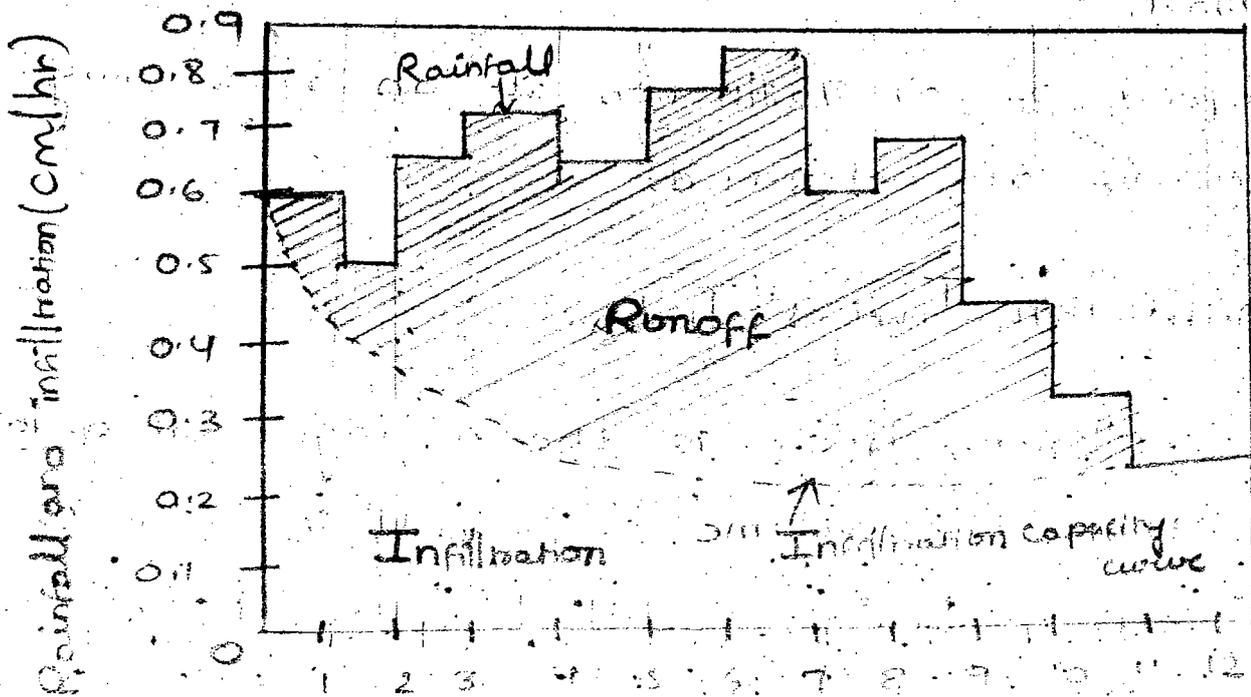
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* Runoff coefficients

$$R = K.P$$

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 falls 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 (ϕ) the rainfall rate whichever is less.

IC curve limitations

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 heterogenous 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 (ϕ) W-Index & ϕ -Index

ϕ -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 ϕ 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 ϕ -index minus average rate of retention by interception and depression storage.

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

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

$$\phi_i = \frac{A_2 + A_3 + A_4 + A_5}{t_{ex1} + t_{ex2} + t_{ex3}}$$

Where.

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

$t_{ex1}, t_{ex2}, t_{ex3} =$ 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_{01} = Total period of Rainfall.

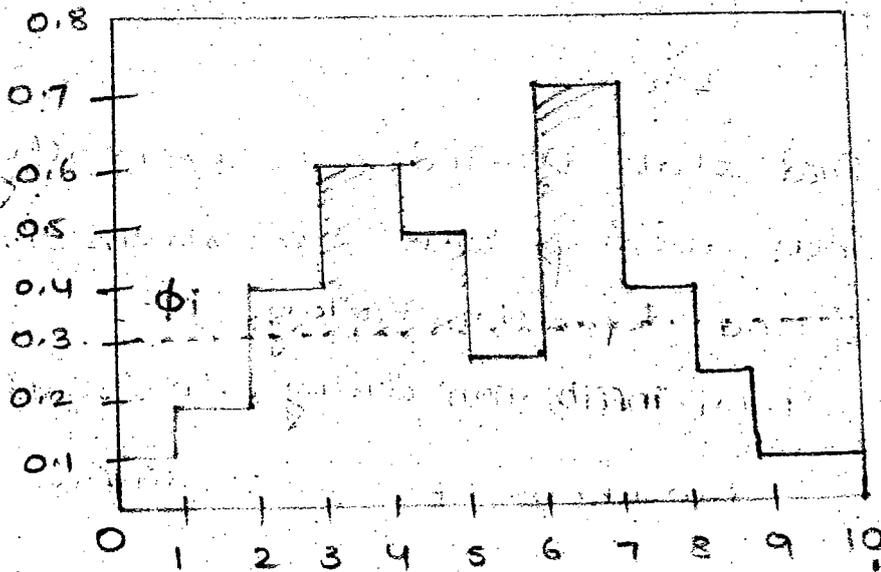
The W-index is calculated from the expression is

$$W_i = \frac{P - R - S_p}{t_{01}} \text{ cm/hr.}$$

Where S_p = Surface Retention.

t_{01} = Duration of rainfall in hours.

Q_i curve:



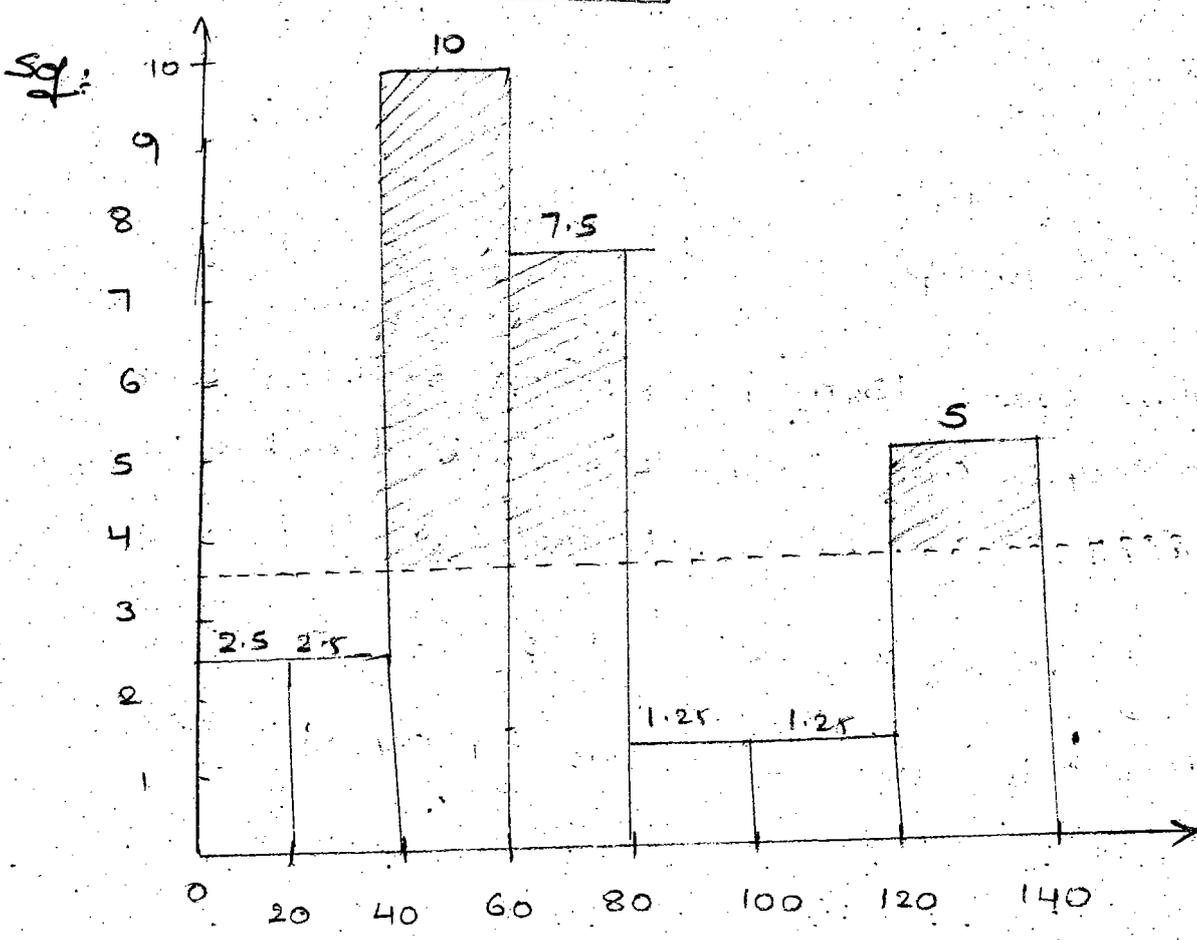
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1. The following are the rate of rainfall for successive 20 min period for a rainfall of 140 minutes duration.

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 ϕ_i as 3.2 cm/hr
 Find out net runoff in cm
 Total runoff & value of W-Index.



Step 1:

$$\begin{aligned} \text{Net runoff } R &= \sum (i - \phi_i) t \\ &= \left[(10 - 3.2) \frac{20}{60} + (7.5 - 3.2) \frac{20}{60} + (5 - 3.2) \frac{20}{60} \right] \\ &= 4.8 \text{ cm/hr} \end{aligned}$$

Step 2

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

Step 3:

Windex

$$\begin{aligned} W_i &= \frac{P - R - S_2}{E_{T1}} \\ &= \frac{10 - 4.3 - 0}{146/60} = 2.44 \text{ cm/hr} \end{aligned}$$

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

28101119.

2. Sol: Given data:

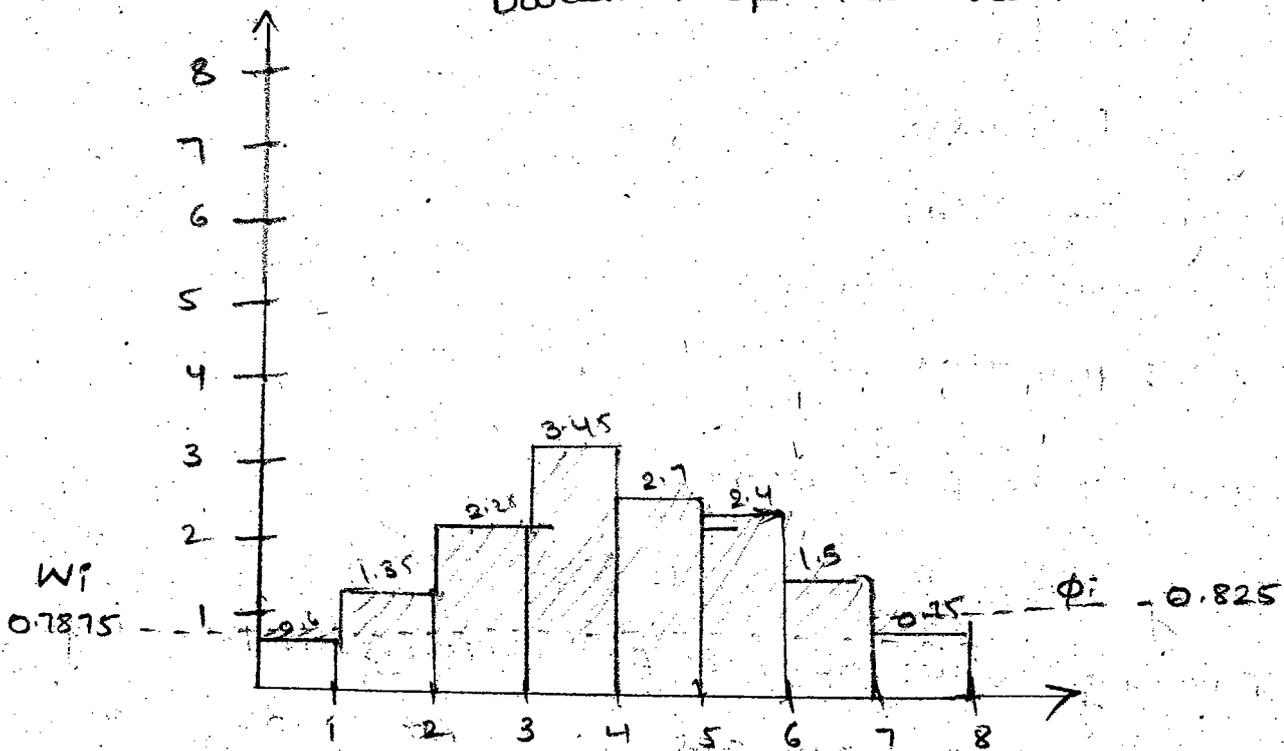
Precipitation (P) = 15 cm

Direct Runoff (R) = 8.7 cm

As we know that $\phi_{index} \geq W_i$

$$W_i = \frac{P - R - S_{1st}}{t_{ex}} = \frac{15 - 8.7 - 0}{8} = 0.7875 \text{ cm/hr}$$

$$\phi_i = \frac{\text{Total infiltration during excess rainfall} - (\text{Infiltration}_{1st \text{ ord}}) - (\text{Infiltration}_{last \text{ ord}})}{\text{Duration of excess rainfall.}}$$



As 1st and last hour rainfall is less than w-index so they donot give any excess rainfall i.e Runoff

∴ The excess rainfall may be occur in b/w

$$\phi_i = \frac{\text{Total infiltration during excess rainfall} - (\text{Infiltration}_{1st \text{ ord}}) - (\text{Infiltration}_{last \text{ ord}})}{\text{Duration of excess rainfall.}}$$

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

Check:

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

29/10/19.

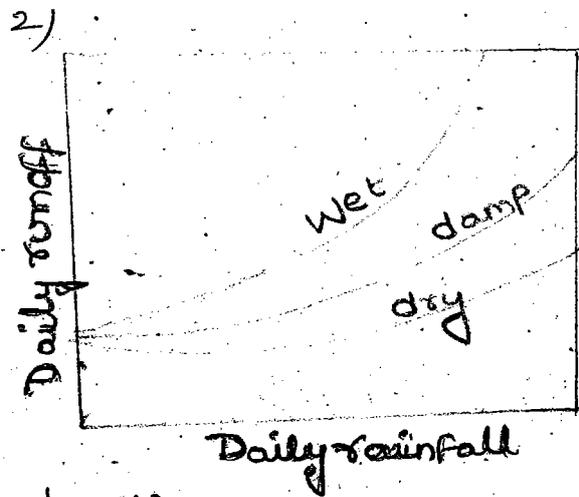
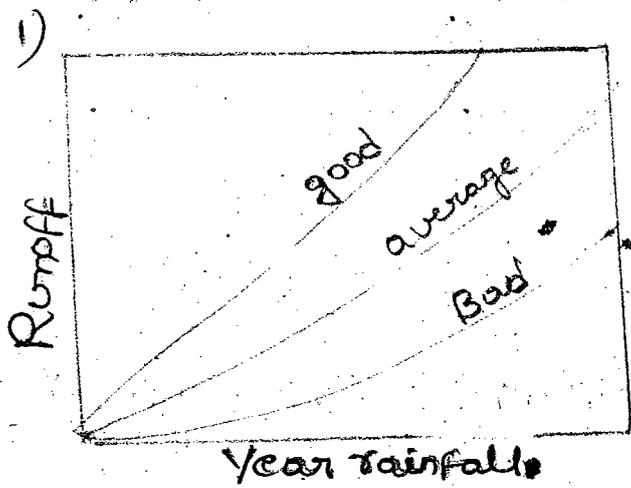
* Empirical Formulae and Charts.

1. Burdow's runoff coefficient
2. Strangor's charts and tables
3. Ingle's Formulae
4. Lacey's Formulae
5. Khos Law's formulae
6. Parker's formulae.

* Burdow's runoff coefficient:

This is Study 140 km² 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.

	Burdow'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 hardly cultivation	45%



* Stranger's Tables and charts

He proposed tables & charts for computation of runoff in plains of South India. These charts & tables give 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)

* Inglis's Formula:

For Bombay presidency, Western Ghats and plains of Maharashtra

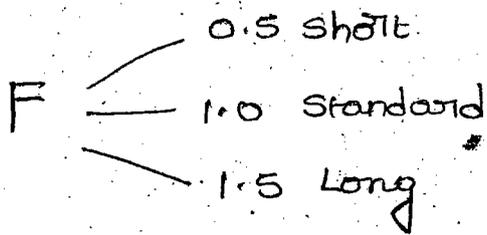
Ghats : $R = 0.85P - 30.5$

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

Indo-gangetic plain:

$$R = \frac{P}{1 + \frac{304.8P}{P^2}} \quad (P, R \text{ in cm})$$

P → Type of Monsoon for certain period.



Svalue: Depending upon classification of catchment by Beilow

A → 0.25

B → 0.6

C → 1.0

D → 1.7

E → 3.45

4. Khosla's Formula

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

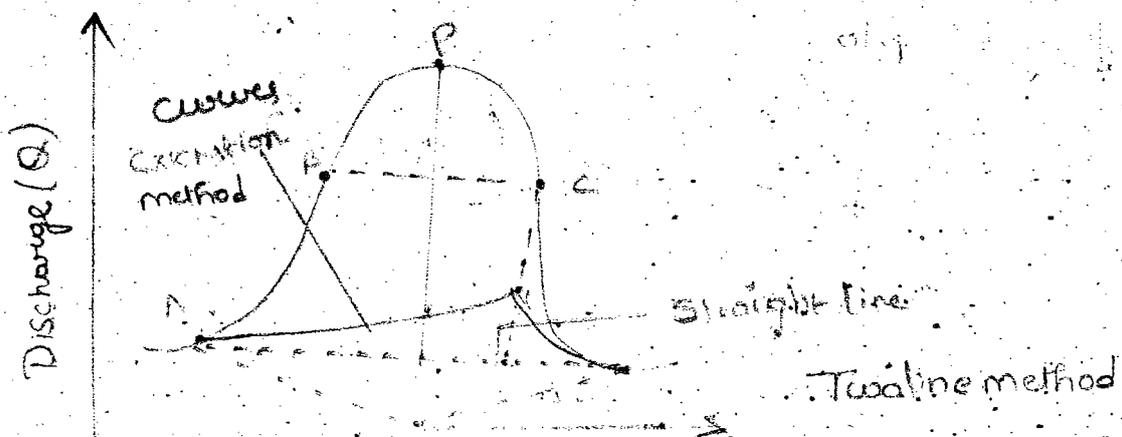
5. Parker's Formula

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

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

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

Base flow Graph

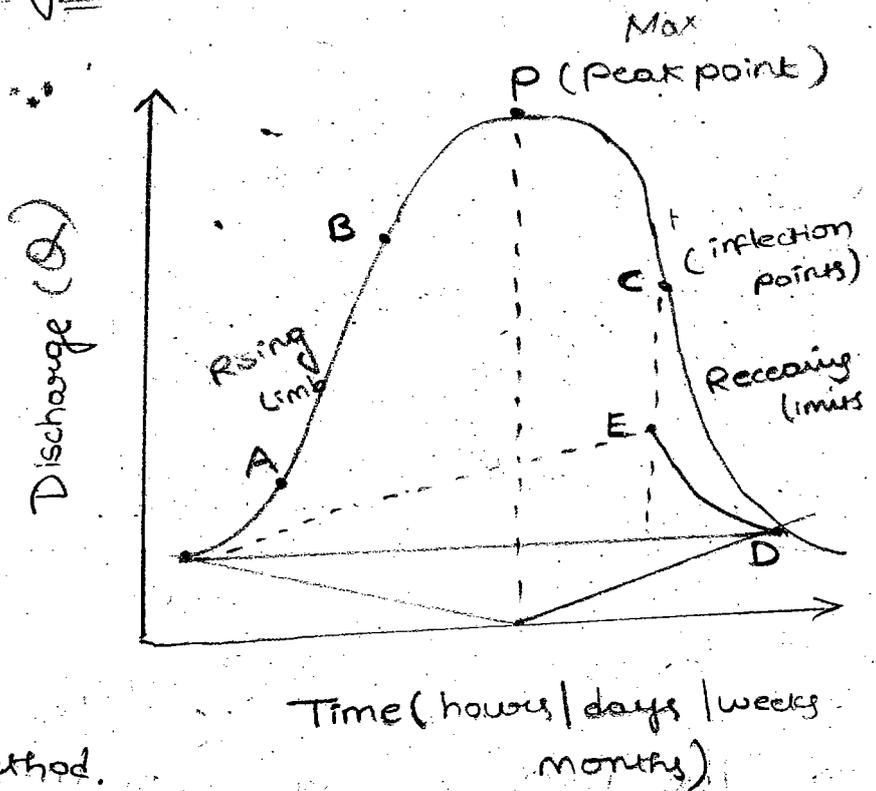


08/02/19:

* Hydrograph Analysis:

Components:

1. Rising Limb
2. peak point
3. Inflection point
4. Receding limits



Base flow separation

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

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

(Time) Hour	0	3	6	9	12	15	18	21	24	27
ordinates	10	25	40	60	75	35	20	15	10	5

Assume Baseflow 10 m^3 per second. Find out ordinates of direct runoff hydrograph & runoff depth in cm if area of catchment is 20 km^2 .

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

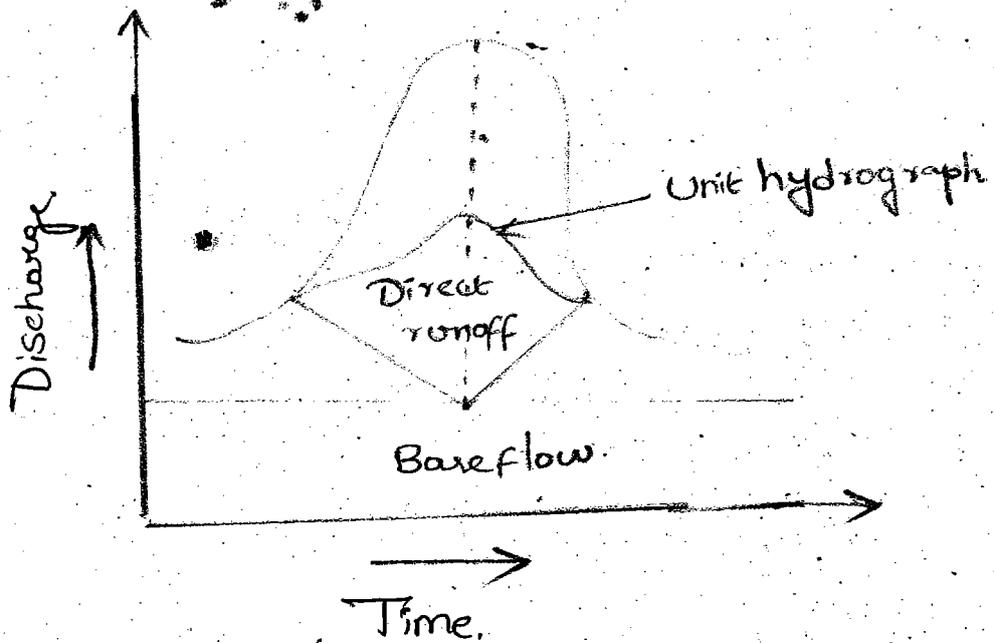
$$D.R = \frac{0.36(10 + 25 + 40 + 60 + 75 + 35 + 20 + 15 + 10) 23}{20}$$

$$= 15.66 \text{ cm}$$



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 base flow is uniform at $20 \text{ m}^3/\text{s}$. Area of catchment is 200 km^2 .

Time (hours)	Ordinates of flood Hydrograph	Baseflow.
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 hydrograph	Baseflow	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	430	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

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

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

Ordinates of unit hydrograph. $\left(\frac{\text{DRH ord}}{\text{Runoff}} \right)$

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

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

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

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

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

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

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

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

$$\Sigma O = 138.882$$

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

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

* Exp

Derive a 2-hr unit hydrograph from following total runoff hydrograph resulting from rainfall of effective duration 2hrs. Drainage basin area is 104 km².

Date	Time (hr)	Runoff (m ³ /s)	Baseflow (m ³ /s)
July 10	06	14.2	14.2
	08	158.5	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 runoff = $\frac{0.36(\sum O) \times T}{A}$

$$= \frac{0.36(1659.3) \times 2}{104}$$
$$= 11.48 \text{ cm}$$

Date	Time	Runoff	Baseflow	ordinates of DRH	ordinates of stor 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	270.8	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	74.7
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

Σ ordinates of unit hydrograph = 144.481.

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

14/02/19.

* 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 + Baseflow

The following data of 2h unit hydrograph, if rainfall exceeds 8cm for an intense rainfall of 2hour on same catchment. Determine the ordinates of flood hydrograph. Base flow of ordinates are given below.

Sol:

Date	Time	Ordinate of unit hydrograph	Ordinate of D.R.	Baseflow	Ordinate 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	9.64
	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 rainfalls of same duration, t

Find the ordinates of a storm hydrograph resulting from a 3h with rainfalls of 2, 6.75, 3.75mm respectively during subsequent 3 hours intervals. The ordinates of unit hydrograph are given in the following table. Assume an initial loss of 5mm and ϕ index of 2.5mm/hr and a constant base flow of $10\text{m}^3/\text{sec}$

Time	Ordinates of UH.	Rainfall Excess.	Surface Runoff during 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	273.7	2190	1095		
12	500		375	3000	1500		
15	390		292.5	2340	1170		
18	270		232.5	1860	930		
21	230		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

$$\Rightarrow 20 - (2.5 \times 3) = 12.5 - 7.5 = 4.5 \text{ mm} = 0.45 \text{ cm}$$

Rainfall excess during 2nd 3 hours

$$67.5 - (2.5 \times 3) = 62.5 \text{ mm} = 6.25 \text{ cm}$$

Rainfall excess during 3rd and last 3 hours

$$37.5 - (2.5 \times 3) = 32.5 \text{ mm} = 3.25 \text{ cm}$$

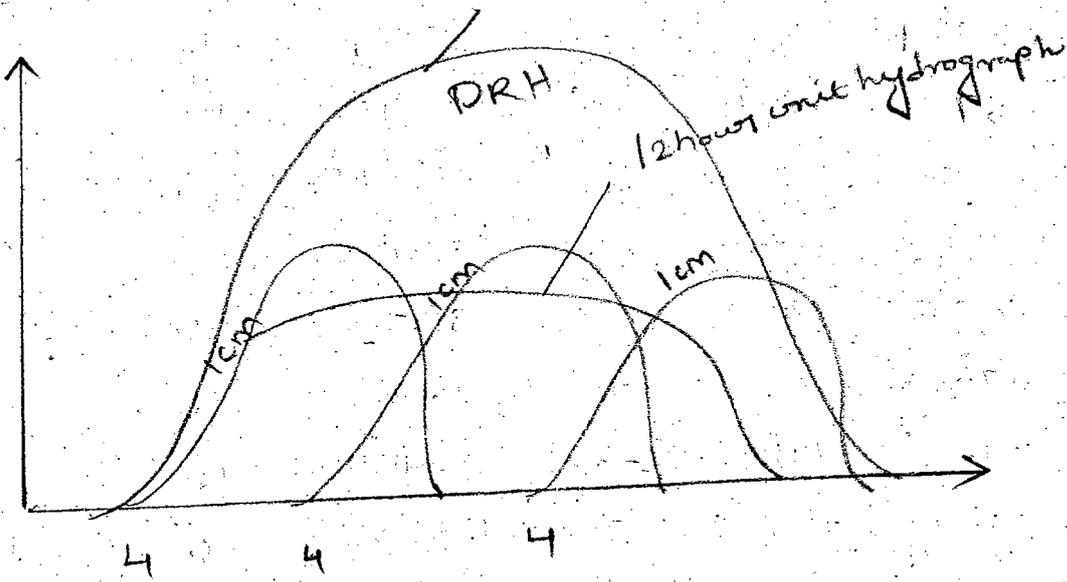
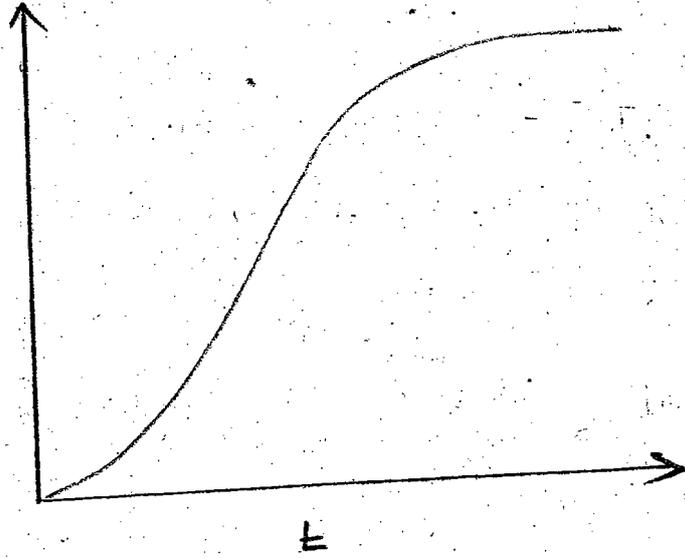
Rainfall excess	Surface run-off from rainfall excess during successive unit periods				Baseflow	Total Discharge
	0.75	6.00	3.00	Total		
0.75	0			0	10	10
6.00	82.5	0		82.5	10	92.5
3.00	273.4	660	0	934	10	944
	375	2190	330	2895	10	2905
	292.5	3000	1095	4387.5	10	4397.5
	232.5	2340	1500	4072.5	10	4082.5
	187.5	1860	1170	3217.5	10	3227.5
	176.25	1500	930	2606.25	10	2616.25
	131.25	1410	750	2291.25	10	2301.25
	97.5	1050	705	1852.5	10	1862.5
	71.25	780	525	1376.25	10	1386.25
	48.75	570	390	1008.75	10	1018.75
	30	390	285	705	10	715
	16.5	240	195	451.5	10	461.5
	7.5	132	120	259.5	10	269.5
	0	60	66	126	10	136
		0	30	30	10	40
			0	0		

14/02/19.

S - Hydrograph.

S = Summation

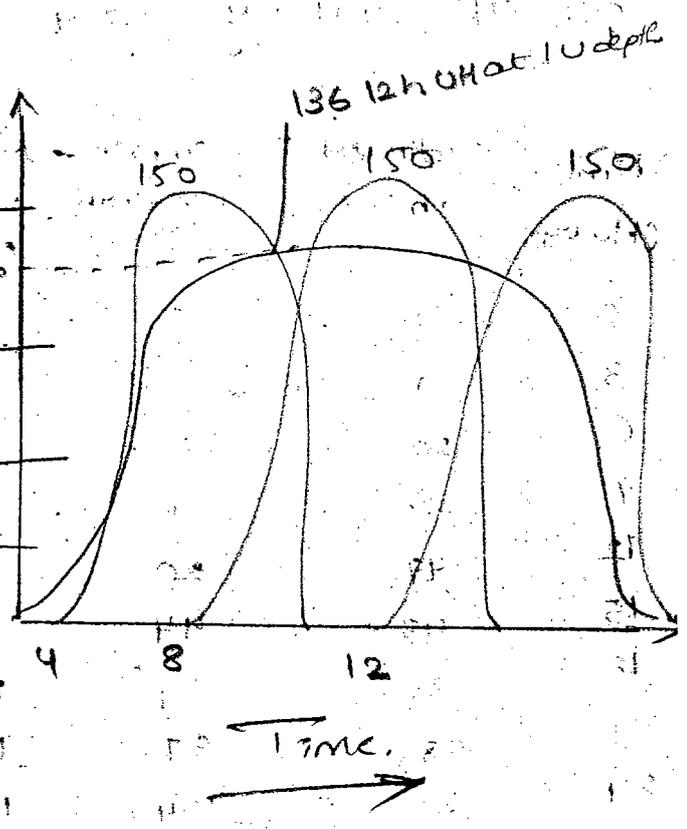
It is mainly imp
for unit hydrograph
to many hydrographs @



15/02/19.

* Given the ~~OH~~ of 4-hour ~~UH~~ below. Derive the
Ordinates of 12-h for the same catchment.

Hourly	ord. of 4hr UH (A)	ord of 4h UH lagged by 4h (B)
0	0	-
4	20	0
8	80	20
12	130	80
16	150	130
20	130	150
24	90	130
28	52	90
32	27	52
36	15	27
40	5	15
44	0	5
48		0
52		



Hourly	ord of 4h-UH (A)	ord of UH lagged by 4h (B)	ord of UH lagged by 4h (C)	ord 12h UH with 3cm	ord of 12h with 10 depth $(\frac{20}{3})$
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

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

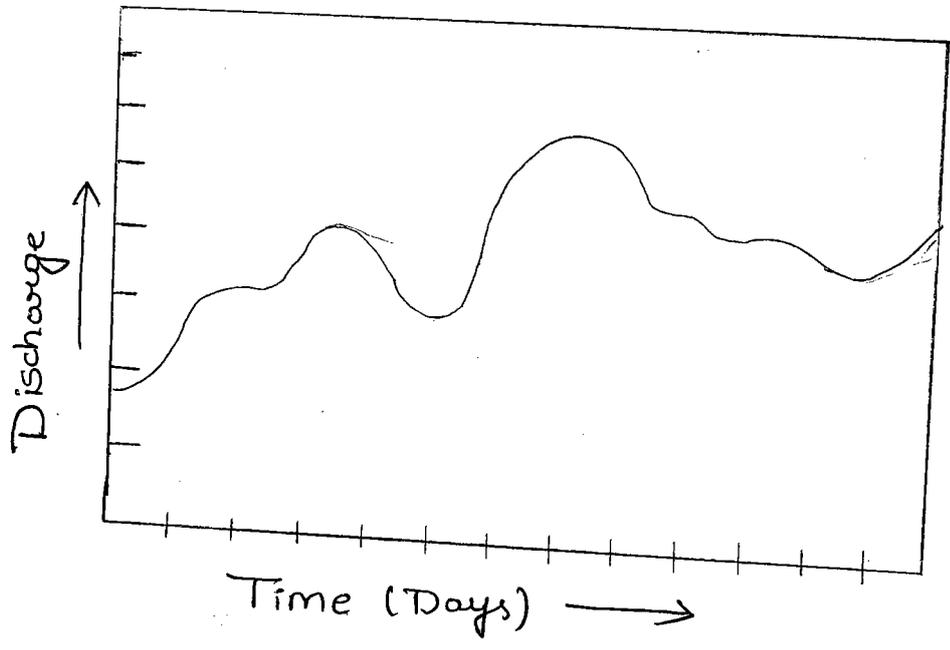
Time (Hour)	Ordinates of 6h UH	Offset ordinates	S-curve Ordinates	offset of S-curve ordinates	Δ of old	9hour UH with S-curve ($\Delta \times \frac{2}{3}$)
0	0	-	0	-	0	0
3	9	-	9	0	9	6
6	20	0	20	9	11	7.33
9	35	9	44	20	24	16
12	49	20	69	44	25	16.67
15	43	44	87	69	18	12
18	35	69	104	87	17	11.33
21	28	87	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 = $\Delta \times \frac{2}{3}$ 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.

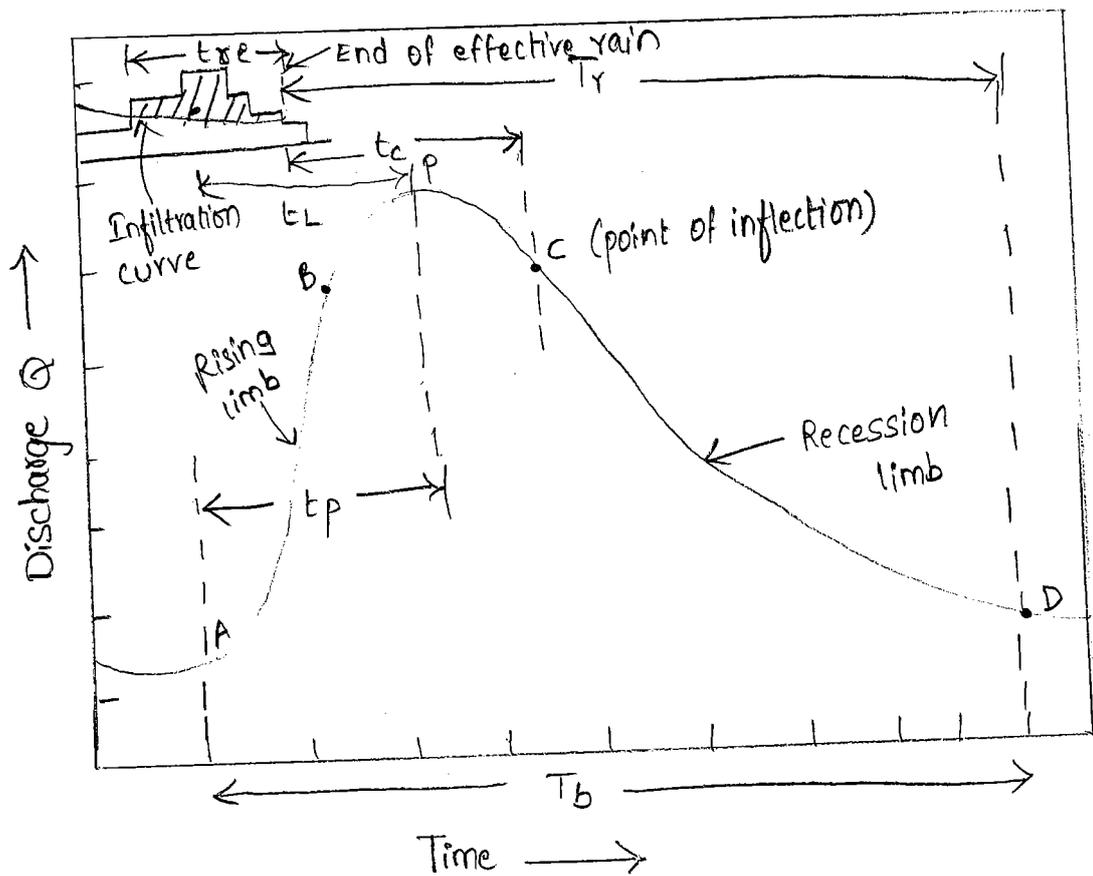
As the runoff includes the contributions from surface runoff, subsurface runoff (or inter flow) and groundwater runoff. (or base flow).



STREAM 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 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.

* Seperation Of Base flow:

There are three methods.

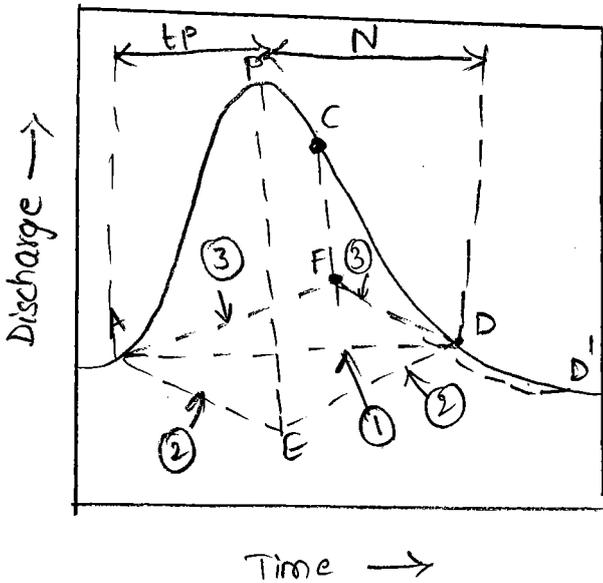
1. Straight line Method
2. Two line Method
3. Curves extension method.

1. Straight line Method:

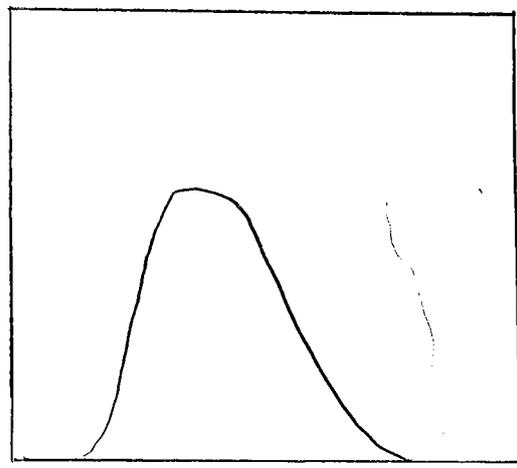
In a storm hydrograph direct runoff & base flow can be seperated by joining point of rise and point of end by a simple straight line AC.

- * Position above AC - Runoff
- Below AC - Base flow.

* Simplex Method.



(a) Three methods of Seperation.



(b) Resulting DRH.

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. Curve 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 (AGD)

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

①

④

* 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

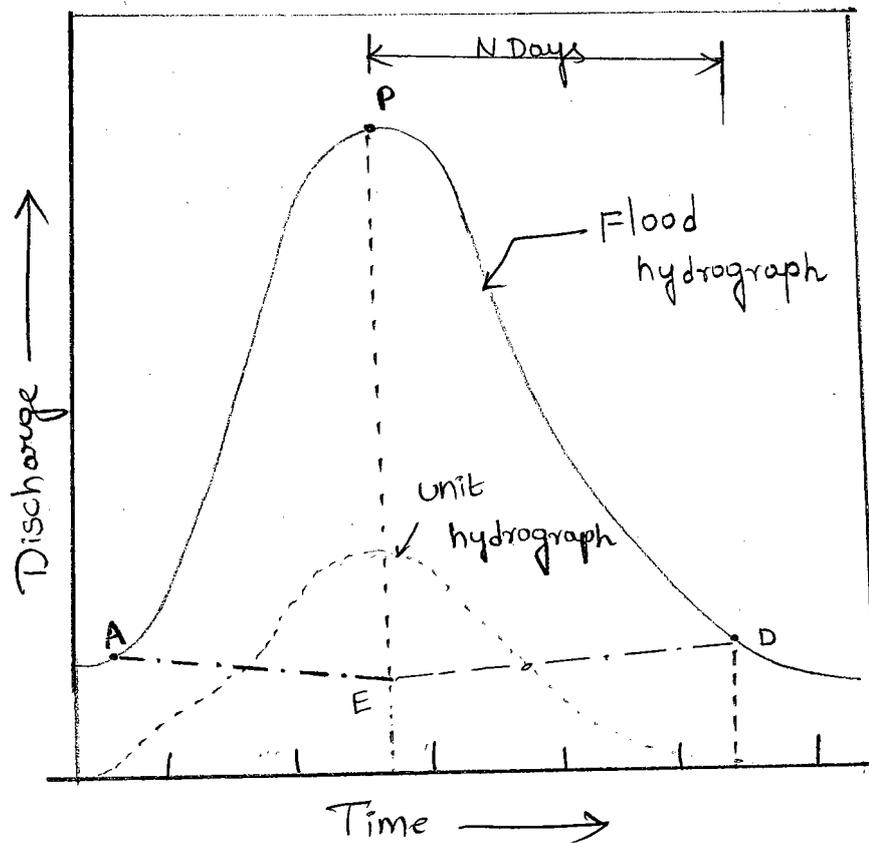
of direct run-off due to an effective rainfall of unit duration is constant.

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. From the past records of the river discharge for that storm, plot the storm 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 runoff.
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:

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

Where

$\sum O$ = 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 (m^3/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 $20 km^2$.

Sol: Given data:

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

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

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

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

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

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

2
sol.

Time (hours)	Ordinates of flood hydrograph	Baseflow	ordinate 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 $\left(\frac{\text{DRH ord}}{\text{runoff}} \right)$

- | | | |
|----------------------------------|----------------------------------|--------------------------------|
| 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

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

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 km^2 .

Date	Time (hour)	Runoff (m^3/s)	Baseflow (m^3/s)	Ordinates of DRH	Ordinates of 2 hour 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	21.32
	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

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

$$\Sigma \text{ ordinates of unit hydrograph} = 144.481$$

Check:

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

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

1. Ordinates of Direct runoff hydrograph is calculated

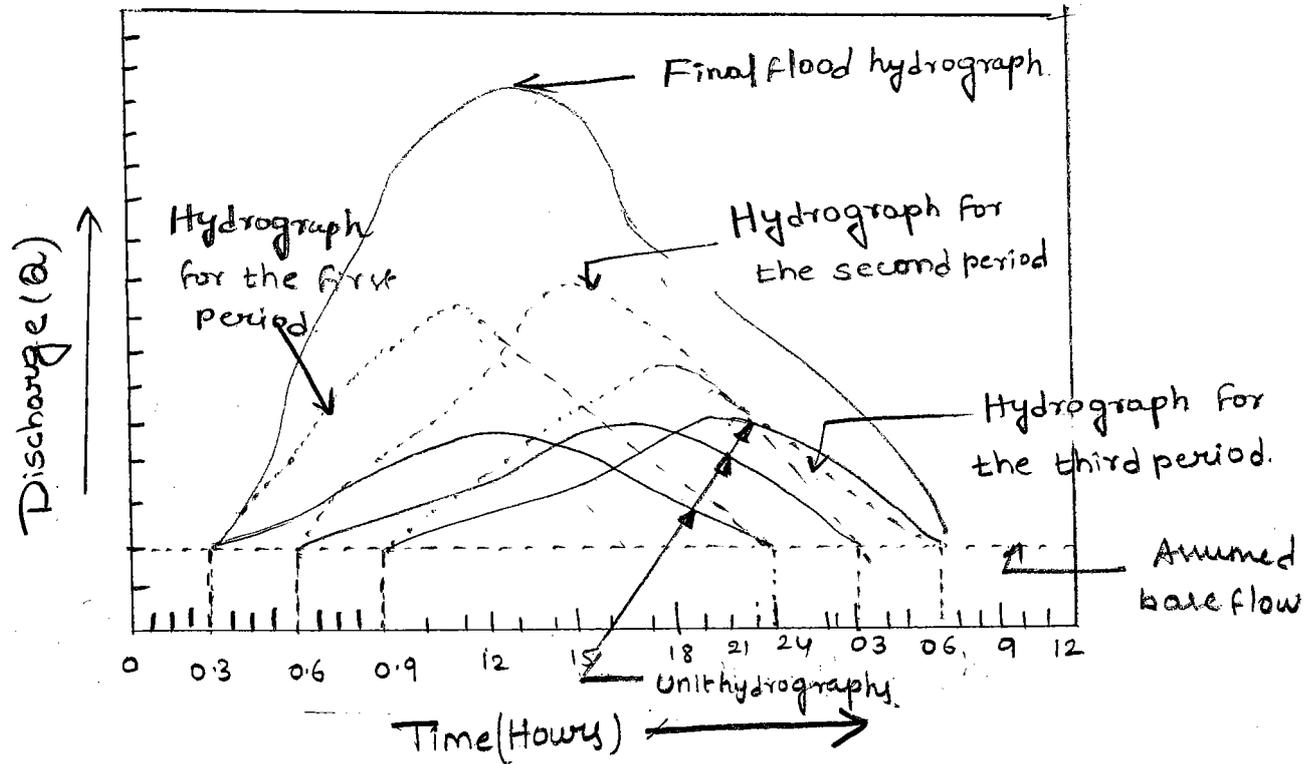
$$DRH = (\text{runoff})_{cm} \times \text{Ordinates of UH.}$$

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) x n	Base flow (5)	Total ordinate 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 13 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 (cumecs)	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 2.5mm/hr and baseflow of 10 cumecs.

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	274.0	660	0	934.0	10	944.0
12	500		375.0	2190	330	2895	10	2905.0
15	390		295.5	3000	1045	4337.5	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
36					0	0	10	100.0

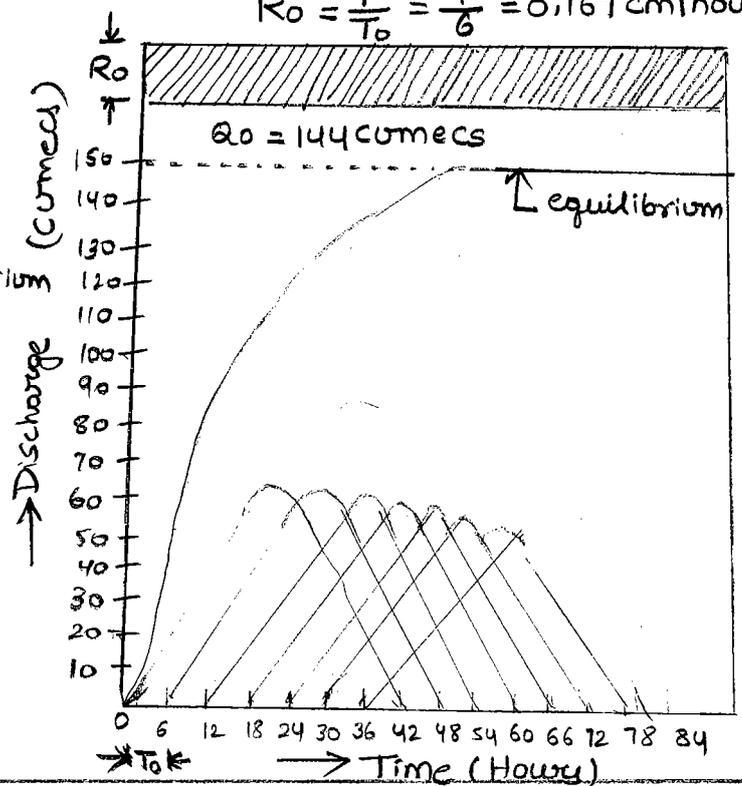
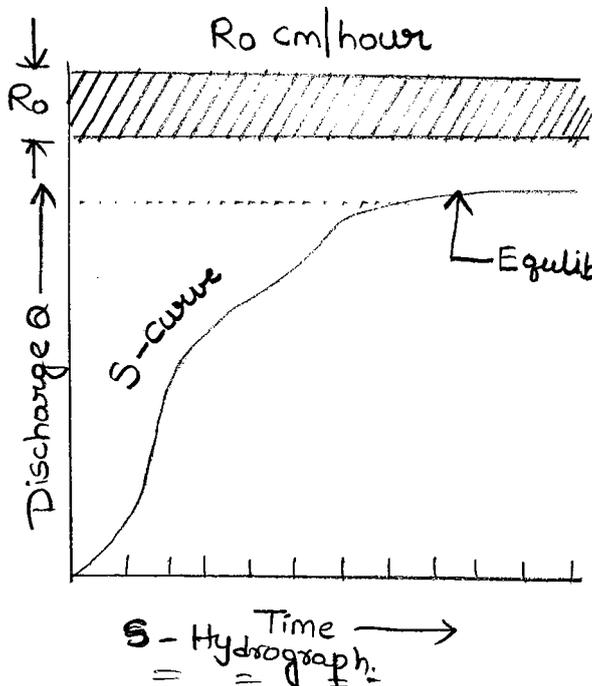
S - Hydrograph (Summation Hydrograph).

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.

$$R_0 = \frac{1}{T_0} = \frac{1}{6} = 0.167 \text{ cm/hour}$$



1. Ordinates of 6 hour unit hydrograph are given.

Derive s-curve of 9hour UH.

Time (Hours)	ord of 6h UH.	Offset ordinates	S-curve Ordinates	Offset of S-curve ordinates	difference of ord (Δ)	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.

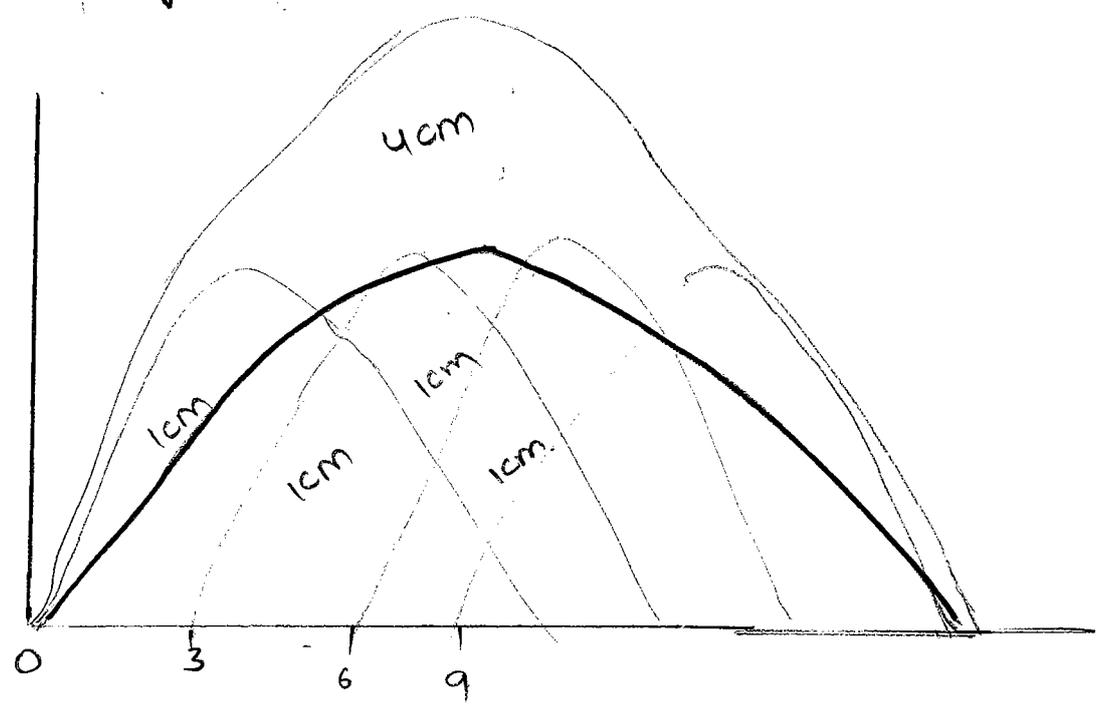
* Shorter duration: s-curve method.

Superposition method:

Given duration of UH = t_0 hour.

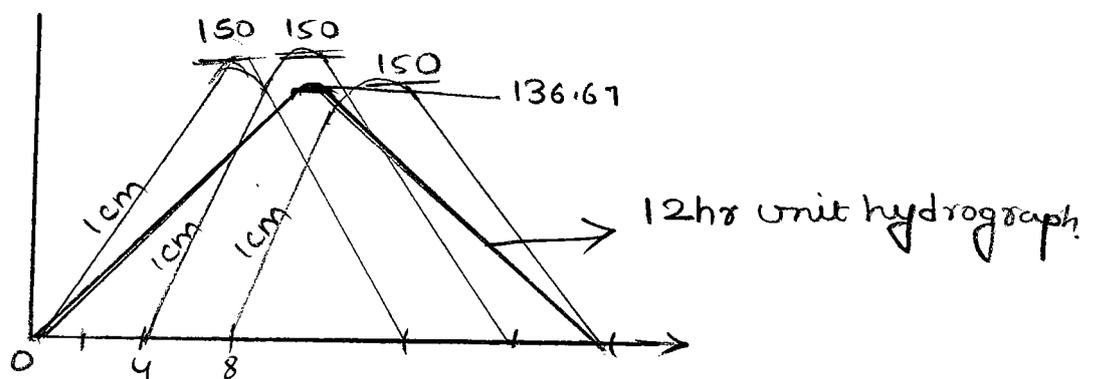
Required UH duration = T_0 hour.

' 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 establish 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 5000km^2 and less than 2km^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)

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

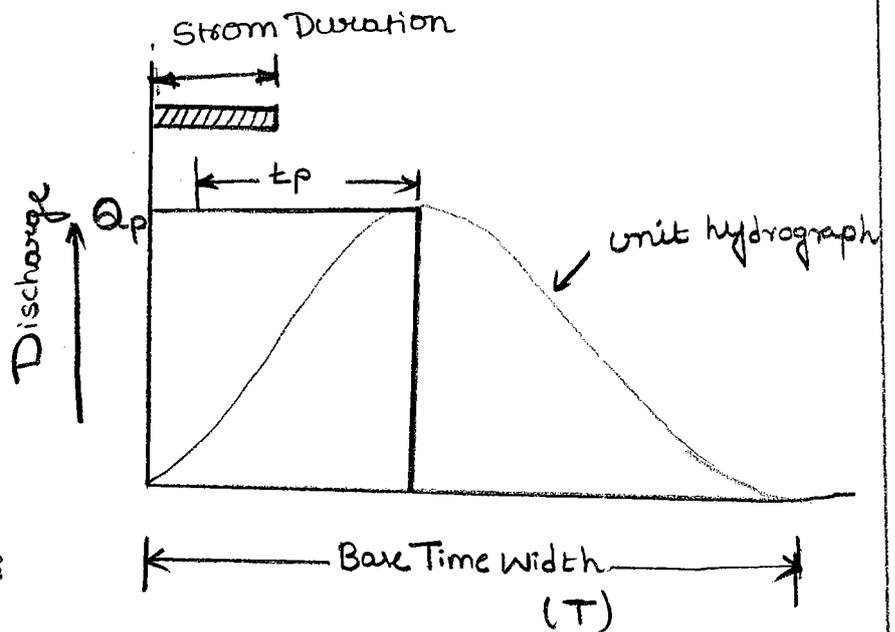
(ii) Peak discharge (Q_p)

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

(iii) Lag time (t_p):

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

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



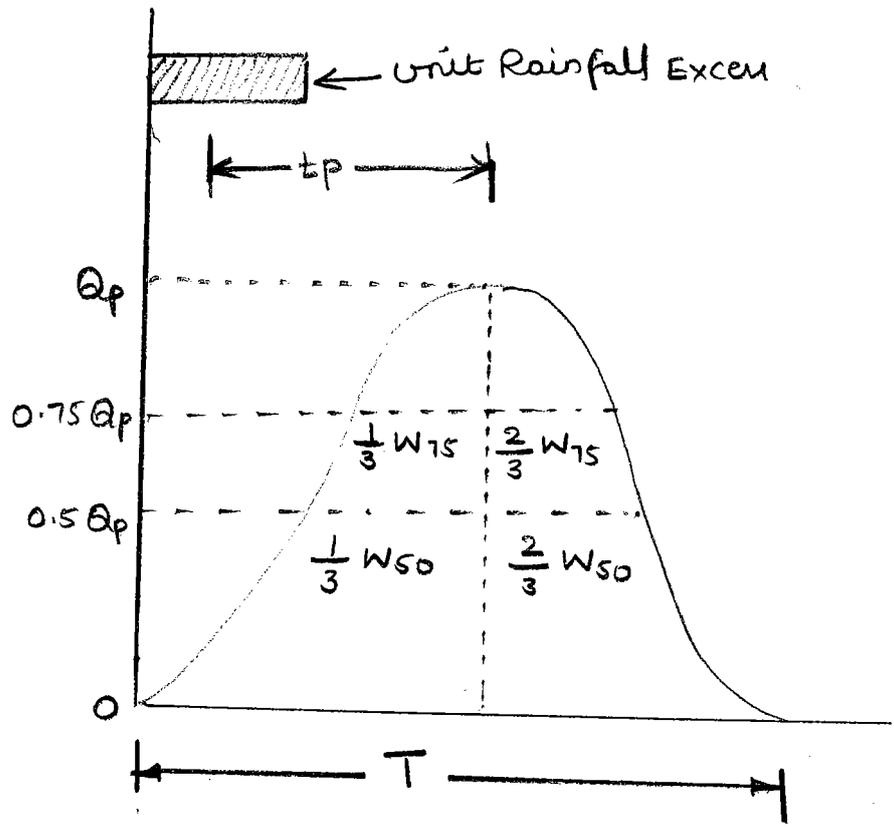
Here

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_t = Regional constant representing the watershed slope and storage (C_t varies from 0.3 to 6)

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



Introduction:

Floods :- Floods are natural occurrences where an area of land that is normally dry abruptly becomes submerged in water. In simple terms, flood can be defined as an overflow of large quantities of water onto a normally dry land. Flooding happens in many ways due to overflow of streams, rivers, lakes & oceans & as a result of Excessive rain.

→ Whenever flooding takes place, there is the possibility of loss of life, hardship to people, and Extensive damage to property. This is because flooding can carry bridges, cars, houses, and Even people. Flooding also destroys crops and can wipe away trees and other important structures on land. Some floods occur abruptly and recede quickly whereas others take several days & Even months to form and to recede because of Variation in size, duration, and the area affected.

* "European Union Floods Directive" defines a flood as a covering by water of land not normally covered by water. In the sense of "flowing water", the word may also be applied to the inflow of the tide.

* Causes of Flooding:

→ Many conditions result in flooding. Hurricanes, clogged drainages, and rainfall are some of the conditions that have led to flooding in various regions across the globe. Here are the leading causes of flooding.

1. > Rain:

→ Rain is the leading contributor to most of the flooding cases witnessed across the world. Too much rain causes water to flow overland contributing to flooding. In particular, It is due to high rainfall intensity over a prolonged period.

→ Depending on the rainfall distribution, the amount of rain, and soil moisture content, short rainfall periods can also result in flooding. Light rains for longer periods - several days or weeks, can also result in floods. The rain water erosive force can weaken the foundations of buildings, causing tumbles and cracks.

2. River overflows:-

→ Rivers & streams can overflow their banks. This happens when the river & stream holds more water upstream than usual, and it flows downstream to the neighbouring low-lying areas, typically referred to as the flood plains. As a consequence, this creates a sudden discharge of water into the adjacent lands leading to flooding.

Dams in rivers may also at times overwhelm rivers when the carriage capacity is exceeded, causing the water to burst and get into the flood plains. Flood caused by river overflow has the potential of sweeping everything in its path downstream.

3. Lakes and coastal flooding:-

→ Lake and coastal flooding occurs when large storms & tsunamis cause the water body to surge inland. These overflows have destructive power since they can destroy ill-equipped structures to withstand water's strength such as bridges, houses and cars.

In the coastal areas, strong and massive winds and hurricanes drive water on to the dry coastal lands and give rise to flooding. The situation is even worsened when the winds blowing from the ocean carry rains in them. Sea water from the tsunami & hurricane can cause widespread damage.

4. Dam Breakage:-

→ Dams are man-made structures used to hold water from flowing down from a raised ground. The potential energy stored in the dam water is used to generate electricity. At times, the walls can become weak and break because of overwhelming carriage capacity. Due to this reason, breakage of the dam can cause extensive flooding in the adjacent areas.

Flooding occurs when the embankments built along the sides of the river to stop high water from flowing onto the land break. Sometimes, the excess water from the dam is deliberately released from the dam to prevent it from breaking thereby causing floods.

5. Melting of the Glaciers and Mountain tops:

→ In the cold regions, ice and snow build up during the winters. When the temperature rises in summer, the accumulated (shows) snows and ice are subjected to melting resulting in vast (moments) movements of water into lands that are normally dry. Regions with mountains that have ice on top of them also (provided) experience the same outcome when the atmospheric temperature rises. This type of flooding is usually termed as snowmelt flood.

6. Clogged drainages:

→ Flooding also takes place when snowmelt or rainfall runoff cannot be channeled appropriately into the drainage systems forcing the water to flow overland. Clogged or lack of proper drainage system is usually the cause of this type of flooding.

* The areas remain flooded until the stormwater systems or waterways are rectified. Instances where the systems or waterways are not rectified, the areas remain flooded until the excess water evaporates or is transpired into the atmosphere by plants.

* Effects of floodings:

→ primary Effects:

- > The primary effects of flooding include loss of life and damage to buildings and other structures, including bridges, sewerage systems, roadways and canals.
- > Floods also frequently damage power transmission and sometimes power generation, which then has knock-on effects caused by the loss of power.
- > This includes loss of drinking water treatment and water supply, which may result in loss of drinking water (or) severe water contamination.
- > It may also cause ^{the} loss of sewage disposal facilities.
- > Lack of clean water combined with human sewage in the flood waters raises the risk of waterborne diseases, which can include typhoid, giardia, cryptosporidium, cholera and many other diseases depending upon the location of flood.
- > Damage to road and transport infrastructure may make it difficult to mobilize aid to those affected or to provide emergency health treatment.

→ Flood waters typically inundate (flood) farmland, making the land unworkable and preventing crops from being planted or harvested, which can lead to shortages of food both for humans and farm animals. Entire harvests for a country can be lost in extreme flood circumstances. Some tree species may not survive prolonged flooding of their root systems.

→ Secondary and long-term effects:

> Economic hardship due to a temporary decline in tourism, rebuilding costs, or food shortages leading to price increases is a common after-effect of severe flooding. The impact on those affected may cause psychological damage to those affected, in particular where deaths, serious injuries and loss of property occur.

> Urban flooding can cause chronically wet houses, leading to the growth of mold and resulting in adverse health effects, particularly respiratory symptoms.

> Urban flooding also has significant economic implications for affected neighbourhoods

- In the United States, industry experts estimate the wet basements can lower property values by 10-25% and are cited among the top reasons for not purchasing a home.
- According to the U.S. Federal Emergency Management Agency (FEMA), almost 40% of small businesses never reopen their doors following a flooding disaster.
- In the United States, insurance is available against flood damage to both homes and businesses.

* Benefits:

- > floods can also bring many benefits, such as recharging ground water, making soil more fertile and increasing nutrients in some soils.
- > Flood waters provide much needed water resources in arid and semi-arid regions where precipitation can be very unevenly distributed throughout the year and kills pests in the farming land.

- > Freshwater floods particularly play an important role in maintaining Ecosystems in river corridors and are a key factor in maintaining flood plain biodiversity.
- > Flooding can spread nutrients to lakes and rivers, which can lead to increased biomass and improved fisheries for a few years.

(> ~~for~~ some fish species, an overabundance)

- > periodic flooding was essential to the well-being of ancient communities along the Tigris - Euphrates River, the Nile River, the Indus River, the Ganges and the Yellow River among others. The viability of hydropower, a renewable source of energy, is also higher in flood prone regions.

* Flood Frequency Studies:

→ Flood frequency: - It denotes the likely hood of a flood being equal (or) exceeded.

→ Recurrence Interval (T_R): - Denotes the no. of years in which a given flood can be expected once.

$$T_R = \frac{100}{F}$$

→ calculation of R.I.:-

1. California Method: - $T_R = \frac{N}{M}$

2. Hazen's Method: - $T_R = \frac{2N}{2m-1}$

3. Weibull's Method: - $T_R = \frac{N+1}{m}$

4. Gumbel's Method: - $T_R = \frac{N}{m+c-1}$

c → Gumbel's correction

* depends on $\frac{m}{N}$ ratio.

* Gumbel's correction:

$\frac{m}{N}$	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.08	0.06
c	1	0.95	0.88	0.865	0.78	0.73	0.66	0.59	0.52	0.4	0.38	0.28.

→ probability of occurrence (p) :-

> the probability of Event being Equal & Exceeded in any one year is the probability of occurrence (p) has for a period of T_r years.

$$p = \frac{1}{T_r}$$

* the probability that the flood will not occur in an year is known as probability of Non occurrence.

$$q = 1 - p$$

Examples

* the following flood discharge data is available at a catchment. Estimate ' T_r ' for a flood of $6000 \text{ m}^3/\text{sec}$ - use all formulae.

Year	flood discharge (m^3/s)	data in order	Rank
1991	10,200	11,640	1
92	6000	10,200	2
93	7200	9600	3
94	2500	8270	4
95	9600	7200	5
96	5400	6000	6
97	3600	5400	7
98	4950	4950	8
99	8270	3600	9
2000	11,640	2500	10

i) California Method, $T_r = \frac{N}{m}$

$$T_r = \frac{10}{6} = 1.67 \approx 2 \text{ years}$$

ii) Hazen's Method, $T_r = \frac{N+1}{m}$

$$T_r = \frac{11}{10-1} = \frac{11}{9} \approx 1 \text{ year}$$

(6)

iii) Weibull's Method, $T_r = \frac{11}{6}$

$$T_r = 1.83 \text{ years.}$$

iv) Gumbell's Method, $\frac{M}{N} = \frac{6}{10} = 0.6 \Rightarrow C = 0.78$

$$T_r = \frac{10}{6 + 0.78 - 1}$$

$$T_r = 1.73 \text{ years}$$

* Rational formulae

$$Q = KAR \text{ (i), } Q = CIR$$

$$Q = F_c KAR$$

$F_c \rightarrow$ factor depending on units taken.

'K' varies for different regions

$$K_{eff} = \frac{K_1 A_1 + K_2 A_2 + \dots + K_N A_N}{A_1 + A_2 + \dots + A_N}$$

* Estimation of flood discharges.

→ Design flood: - It is the flood discharge adopted for the design of a hydraulic structure after careful consideration of hydrological aspects and design aspects.

→ Standard project flood: (SPP)

> the flood obtained by severe combination of Meteorological and hydrological factors.

Extreme combinations are not considered.

→ probable Maximum flood:

> here Extreme flood physically on a given catchment is considered.

Most severe combinations of hydrological and Meteorological factors are considered. Rare combinations are also considered.

Methods of Estimation of flood as follows. they are,

1) By physical indicators of past flood.

2) By using Empirical formulae - Flood discharge formulae.

3) flood frequency service.

4) By unit graph method

5) By rational method.

* By physical indicators of past floods

→ Marks/identification on surrounding areas

→ Investigation of surrounding people.

→ From the dimension of rivers, mean velocity discharge can be calculated.

* Empirical formulae

→ the Equations of the form, $Q = kA^n$

k → flood discharge coefficient.

Dickers formulae

$$Q = CA^{3/4}$$

used for North central and Eastern India.

C' depends on catchment location.

Central India:- 13.9-19.5

Eastern India:- 22.2-25

Northern India:- 11.4

Ryvels formulae

$$Q = CA^{2/3}$$

used for Madras catchment.

C' depends on location.

Area within 24 km from the coast - 6.45

Area within 24-161 km from coast - 8.45

limited area near hills - 10.1

Inglis formulae

$$Q = \frac{123A}{\sqrt{A+10.4}} \approx 123\sqrt{A} \text{ (approx)}$$

— this is applicable for former Bombay presidency.

⑧

Nawab Jung Bahadur formula:

$$Q = CA(0.993 - \frac{1}{16} \log A)$$

C value ranges from 40-60

applicable to old Hyderabad catchments.

Fanning's formula:

(F.P.S)

$$Q = CA^{5/6}$$

applicable for American catchments.

$$C = 2.54$$

Peller's formula:

$$Q = CA^{0.8} (1 + 0.8 \log T) (1 + 2.67A^{-0.2})$$

T → No. of years after which such a flood is to reoccur.

Q → Max. discharge (m^3/s)

C → (0.185 to 1.3)

A → Area of catchment in km^2

* Methods used to control floods:

→ floods can cause many problems and in serious cases, lives may be taken as well.

this is why it is important to take preventive measures to stop the floods from happening in the first place. Flood control is referred to as measures taken to prevent floods from happening.

* Flooding has many negative impacts, from damaging property to even taking lives. Flooding also transports other sediments to other places. This pollutes the habitats that wildlife may reside in. If the floods are to make their way into urban areas then it may cause disruption to traffic, interfere with drainage and electrical systems. This causes millions of dollars in damage. Thus, it would be less costly and safe to prevent the flood from happening in the first place.

* Methods used to prevent floods: Structural Methods ↪

→ "Dams" are one way that can be used for flood control. Dams are barriers that control the flow of water from a big water source such as a river or reservoir. Unlike other barriers, dams are used to retain water. The advantage with dams is that they are able to generate electricity through hydropower.

→ Another type of method of flood control that can be used would be "flood gates". Flood gates are systems that have adjustable gates to control the flow rate of a river. The water can either be stored or routed depending on the situation. Also, flood gates can also lower the water levels from canal channels or the main river channel. This allows more water to flow into a storage area if a flood is being predicted.

→ The next method that can be used for flood control would be a "flood wall". Similar to dams, flood walls serve the purpose of containing water of rivers or other water channels. However, flood walls are only temporary. They are used in areas where there is limited space or if a construction of other barriers would interfere with the surrounding environment. Flood walls are made out of fabricated concrete materials. These flood walls may sometimes have flood gates which allow people and vehicles to pass through. They are only closed in case of a flood.

→ In Asian countries, "flood diversion" is used to divert the flood away from more populated cities.

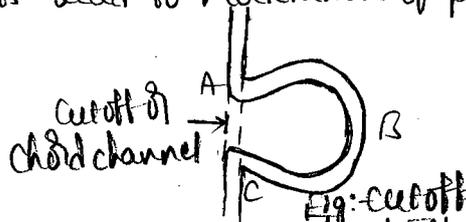
→ To control coastal flooding, there are some methods such as sea walls, beach nourishment and barrier islands that can be built along to coast to prevent flooding from the ocean.

> Sea walls may corrode over time and collapse.

> Beach nourishment is the addition of sand to the existing coast so that the tides will not reach the populated areas that quickly. However, it is a costly method that takes a considerable amount of time to complete.

→ Water Shed Management:-

- > Land treatment and watershed management in the basin aims to cutting down and delaying the runoff before it gets into the river. watershed management measure includes developing the vegetative and soil cover in conjunction with land.
- > Treatment works like check dams, contour bunding, terraces etc. these treatment cause. increase in infiltration, increase in Evapotranspiration and reduction in soil erosion. these all treatments lead to moderation of peak flows and increasing of dry weather flows.



* Non-structural method:-

- (a) Flood plain zoning:- when the channel discharges are very high, it is to be expected that the channel will overflow its banks and spill into the flood plains. flood plain management identifies the flood prone areas of a river and regulates the land use so that it restricts the damage due to flood.

Zone	Flood Return period	Example of uses
1	100 years	Residential houses, offices, factories etc.
2	25 years	Parks
3	Present	No construction / Encroachments.

- (b) Flood Forecasting and warnings Forecasting of floods should be done in advance, so that it enables us to give warning to the affected people and take appropriate precautionary measures. These techniques can be divided on the basis of time of forecasting.

- (i) Short-range forecasts:- This method gives advance warning 12-48 hours for flood.
- (ii) Medium-range forecasts:- This method gives advance warning of 2-5 days for floods, by using rainfall-runoff relationship.
- (iii) Long-range forecasts using ocean and meteorological satellite data, time of occurrence of event are predicted well in advance.

(c) Evacuation and Relocation

- (d) Flood Insurance: Flood insurance provides a mechanism to modify the impact of loss burden. (11)

* Types of flood:-

→ Large area flood

→ Small area flood.

(i) Large area flood:-

→ This type of flood occur due to storm of low intensity having a duration of a few days to several weeks. Sometimes, snow melt may also be a reason to cause large area floods. The time period of maximum total precipitation do not necessarily coincide with the time of occurrence of large area floods.

(ii) Small Area flood:-

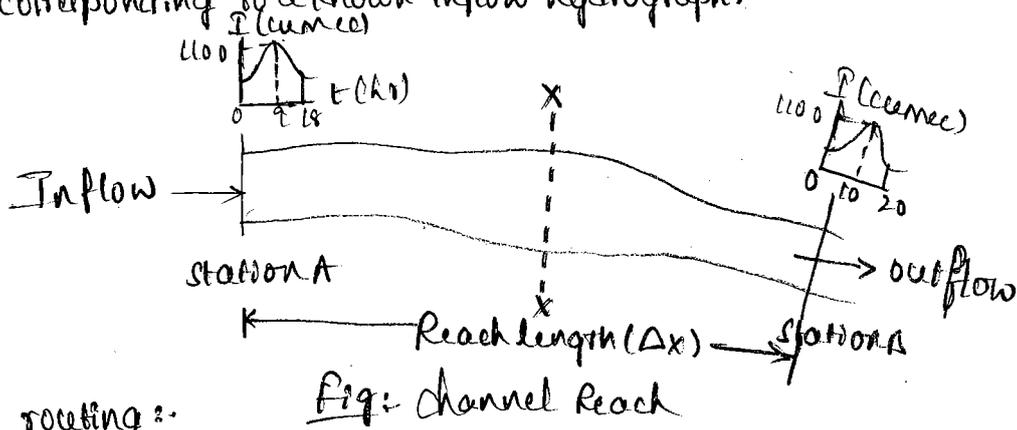
→ Storm of high intensity and duration of one day or less causes small area floods.

Such flows cause good damage to agricultural land in the form of excessive soil erosion. This is the major cause of sedimentation in reservoir and river. In this type, the total flood volume is not much but such floods cause serious local area damage.

→ The importance of structure and economic development of surrounding area. dictate the design criteria for choosing the flood magnitude.

* Flood routing:-

→ Flood routing is a process of determining peak discharge or stage of outflow hydrograph, corresponding to a known inflow hydrograph.



* Uses of flood routing:-

- In Estimation of design flood.
- In designing of reservoir.
- In designs of flood control structure.
- In determining adequacy of spillway
- In study of flood wave.

* flood wave:-

→ flood wave in open channels are also recognised as long progressive waves with the only difference that the movement of water in downstream direction, is also associated with the movement of water in open channel or reservoir.

- By associating flood wave with water movement give two type of flood waves:
 - > the wave which travel downstream is known as primary wave.
 - > the wave which travel upstream is known as Secondary wave.

* Types of flood routing:-

→ on the basis of application, flood Routing can be classified as

- (i) Reservoir Routing
- (ii) channel Routing

(i) Reservoir Routing:

→ In reservoir routing the effect of a flood wave entering a reservoir is studied to predict the variations of reservoir elevation and outflow discharge with time.

this form of routing is used:

- (a) In the design of capacity of spillways and other reservoir-outlet structures.
- (b) In locating and sizing of the capacity of reservoir to meet specific requirements.

(ii) Channel Routing:

→ In channel routing the change in the shape of a hydrograph as it travel down a channel is studied to predict the flood hydrograph at various section of the reach.

* Various Method of Reservoir Routing:-

→ Modified pul's method:-

> The equation used before is rearranged as

$$\left(\frac{I_1 + I_2}{2}\right) \Delta t + \left(S_1 - \frac{O_1 \Delta t}{2}\right) = \left(S_2 + \frac{O_2 \Delta t}{2}\right)$$

At the starting of flood routing, the initial storage and outflow discharge are known, which means all the terms of left hand side are known.

> The various steps are to be taken:

(i) For the 1st time interval Δt , $\left(\frac{I_1 + I_2}{2}\right) \Delta t$ and $\left(S_1 - \frac{O_1 \Delta t}{2}\right)$ are known and hence.

$\left(S_2 + \frac{O_2 \Delta t}{2}\right)$ is determined.

(ii) The water surface elevation corresponding to $\left(S_2 + \frac{O_2 \Delta t}{2}\right)$ is found by using curve of storage - Elevation and discharge Elevation. The outflow discharge O_2 at the end of time step Δt is found from the curve outflow discharge - Elevation.

(iii) Subtracting $O_2 \Delta t$ from $\left(S_2 + \frac{O_2 \Delta t}{2}\right)$ gives $\left(S - \frac{O \Delta t}{2}\right)$ for the beginning of the next time step.

(iv) The procedure is repeated till entire inflow hydrograph is routed.

* Hydrological channel Routing

→ In channel routing the storage is a function of both outflow and inflow discharge.

$$S = f(I, Q)$$

→ the water surface in a channel reach is not only unparallel to the channel bottom but also varies with time. the flow in a channel during a flood is spatially varied unsteady flow.

→ the total volume stored in a channel reach can be considered under two categories.

(i) prism storage

(ii) wedge storage.

* prism storages

→ It is the volume formed by an imaginary plane parallel to channel bed, drawn upstream from the outflow section to the inflow section.

* wedge storages

→ It is the triangular volume enclosed between the actual water surface profile and the top surface of the prism storage.

→ At fixed depth at a downstream section of a river reach, the prism storage is constant while the wedge storage changes from a positive value at an advancing flood (in this case depth increases) to a negative value during receding flood (in this case depth decreases).

→ the prism storage is steady so it is similar to reservoir and expressed as $S_p = f(I)$

the wedge storage can be expressed as $S_w = f(Q)$

→ the total storage.

$$S = k[xI^m + (1-x)Q^m]$$

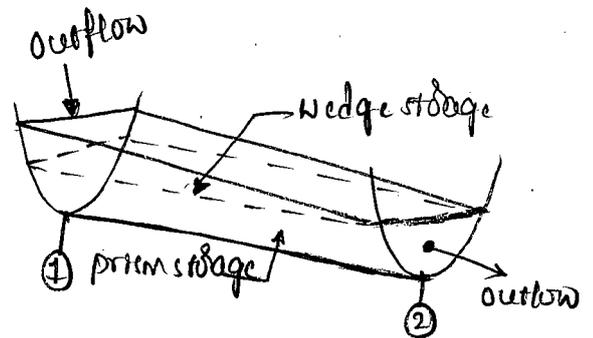


Fig: storage in a channel reach.

* Muskingum Equation

→ Considering the above Equation of total storage:

> M is taken as 1, as found for natural river,

$$S = K[xI + (1-x)O]$$

K = a coefficient parameter

M = a constant Exponent

x = weightage constant.

Now the storage have linear relationship with inflow and outflow.

> x is a dimensionless weighing factor between inflow and outflow, its value varies between 0 to 0.5. for nature river 0.1 to 0.3.

> when $x=0.5$, inflow will not cause any influence on storage, and storage will become a function of outflow only, now called a linear storage or linear reservoir.

> K is known as storage-time constant. It is approximately equal to the time of travel of a flood wave through the channel reach.

the muskingum Equation can be write down as

$$Q_2 = C_0 I_2 + C_1 I_1 + C_2 O_1$$

$$\text{Here } C_0 = \frac{-Kx + 0.5\Delta t}{K(1-x) + 0.5\Delta t}$$

$$C_1 = \frac{Kx + 0.5\Delta t}{K(1-x) + 0.5\Delta t}$$

$$C_2 = \frac{K(1-x) - 0.5\Delta t}{K(1-x) + 0.5\Delta t}$$

NOTE:- $C_0 + C_1 + C_2 = 1$

Examples:

→ The storage in a stream reach has been studied, and x and K have been identified as 0.28 and 1.6 days. If the inflow hydrograph in the stream reach, as the flood starts coming in and passes, is given by the following table, complete the outflow hydrograph (plotting is not needed).

Hours	0	6	12	18	24	30
I (m^3/sec)	35	55	92	130	160	140

Q. Given, $K = 1.6$ days
 $= 1.6 \times 24h = 38.4$ days
 $x = 0.28$

Coefficients:-

$$C_0 = - \left[\frac{38.4 \times 0.28 + 0.5 \times 6}{38.4 - 38.4 \times 0.28 + 0.5 \times 6} \right] = \frac{-7.752}{30.648} = -0.253$$

$$C_1 = \frac{38.4 \times 0.28 + 0.5 \times 6}{38.4 - 38.4 \times 0.28 + 0.5 \times 6} = \frac{13.752}{30.648} = 0.449$$

$$C_2 = \frac{38.4 - 38.4 \times 0.28 - 0.5 \times 6}{38.4 - 38.4 \times 0.28 + 0.5 \times 6} = \frac{34.648}{30.648} = 0.806$$

Check:- $C_0 + C_1 + C_2 = -0.253 + 0.449 + 0.806 = 1.0$

The outflow Q_2 at the end of each interval by using the Muskingum Equation may be calculated from the Equation

$$Q_2 = C_0 I_2 + C_1 I_1 + C_2 Q_1$$

The calculations are carried out in table.

Time (1)	Inflow (cumecs) (2)	$C_0 I_2$ $= (-) 0.253 I_2$ (3)	$C_1 I_1$ $= 0.449 I_1$ (4)	$C_2 Q_1$ $= 0.806 Q_1$ (5)	Q_2 in cumecs (3) + (4) + (5) (6)
0	35	—	—	—	35.00*
6	55	-0.253×55 $= -13.915$	0.449×35 $= 15.715$	0.806×35 $= 28.21$	29.94*
12	92	-0.253×92 $= -23.276$	0.449×55 $= 24.695$	0.806×29.94 $= 24.072$	25.49**

18	130	-0.253×130 $= -32.89$	0.449×92 $= 41.308$	0.806×25.49 $= 20.494$	28.91**
24	160	-0.253×160 $= -40.48$	0.449×130 $= 58.37$	0.806×28.91 $= 23.266$	41.13
30	140	-0.253×140 $= -35.42$	0.449×160 $= 71.84$	0.806×41.13 $= 33.068$	69.49

The outflow hydrograph ordinates are thus, obtained in col. (6) w.r.t. time in col. (4)

2nd sum:

→ Route the following flood through a river reach for which the Muskingum coefficients k and x are 22h and 0.25, respectively. At time $t=0$, the outflow discharge is $40 \text{ m}^3/\text{s}$.

Hours	0	12	24	36	48	60	72
Inflow (m^3/s)	40	65	165	250	240	205	170

plotting the hydrograph is not needed.

A. using Muskingum's Equations, we have

$$C_0 = \frac{-kx + 0.5\Delta t}{k - kx + 0.5\Delta t}$$

$$C_1 = \frac{kx + 0.5\Delta t}{k - kx + 0.5\Delta t}$$

$$C_2 = \frac{k - kx - 0.5\Delta t}{k - kx + 0.5\Delta t}$$

$$C_0 + C_1 + C_2 = 1 \text{ (for verification)}$$

and

Here, in the given Equation

$$k = 22 \text{ h}$$

$$x = 0.25$$

$$\Delta t = 12 \text{ h (time interval)}$$

$$C_0 = \frac{(-)(22 \times 0.25 - 0.5 \times 12)}{22.5} = 0.022$$

$$C_1 = \frac{(22 \times 0.25 + 0.5 \times 12)}{22.5} = 0.511$$

$$C_2 = \frac{(22 - 22 \times 0.25 - 0.5 \times 12)}{22.5} = 0.467$$

check: $C_0 + C_1 + C_2 = 1.0$ (which is correct).

Now, the outflow ordinates are worked out in col. (6) of table using

$Q_2 = C_0 I_2 + C_1 I_1 + C_2 Q_1$, assuming the initial value of outflow = $40 \text{ m}^3/\text{s}$ as given the table is otherwise self explanatory.

NOTE: I_2 stands for inflow at the end of the interval and I_1 at the start of interval.

Time from start (h) (1)	Inflow in cumecs (2)	$C_0 I_2$ $= 0.222 I_2$ (3)	$C_1 I_1$ $= 0.511 I_1$ (4)	$C_2 Q_1$ $= 0.467 Q_1$ (5)	Q_2 in cumecs (3) + (4) + (5) (6)
0	40	—	—	—	40* (given)
12	65	-0.222×65 $= 14.3$	0.511×40 $= 20.44$	0.467×40 $= 18.68$	40.55
24	165	-0.222×165 $= 36.3$	0.511×65 $= 33.32$	0.467×40.55 $= 18.94$	55.79
36	250	5.5	84.32	26.05	115.84
48	240	5.28	127.75	54.11	187.14
60	205	4.51	122.64	87.39	214.54* (peak)
72	140	3.74	104.76	100.19	208.69

NOTE: the above routing shows that the peak which occurred at $t=36$ hrs at upstream point of river reach, now occurs at $t=60$ hrs at downstream point, i.e., at a lag of 24 hrs. The peak discharge also reduces from 250 cumecs to 214.54 cumecs.

GROUND WATER AND WELL IRRIGATION

UNIT - V

INTRODUCTION

①

Ground water hydrology is the science of occurrence, distribution and movement of water below the surface of earth. The largest available source of fresh water lies underground. The total ground water potential is estimated to be one third the capacity of oceans.

Aquifer: Aquifers are the permeable formations having structures which permit appreciable quantity of water to move through them under ordinary field conditions thus these are the geologic formations in which ground water occurs (ie sands and gravels)

Aquiclude: Aquicludes are the impermeable formations which contain water but are not capable of transmitting and supplying a significant quantity (eg, clays)

Aquifuge: Aquifuge is an impermeable formation which neither contains water nor transmits any water
ex: Granite, shale.

Aquitard: Saturated geological formation poorly permeable and hence does not yield water freely into the well
It may transmit vertically appreciable quantity of water to/from adjacent aquifer

Ex: Sandy clay.

Occurance of ground water:

The ground water strata formation possesses

- i) Porosity
- ii) Permeability

Porosity: Porosity (n) is defined as the ratio of the volume of openings or pores (or voids) V_u in the material to its total volume V and is expressed as percentage

$$n = \frac{V_u}{V} \times 100$$

$n > 20$	large	Mere porosity
$5 < n < 20$	Medium	alone cannot
$n < 5$	low	given G.W.

Permeability: Capacity to permit water through soil

Permeability of unconsolidated sedimentation is to transmit water through it

Transmissibility: Which represents the same physical meaning and differ mathematically

Def: Capability of entire soil formation of full depth and unit width is known as transmissibility

Specific Yield: The specific yield of an aquifer is defined as the ratio expressed as percentage, of the volume of water which after being saturated, can be drained by gravity to its own volume

$$\text{Specific yield} = \frac{\text{Volume of water drained by gravity}}{\text{Total volume}}$$

(8)

$$S_y = \frac{w_y}{V} \times 100$$

Specific Retention: The specific retention (S_r) of an aquifer is the ratio, expressed as a percentage, of the volume of water it will retain after saturation against the force of gravity to its own volume.

$$S_r = \frac{w_r}{V} \times 100$$

w_r = volume of water retained

$$\text{Porosity } n = \frac{V_w}{V} \times 100 = \frac{w}{V} \times 100$$

w = volume of water = V_w in a saturated aquifer
 $= w_y + w_r$

$$n = S_y + S_r$$

Divisions of Subsurface water:

- a) Zone of Aeration
- b) Zone of saturation

Zone of aeration:

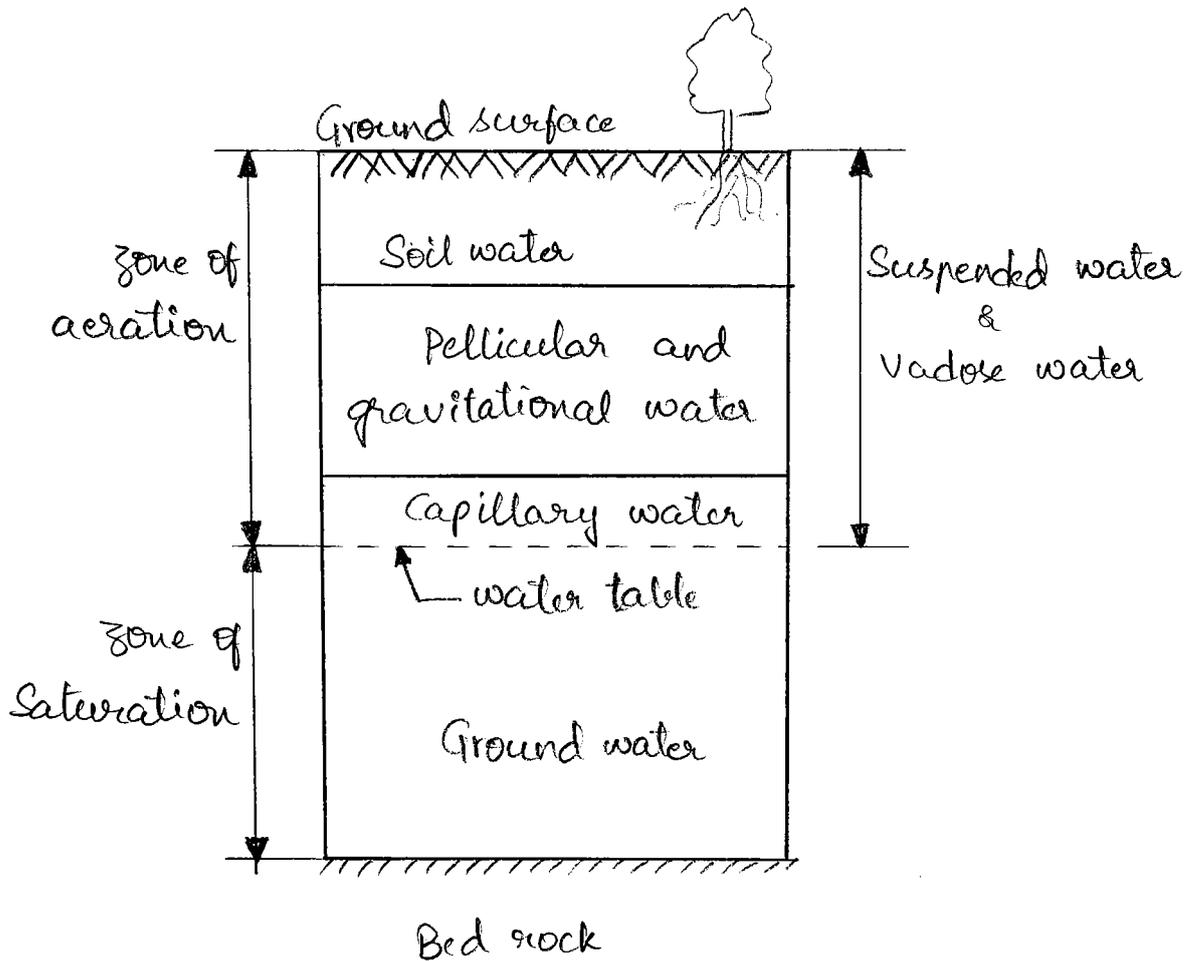
consisting of :

- i) Soil water zone : Soil water
- ii) Intermediate zone: Pellicular and gravitational water
- iii) Capillary zone: Capillary water

Zone of saturation:

Ground water fills all the interstices in the saturated zone

Water table: In the absence of the confining impermeable layer, the static level of water in wells penetrating the zone of saturation is called the water table



DIVISIONS OF SUBSURFACE WATER

Aquifer: An aquifer is an underground body of rock or sediment that serves as a storage reservoir for ground water ⁽³⁾

Types Of Aquifers:

Aquifers are mainly of two types:

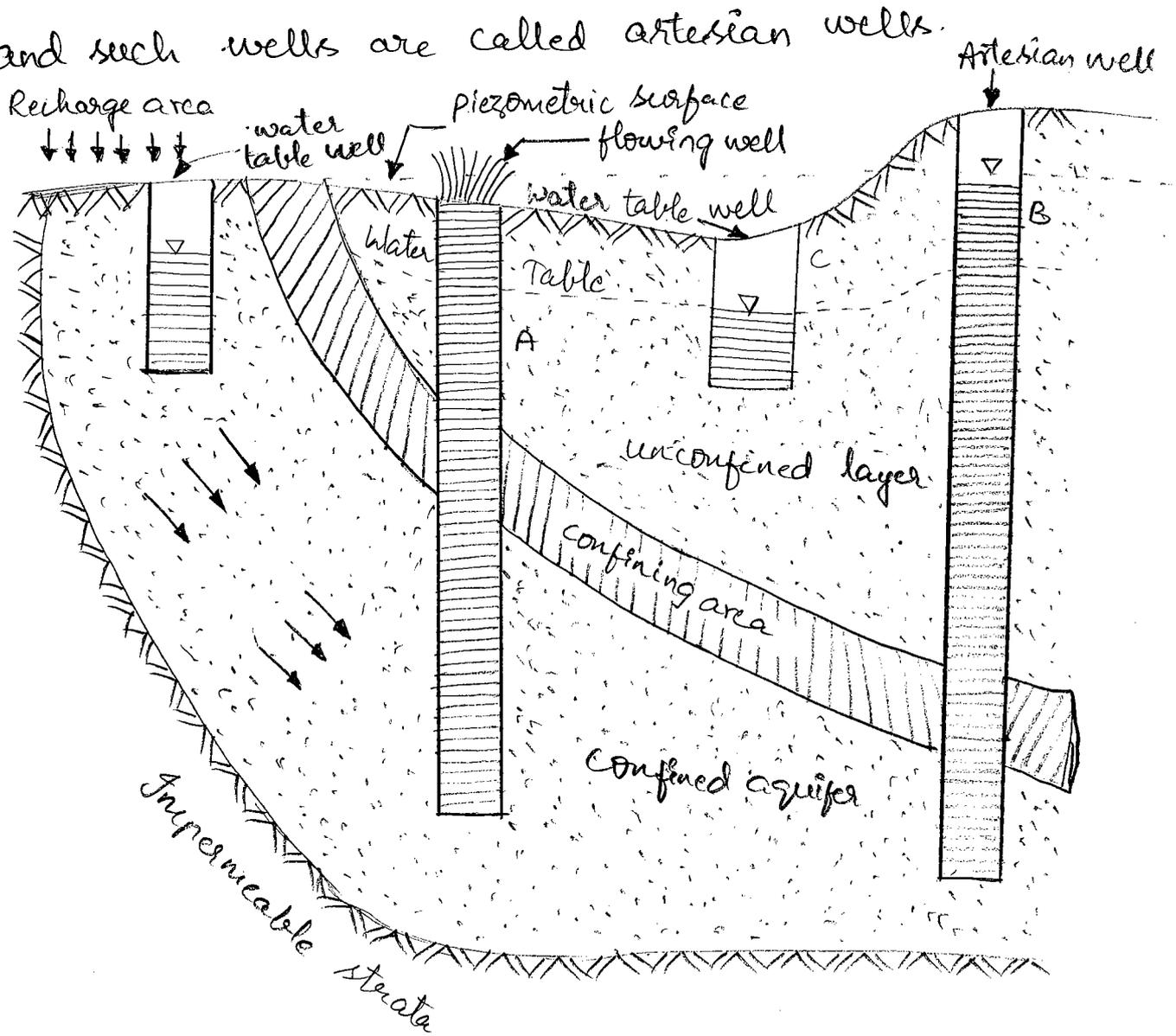
1. Unconfined aquifer
2. Confined aquifer (artesian aquifer)

Unconfined aquifer: Unconfined aquifer or water table aquifer is the one in which a water table serves as the upper surface of the zone of saturation. It is also sometimes known as the free, phreatic or non-artesian aquifer. In such an aquifer, the water table varies in undulating form and in slope. Rises and falls in the water table corresponds to changes in the volume of water in storage within unconfined aquifer.

Confined aquifer: A second common type of aquifer is a confined aquifer which is isolated from pressure communication with overlying or underlying geologic formations and with the land surface and atmosphere by one or more confining layers or confining units.

Confined aquifers differ from unconfined aquifers in two

fundamental and important ways. First, confined aquifers are typically under considerable pressure which may be derived from recharge at higher elevation or from the weight of the overlying rock and soil (known as the overburden). In some cases the pressure is high enough that wells drilled into the aquifer are free flowing. This condition requires that the water pressure in the aquifer is sufficient to drive water up the well bore and above the land surface and such wells are called artesian wells.



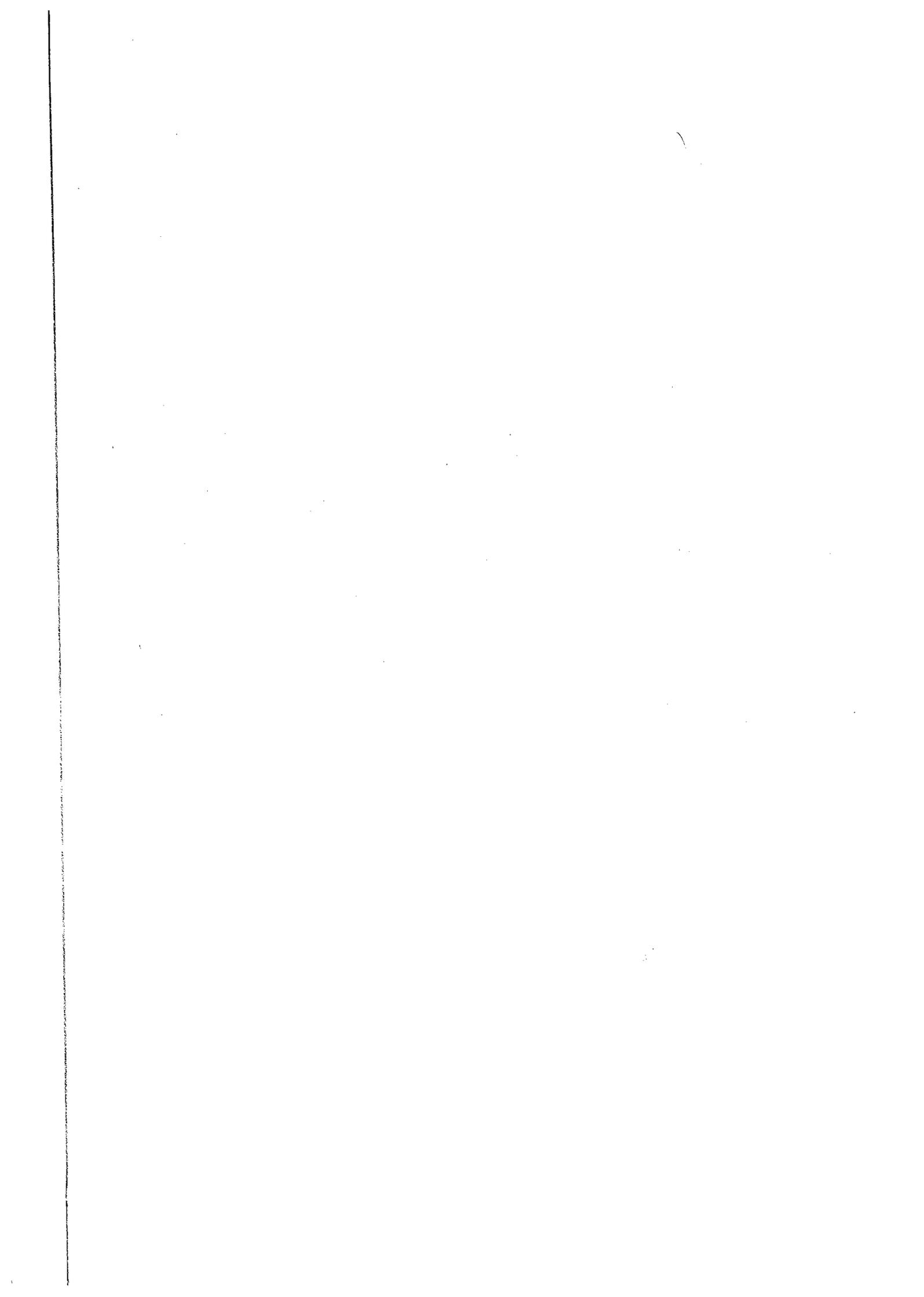
CONFINED AND UNCONFINED AQUIFERS

Perched aquifer: It is a special type of (aquifer) unconfined aquifer, and occurs where a ground water body is separated from the main ground water by a relatively impermeable stratum of small aerial extent and by the zone of aeration above the main body of ground water.

Storage Coefficient :

The water yielding capacity of a confined aquifer can be expressed in terms of its storage coefficient.

Storage coefficient is defined as the volume of water that an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in the component of head normal to that surface.



Acquifer parameters:

Coefficient of permeability (K):

It is defined as the velocity of flow which will occur through the total c/s area of the soil (or) aquifer under a unit hydraulic gradient.

$$K = \frac{Q}{A}$$

Coefficient of Transmissibility (T):

It is defined as the rate of flow in (m^3/day) through a vertical strip of aquifer of width 1m, extending full saturation height under unit hydraulic gradient.

$$T = K \times b$$

Specific yield and specific retention:

Specific yield (S_y): volume of water drained from aquifer by gravity force divided by total volume of aquifer drained.

Specific Retention (S_{ri}): volume of water held by aquifer against gravity force divided by total volume of aquifer drained.

$$S_{ri} + S_y = n$$

Specific capacity: specific capacity of well is defined as rate of flow from a well per unit of draw down.

Coefficient of storage (A):

→ Defined for confined aquifer's only.

It is defined as the volume of water that a confined aquifer releases (or) stores in per unit surface area of aquifer

or unit change in the component of head perpendicular to the surface.

→ Range varies from 0.00005 to 0.005

formulae:

I. confined aquifer:

$$\rightarrow Q = \frac{2.72T(H-h)}{\log_{10}\left(\frac{R}{r}\right)} \quad [T=kb]$$

$$\rightarrow Q = \frac{2.72TS}{\log_{10}\left(\frac{R}{r}\right)}$$

for observation wells by thiem's equation:

$$\rightarrow Q = \frac{2.72T(h_2-h_1)}{\log_{10}\left(\frac{r_2}{r_1}\right)} \Rightarrow \frac{2.72T(s_1-s_2)}{\log_{10}\left(\frac{r_2}{r_1}\right)}$$

for straight length:

$$\rightarrow Q = \frac{2.72Kbs}{\log_{10}\left(\frac{r_2}{r_1}\right)} \Rightarrow \frac{2.72Kbs}{\log_{10}\left(\frac{R}{r}\right)}$$

Coefficient of Transmissibility:

$$T = \frac{Q \log_{10}\left(\frac{r_2}{r_1}\right)}{2.72(s_1-s_2)}$$

for 1 log cycle:

$$T = \frac{Q}{2.72\Delta s}$$

II. unconfined aquifer:

$$\rightarrow Q = \frac{1.36 K (H^2 - h^2)}{\log_{10} \left(\frac{R}{r} \right)} \quad (\text{Dupit's equation})$$

$$\rightarrow Q = \frac{1.36 K S (S + 2h)}{\log_{10} \left(\frac{R}{r} \right)}$$

$$\rightarrow Q = \frac{2.72 K S \left(h + \frac{S}{2} \right)}{\log_{10} \left(\frac{R}{r} \right)} \Rightarrow \frac{2.72 K S \left(L + \frac{S}{2} \right)}{\log_{10} \left(\frac{R}{r} \right)}$$

[L \rightarrow strainer length, L=h]

for observation wells by Thiem's equation:

$$\rightarrow Q = \frac{1.36 K (h_2^2 - h_1^2)}{\log_{10} \left(\frac{R}{r} \right)}$$

Coefficient of transmissibility:

$$T = \frac{Q \log_{10} \left(\frac{R}{r} \right)}{2.72 \Delta s'}$$

for 1 log cycle:

$$T = \frac{Q}{2.72 \Delta s'}$$

Well hydraulics:

Darcy's law: The percolation of water through soil was first studied by Darcy (1856) who demonstrated experimentally that for laminar flow conditions in a saturated soil, the rate of flow, (Q) the discharge per unit time is proportional to the hydraulic gradient, and it could be expressed as follows:

$$Q = KiA$$

(Q)

$$v = \frac{Q}{A} \Rightarrow Ki$$

Where Q = rate of flow

i = hydraulic gradient

K = Darcy's coefficient of permeability

A = Total cross-sectional area of soil mass

perpendicular to the direction of flow.

v = flow velocity

Darcy's law is valid only for laminar flow. Because of very small pore dimensions in fine grained soils, a laminar flow should exist, but in coarse grained soils turbulent flow may be expected under certain conditions. It has been borne out by experiments that the limits of validity of Darcy's law may be fixed with respect to particle size, velocity of flow and hydraulic gradient.

Steady radial flow to a well : Dupit's theory :

③

When a well is penetrated into an extensive homogeneous aquifer, the water table initially remains horizontal in the well. When the well is pumped, water is removed from the aquifer and the water table (or) piezometric surface, depending upon the type of the aquifer, is lowered resulting in a circular depression in the water table (or) the piezometric surface.

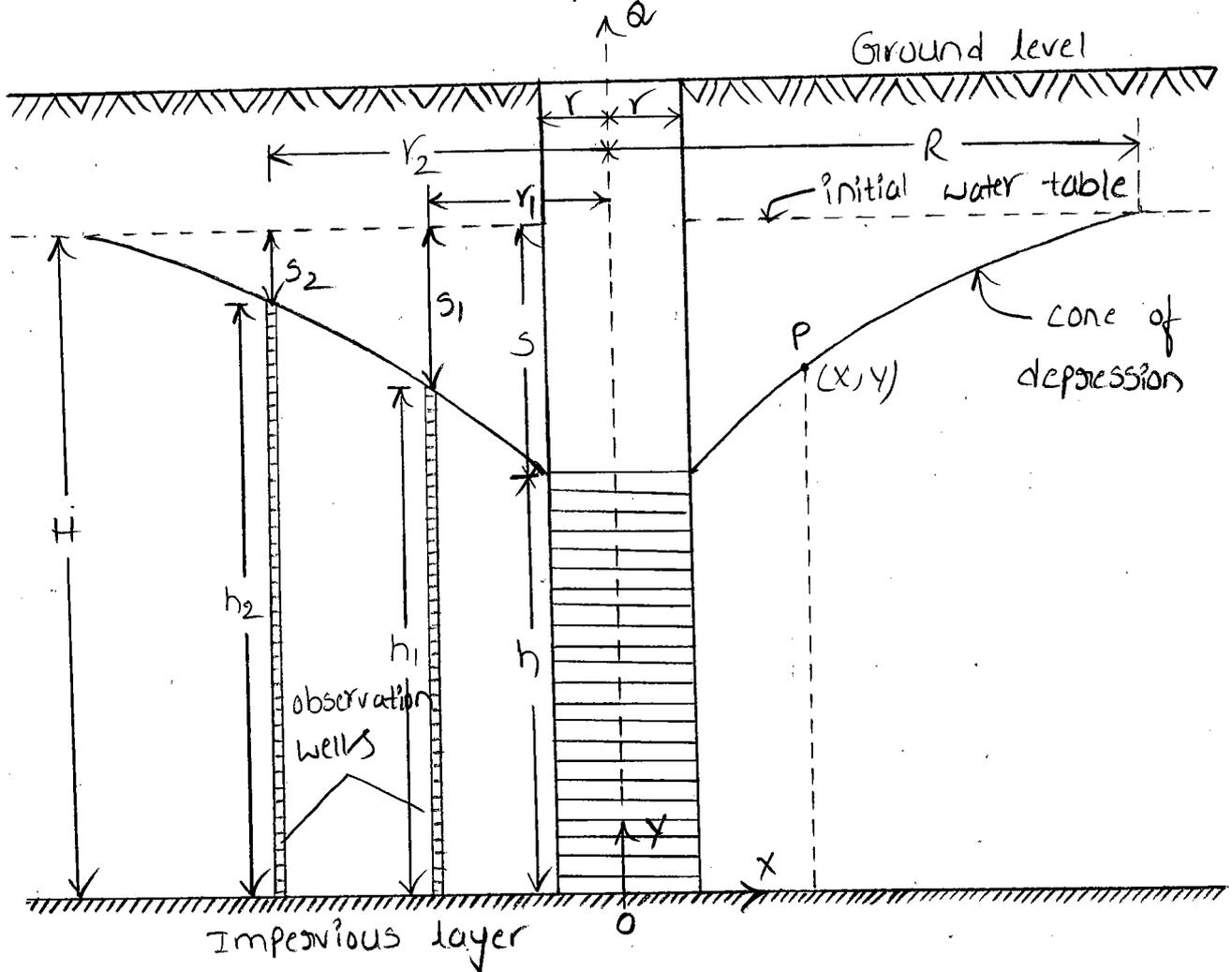
This depression is called the cone of depression (or) the drawdown curve. At any point, away from the well, the drawdown is the vertical distance by which the water table (or) the piezometric surface is lowered. The analysis of such radial flow towards a well was originally proposed by Dupit in 1863 and later modified by Thiem (1906). For the sake of analysis, we shall take 2 cases.

- 1) Well in unconfined aquifer, and
- 2) Well fully penetrating a confined aquifer.

1) unconfined aquifer:

following fig shows a well penetrating an unconfined (or) free aquifer to its full depth.

unconfined aquifer



Where $R =$ Radius of influence

$s =$ Draw down

$h =$ depth of water in main well

$H =$ Total depth of water

$r_1 =$ Radius of observation well (1)

$r_2 =$ Radius of observation well (2)

$h_1 =$ Height/depth of water in observation well (1)

$h_2 =$ Height/depth of water in observation well (2)

$s_1 =$ Draw down of well (1)

$s_2 =$ Draw down of well (2)

$$Q = \frac{1.36 K (H^2 - h^2)}{\log_{10} \left(\frac{R}{r} \right)}$$

$$Q = \frac{1.36 K (h_2^2 - h_1^2)}{\log_{10} \left(\frac{r_2}{r_1} \right)}$$

$$Q = \frac{2.72 K S \left(L + \frac{S}{2} \right)}{\log_{10} \left(\frac{R}{r} \right)}$$

Assumptions and Limitations of Dupit's theory:

Dupit's theory of flow for unconfined aquifer is based on the following assumptions:

→ The velocity of flow is proportional to the tangent of the hydraulic gradient instead of sine.

→ The flow is horizontal and uniform everywhere in the vertical section.

→ Aquifer is homogeneous, isotropic and of infinite axial extent.

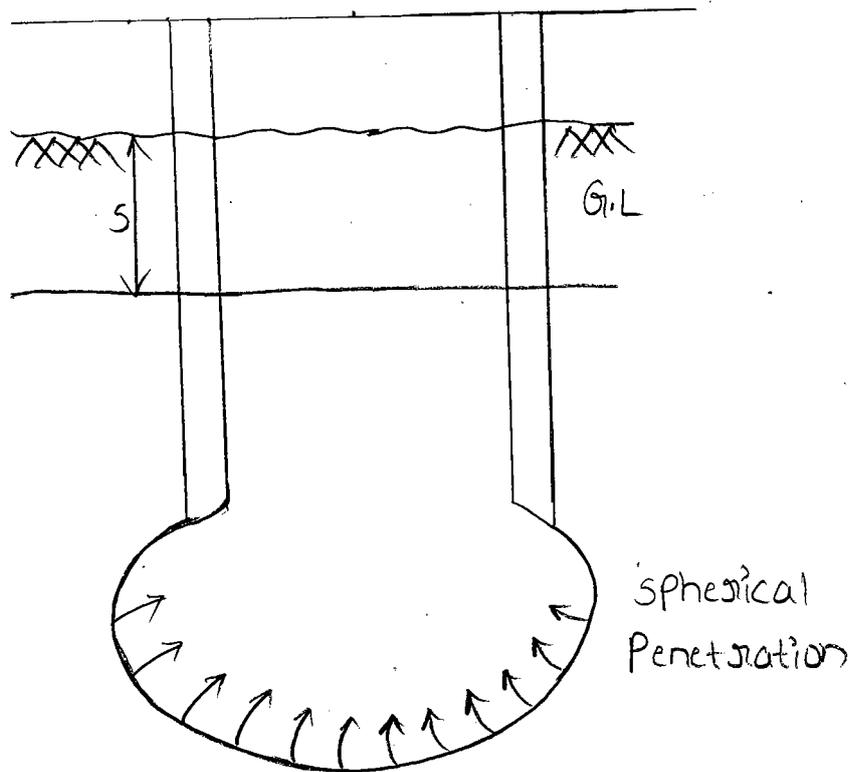
→ The well penetrates and receives water from the entire thickness of the aquifer.

→ The coefficient of transmissibility is constant at all places and at all times.

→ Natural ground water regime affecting an aquifer remains constant with time.

→ flow is laminar and Darcy's law is applicable.

constant level pumping test:



→ using pump, heavy discharge is taken out to create depression head (s).

→ The discharge to be such that outward discharge should be same as inward discharge. (spherical penetration).

from Darcy's equation

$$\begin{aligned}AV &= Q = KiA \\ &= K \cdot \frac{s}{L} \cdot A \\ &= \frac{K}{L} \cdot s \cdot A\end{aligned}$$

$$i = \frac{s}{L}$$

$C \rightarrow$ depends on soil formation.

$$\boxed{Q = CSA}$$

$C \rightarrow$ Percolation intensity coefficient

$$Q \propto s \quad \text{as} \quad Q = AV$$

$$\sqrt{LS}$$

Area of c/s at bottom = $\frac{4}{3}$ (Actual area) in case a spherical cavity is formed.

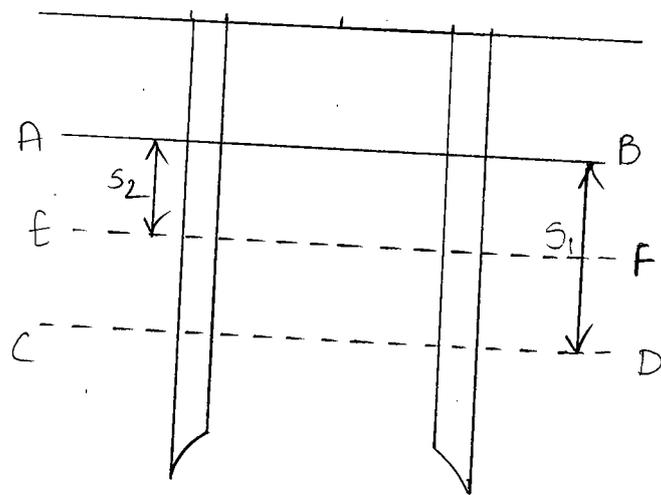
- Recharge velocity cannot be increased beyond the critical velocity (depends on soil formation; varies from soil to soil).
- Head corresponding to critical velocity is called critical head.

Working Head = $\frac{1}{3}$ (critical head)

- Q_{max} from an open well corresponds to critical depression head and max. safe yield corresponds to working head.

Recuperation test:

- When constant head (or discharge) cannot be maintained (unable to maintain) Recuperation test is performed.



- Water is pumped heavily, water level (head) drops from AB to CD.
- Wait for time 't' water level recuperate to EF (recharges)
- As drawdown varies for every interval of time, discharge too varies

AB \rightarrow Initial water level

CD \rightarrow water level in the well when pumping was stopped.

S \rightarrow Depression head (s) drawdown when pumping.

tt \rightarrow water level at time 't' after pumping was stopped.

Let (ds) be change for (dt)

volume of water entering in dV = Area of
Small time (dt) = c/s $A \times (ds)$

Let x-x be water level at any time 't'.

S \leftrightarrow drawdown corresponding to x-x.

If 'Q' is rate of recharge in small time (dt).

Volume of water recharged $dV = Q \cdot dt$

We know $Q < S$

$$Q = c's$$

$$dV = c'sx dt \rightarrow \text{eqn } ①$$

$$dV = A \times ds \rightarrow \text{eqn } ②$$

Equating ① and ②

$$-c's \cdot dt = A \times ds$$

c \rightarrow is introduced because as 't' \uparrow 's' \downarrow

$$- \frac{c'}{A} \cdot dt = \frac{ds}{s}$$

by integrating on both sides we get

$$\frac{c'}{A} \int_0^T dt = - \int_{s_1}^{s_2} \frac{ds}{s}$$

$$\text{at } t=0, s=s_1$$

$$t=T, s=s_2$$

$$\frac{c'}{A} (t)_0^T = \left[\log_e s \right]_{s_1}^{s_2}$$

$$\frac{c'}{A}(T) = \log_e \frac{s_1}{s_2}$$

$$\frac{c'}{A}(T) = 2.303 \log_{10} \left(\frac{s_1}{s_2} \right)$$

$$\frac{c'}{A} = \frac{2.303}{T} \log_{10} \left(\frac{s_1}{s_2} \right)$$

$\frac{c'}{A}$ is called specific capacity (or) specific yield of the formation (Aquifer) and its units are

$$\frac{\text{m}^3/\text{sec}}{\text{discharge}} \left| \frac{\text{m}^2}{\text{area}} \right| \frac{\text{m}}{\text{draw down}}$$

We have, $Q = c's$

$$Q = \left(\frac{c'}{A} \right) \cdot A \cdot s \quad (\times \& \div \text{ by } A)$$

$$Q = \frac{2.303}{T} \log_{10} \left(\frac{s_1}{s_2} \right) \cdot A \cdot s$$

Experimental values: Given by "massiot"

<u>Type of soil</u>	<u>(c'/A) ($\text{m}^3/\text{hr}) / \text{m}^2/\text{m}$)</u>
clay	0.25
sand	0.5
coarse sand	1.0

These values can be assumed by default if NO time to perform experiment.

while solving if data is insufficient (rare cases).

Problem-1:

Design a tube well for the following data.

yield required = $0.08 \text{ m}^3/\text{s}$, thickness of confined aquifer = 30 m , Radius of circle of influence = 300 m , permeability coefficient is 60 m/day , draw down 5 m .

Sol: Given that

$$K = \frac{60 \text{ m}}{\text{day}} = \frac{60}{86400} \text{ m/s}$$

$$K = 6.93 \times 10^{-4} \text{ m/s}$$

$$Q = 0.08 \text{ m}^3/\text{s}$$

$$b = 30 \text{ m}$$

$$R = 300 \text{ m}$$

$$s = 5 \text{ m}$$

$$Q = \frac{2.72 K b s}{\log_{10} \left(\frac{R}{r} \right)}$$

$$\log_{10} \left(\frac{300}{r} \right) = \frac{2.72 \times 6.93 \times 10^{-4} \times 30 \times 5}{0.08}$$

$$\left(\frac{300}{r} \right) = 10^{(3.534)}$$

$$r = 0.088 \text{ m}$$

$$\text{diameter, } d = 2r = 0.177 \text{ m} \approx 18 \text{ cm}$$

$$d = 18 \text{ cm}$$

Problem-2:

A tube well penetrates fully on unconfined aquifer. Calculate discharge from the tube well under the following conditions.

Dia of well = 30 cm , draw down = 2 m , effective length of strainer under above draw down is equal to 10 m , coefficient of permeability of aquifer is 0.05 cm/s . Radius of zero draw down = 300 m .

sl: Given,

$$\text{dia of well} = 30\text{cm} = 0.3\text{m}$$

$$\text{Radius, } r = 0.15\text{m}$$

$$\text{Length of strainer, } L = 10\text{m}$$

$$\text{for confined aquifer, } (L=b) \Rightarrow b=10\text{m}$$

$$\text{draw down, } s = 2\text{m}$$

$$\text{coefficient of permeability, } k = \frac{0.05\text{cm}}{s} = 5\text{m/s} \times 10^{-4}$$

$$\text{Radius of zero draw down, } R = 300\text{m}$$

we have discharge,

$$Q = \frac{2.72 k s (L + s/2)}{\log_{10} \left(\frac{R}{r} \right)}$$

$$Q = \frac{2.72 \times 5 \times 2 \left(10 + \frac{2}{2} \right) \times 10^{-4}}{\log_{10} \left(\frac{300}{0.15} \right)}$$

$$Q = 9.06 \times 10^{-3} \text{ m}^3/\text{s}$$

$$Q = 9.06 \text{ lit/sec}$$

Alternatively

$$s = 2\text{m}, L = 10\text{m}, H = 12\text{m}, h = 10\text{m}$$

$$Q = \frac{1.36 \times 5 \times 10^{-4} \left((12)^2 - (10)^2 \right)}{\log_{10} \left(\frac{300}{0.15} \right)}$$

$$Q = 9.06 \times 10^{-3} \text{ m}^3/\text{s}$$

$$Q = 9.06 \text{ lit/sec}$$

Problem-3:

An artesian tube well has a dia of 20cm. Thickness of aquifer is 30m, 'k' is 38m/day. find its yield under a draw down of 4m at well face. Also determine transmissivity of aquifer.

Sol: Given,

$$\text{diameter, } d = 20\text{cm}$$

$$r = 10\text{cm} \Rightarrow 0.1\text{m}$$

$$\text{thickness, } b = 30\text{m}$$

$$\text{permeability, } k = 38\text{m/day} \Rightarrow 38/86400\text{m/s}$$

$$k = 4.39 \times 10^{-4}\text{m/s}$$

$$\text{draw down, } s = 4\text{m}$$

Radius of influence 'R' from Sichardt's eqⁿ

$$R = 3000 s \sqrt{k}$$

$$R = 3000 (4) \sqrt{4.39 \times 10^{-4}}$$

$$R = 251.5\text{m}$$

$$\text{yield/discharge, } Q = \frac{2.72 k b s}{\log_{10} \left(\frac{R}{r} \right)}$$

$$Q = \frac{2.72 (4.398) (30) (4)}{\log_{10} \left(\frac{251.5}{0.1} \right)} \times 10^{-4}$$

$$Q = 0.0422\text{m}^3/\text{s}$$

Coefficient of transmissibility

$$T = k \times b$$

$$T = (4.398 \times 10^{-4}) \times 30$$

$$T = 0.0132\text{m}^2/\text{s}$$

Problem-4:

A well penetrates through 10m thick water bearing stratum of coarse sand having $K = 0.005 \text{ m/s}$. Radius of artesian well is 10cm and is to be worked under a draw down of 4m at well phase. Calculate discharge from the well. What will be % increase in discharge. If the radius of well is doubled. Take $R = 300\text{m}$ in each case.

Sol: Given,

$$\text{Thickness, } b = 10\text{m}$$

$$\text{Permeability, } K = 0.005 \text{ m/s}$$

$$\text{Radius, } r_1 = 0.1\text{m}$$

$$\text{draw down, } s = 4\text{m}$$

$$\text{We have discharge, } Q = \frac{2.72 K b s}{\log_{10} \left(\frac{R}{r_1} \right)}$$

$$Q = \frac{2.72 \times (0.005) \times (10) \times (4)}{\log_{10} \left(\frac{300}{0.1} \right)}$$

$$Q = 0.156 \text{ m}^3/\text{s}$$

If radius is doubled,

$$r_1 = r_1, \quad r_2 = 2r_1$$

$$Q_1 = Q$$

$$Q_2 = \frac{2.72 (0.005) (10) (4)}{\log_{10} \left(\frac{300}{0.2} \right)}$$

$$= 0.1712 \text{ m}^3/\text{s}$$

$$\% \text{ increase } \Delta Q = \frac{Q_2 - Q_1}{Q_1} \times 100 \Rightarrow \frac{0.1712 - 0.156}{0.156} \times 100$$

$$\Delta Q = 9.79 \%$$

Problem-5:

In order to determine the field permeability of a free aquifer pumping out test was performed and following observations were made. Dia of well is 20cm, discharge is $240 \text{ m}^3/\text{hr}$. R.L of original water surface before pumping 240.5m, R.L of water in the well at constant pumping 235.6m, R.L of impervious layer 210m, R.L of water in observation well is 239.8m. Radial distance of observation well from tube well is 50m. Calculate K also calculate

- 1) Error in K if observations are not taken in observation well and radius of influence is assumed as 300m.
- 2) Actual radius influence based on observations of observation well.

Sol: Given,

$$Q = 240 \text{ m}^3/\text{hr}$$

$$r = 0.1 \text{ m}$$

$$H = (240.5 - 210)$$

$$H = 30.5 \text{ m}$$

$$h = (235.60 - 210)$$

$$h = 25.60 \text{ m}$$

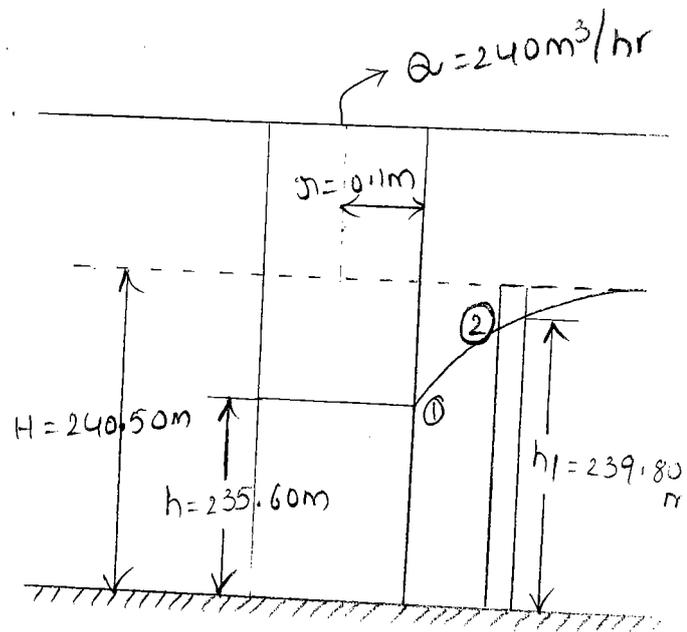
$$h_1 = (239.80 - 210)$$

$$= 29.80 \text{ m}$$

Now by applying thiem's eqⁿ for point ① & ②

$$Q = \frac{1.36K(h_2^2 - h_1^2)}{\log_{10}(r_2/r_1)}$$

$$Q = \frac{1.36K((29.8)^2 - (25.6)^2)}{\log_{10}(50/0.1)} = 240$$



$$K_a = 2.046 \text{ m/hr}$$

1) Consider radius of influence, $R = 300\text{m}$

Substitute in Dupit's eqⁿ

$$Q = \frac{1.36 K ((30.5)^2 - (25.6)^2)}{\log_{10} \left(\frac{300}{0.1} \right)} = 240$$

$$K_o = 2.232 \text{ m/hr}$$

$$\% \text{ error in } K = \frac{K_{\text{obs}} - K_{\text{act}}}{K_{\text{act}}} \times 100$$

$$= \frac{2.232 - 2.046}{2.046} \times 100$$

$$= 9.1\%$$

2) Now actual radius of influence be ' R_m '

$$Q = \frac{1.36 K_{\text{act}} (H^2 - h^2)}{\log_{10} \left(\frac{R}{r} \right)}$$

$$240 = \frac{1.36 (2.046) ((30.5)^2 - (25.6)^2)}{\log_{10} \left(\frac{R}{0.1} \right)}$$

$$\log_{10} \left(\frac{R}{0.1} \right) = 1538.41\text{m}$$

$$R = 153.84\text{m} \approx 154\text{m}$$

Problem-6:

A 60cm dia well is pumped at the rate of 2000lit/min. measurements is near by test wells were made at the same time were: At a discharge of 10m draw down is 4m at a discharge of 20m, the draw down is 2m. The thickness of unconfined aquifer is 40m.

a) find out ' k '

b) If all the observed values are on Dupit's curve. What was

draw down in drain well during pumping.

c) specific capacity, Radius of influence.

d) what is maximum rate at which water can be drawn from main well.

sol: Given,

$$\begin{aligned} (Q)_{\text{tube well}} &= 2000 \text{ lit/min} \\ &= 0.033 \text{ m}^3/\text{s} \\ &= 2880 \text{ m}^3/\text{day} \end{aligned}$$

$$r = 0.3 \text{ m}$$

$$\text{draw down, } s_1 = 4 \text{ m}$$

$$s_2 = 2 \text{ m}$$

$$\therefore h_1 = H - s_1 = 40 - 4 = 36 \text{ m}$$

$$h_2 = H - s_2 = 40 - 2 = 38 \text{ m}$$

$$a) Q = \frac{1.36 K (h_2^2 - h_1^2)}{\log_{10} \left(\frac{r_2}{r_1} \right)}$$

$$\Rightarrow \frac{1.36 K ((38)^2 - (36)^2)}{\log_{10} \left(\frac{20}{10} \right)} = 2880 \text{ m}^3/\text{day}$$

$$K = 4.307 \text{ m/day}$$

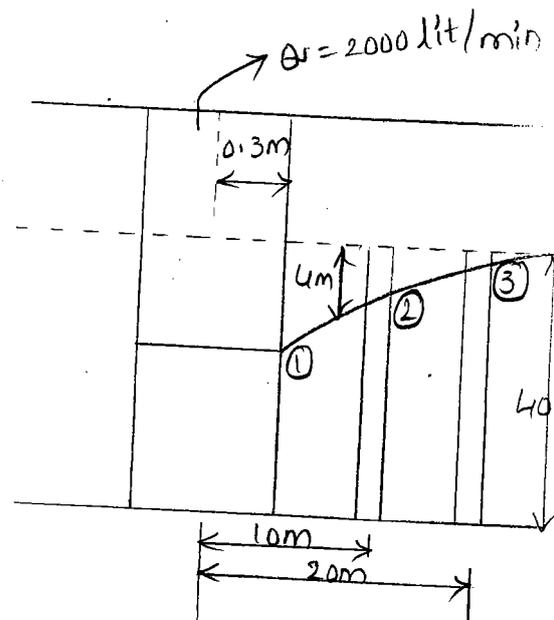
b) Apply thiem's eqⁿ at point ① & point ②

$$Q = \frac{1.36 K (h_2^2 - h_1^2)}{\log_{10} \left(\frac{r_2}{r_1} \right)}$$

$$Q = \frac{1.36 (4.307) ((36)^2 - (h)^2)}{\log_{10} \left(\frac{10}{0.3} \right)} = 2880$$

$$h = 23.39 \text{ m} \approx 23.4 \text{ m}$$

$$\text{draw down, } s = H - h = 16.6 \text{ m}$$



Specific capacity, $\frac{C'}{A} = \frac{2.303}{T} \log_{10}\left(\frac{s_1}{s_2}\right)$

$$T = K \times b \Rightarrow (4.307 \times 40) \Rightarrow 172.28 \text{ m}^2/\text{day}$$

$$\frac{C'}{A} = \frac{2.303}{172.28} \log_{10} \quad (s_1, s_2 \rightarrow \text{not available})$$

We know that, specific discharge of the well is discharge per unit draw down

$$\text{i.e. } s=1 \Rightarrow h = H - s \Rightarrow 40 - 1 \Rightarrow 39 \text{ m}$$

apply dupit's eqⁿ, $Q_s = \frac{1.36 K (H^2 - h^2)}{\log_{10}(R/s)}$

$$Q_s = \frac{1.36 (4.307) (40^2 - 39^2)}{\log_{10}\left(\frac{41.5}{0.3}\right)}$$

$$Q_s = 216.14 \text{ m}^3/\text{day} \quad (\text{m depression head})$$

we have, $Q_s =$

d) Radius of influence, $\log_{10}\left(\frac{R}{s}\right) = \frac{1.36 K (H^2 - h^2)}{Q_s}$

$$\log_{10}\left(\frac{R}{0.3}\right) = \frac{1.36 (4.307) (40^2 - (23.4)^2)}{2880}$$

$$\left(\frac{R}{0.3}\right) = 138.20 \text{ m}$$

$$R = 41.46 \text{ m} \approx 41.5 \text{ m}$$

maximum discharge of well (at $h=0$)

$$Q_w = \frac{1.36 K (H^2)}{\log_{10}(R/s)}$$

$$Q_w = \frac{1.36 (4.307) (40)^2}{\log_{10}\left(\frac{41.5}{0.3}\right)}$$

$$Q_w = 4377.55 \text{ m}^3/\text{day}$$

UNIT-VI Advanced Topics in Hydrology.

CHOW'S METHOD:-

Chow gave a method of solution which avoids curve fitting. He (re)introduced a function $F(u)$ given by the relation:

$$F(u) = \frac{W(u) \cdot e^u}{2.303}$$

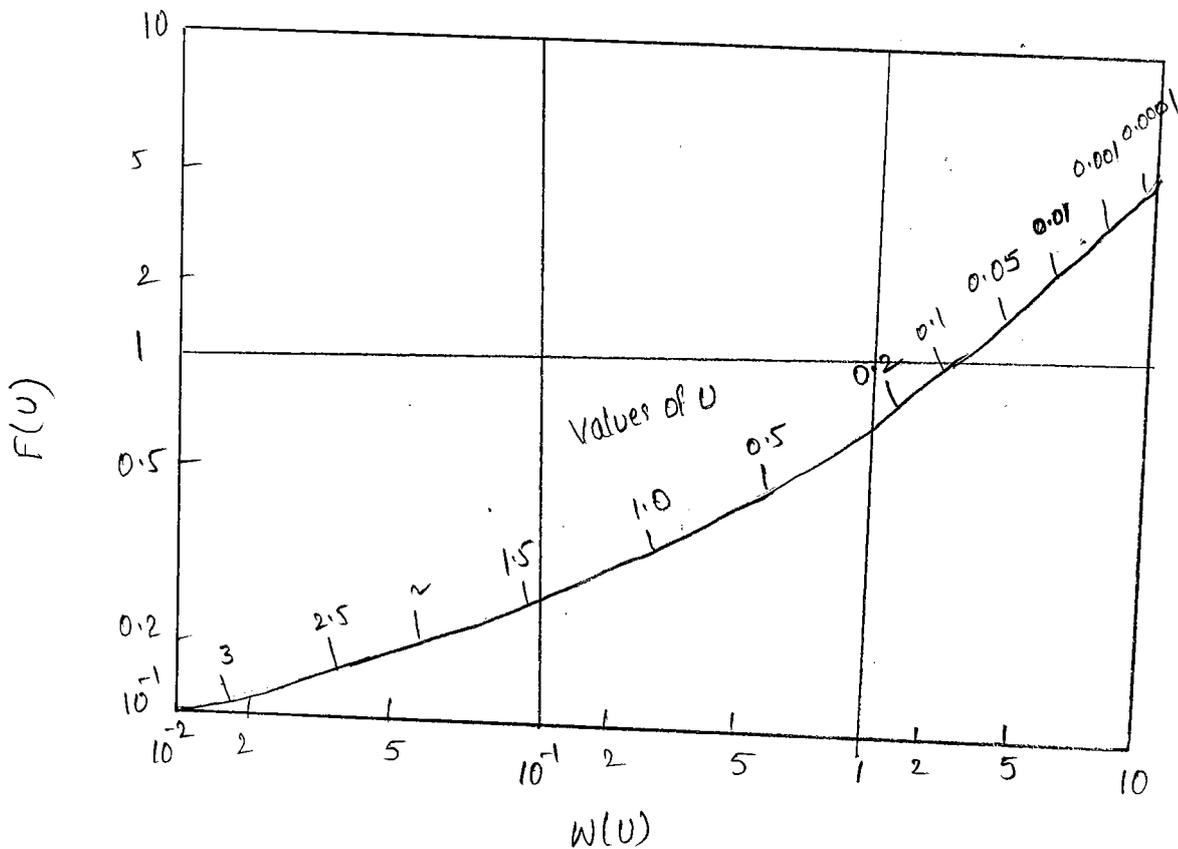


Fig 1. Function $F(u)$

The relation between $F(u)$, $W(u)$ and u is shown in Fig. with the u scale on the curve. The function $F(u)$ is introduced to relate $w(u)$ and u to a certain combination of s and t . The procedure is as follows:

1. Select an observation well near the pumped well and observe the drawdown (s) at all times.
2. plot a graph between s and $\log_{10} t$ as shown in Fig 2. Join the points by a smooth curve.

- on the plotted graph, choose an arbitrary point p and note its co-ordinates s and t .
- Draw the tangent of Curve at the chosen point p and determine the drawdown difference Δs per log cycle of time.
- Compute the function $F(u)$ by the relation.

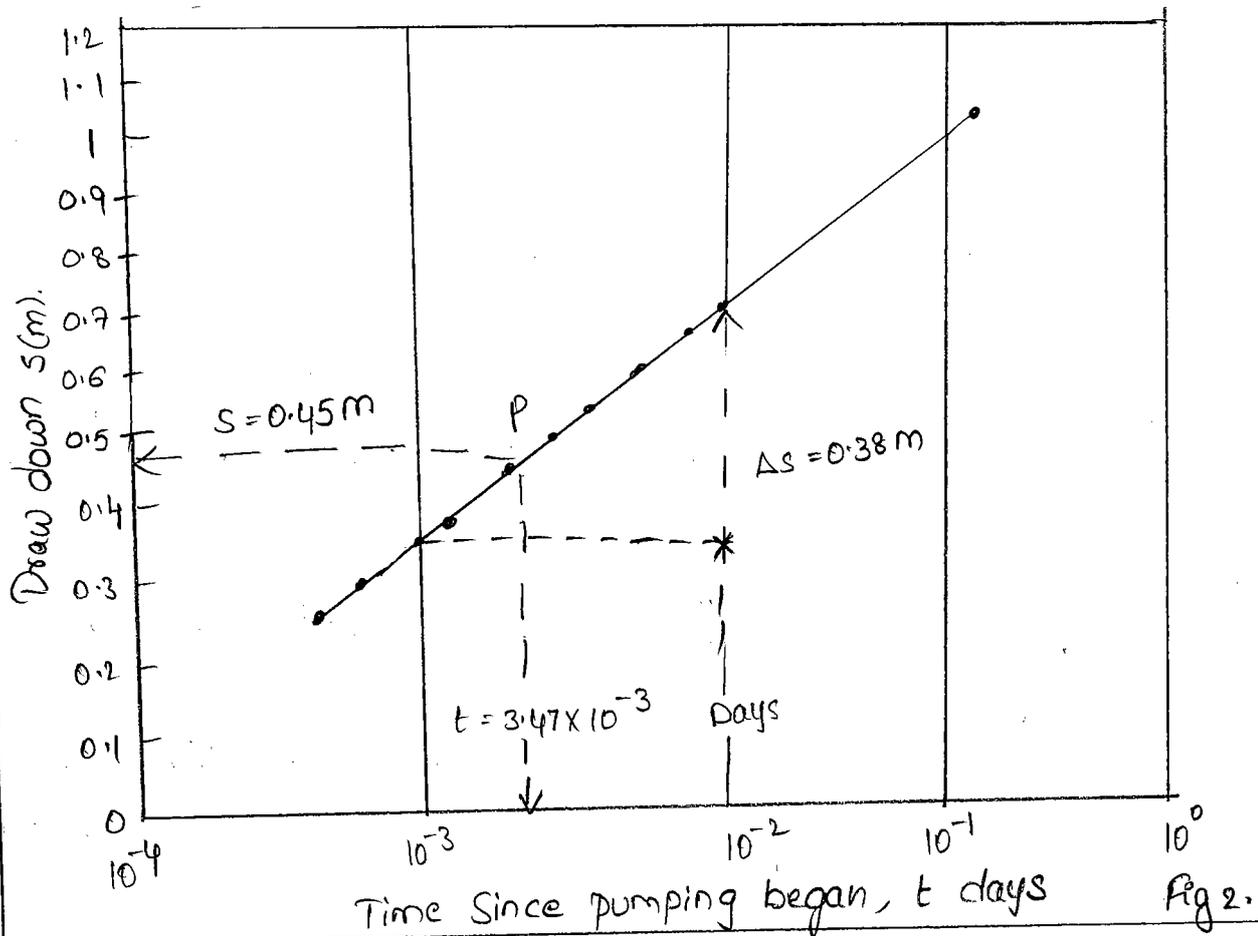
$$F(u) = \frac{s}{\Delta s}$$

- knowing $F(u)$ and using Fig 1. find u and $w(u)$.
- Compute s and T from the following relations:

$$T = \frac{Q}{4\pi S} w(u) \quad \text{and} \quad s = \frac{4uTt}{r^2}$$

Note: For small values of u , we have from Jacob's method:

$$\Delta s = \frac{2.303Q}{4\pi T} \log_{10} \frac{t_2}{t_1} = \frac{2.303Q}{4\pi T} \quad (\text{when } t_2 = 10t_1).$$



$$\text{Also } S = \frac{Q}{4\pi T} W(u)$$

$$F(u) = \frac{S}{\Delta S} = \frac{W(u)}{2.303}$$

For $F(u) < 2$, the above Equation can safely be used. For $F(u) > 2$, u becomes large. Hence (Eq.) above Equation should be used.

INSTANTANEOUS UNIT HYDROGRAPH:-

We have seen earlier that each unit hydrograph representing 1cm of direct runoff, is for some unit duration T_0 . For a catchment, there can be a number of unit hydrographs corresponding to various values of unit duration T_0 . To obtain the runoff hydrograph resulting from a storm of varying duration and varying intensities, it is preferable to have a unit hydrograph of very short unit duration. Theoretically, the shortest unit duration is zero. If the duration of rainfall excess becomes infinitesimally small, the resulting unit hydrograph is called "INSTANTANEOUS UNIT HYDROGRAPH". The IUH is designated as $u(t, 0)$ or simply as $u(t)$.

If two S-curves are drawn at a time lag of t_0 , the ordinate of unit hydrograph of t_0 hour unit duration at any time t is given by $u(t, t_0) = \frac{T_0}{t_0} (S_t - S_{t-t_0}) \rightarrow \text{①}$

where, $u(t, t_0)$ = ordinate of unit hydrograph of unit duration t_0 .

T_0 = unit duration of unit hydrograph from which S-curve has been obtained.

S_t = ordinate of S-curve at any time t .

(S_{t-t_0}) , S_{t-t_0} = ordinate of shift S-curve, shifted by t_0 .

If t_0 is taken as Δt , the ordinates of resulting unit hydrograph of Δt unit duration is given by

$$u(t, \Delta t) = \frac{T_0}{\Delta t} [S_t^{T_0} - S_{t-\Delta t}^{T_0}]$$

(a)

$$u(t, \Delta t) = T_0 \frac{\Delta S_t^{T_0}}{\Delta t}$$

Where $S_t^{T_0}$ is the S-curve ordinate derived from unit hydrograph of T_0 unit duration. In the limit $\Delta t \rightarrow 0$, we get the UH, given by

$$\lim_{\Delta t \rightarrow 0} u(t, \Delta t) = T_0 \frac{dS_t^{T_0}}{dt}$$

$$(b) \quad u(t) = T_0 \frac{dS_t^{T_0}}{dt} = \frac{1}{R} \frac{dS_t^{T_0}}{dt}$$

Hence $\left\{ \begin{array}{l} \text{the ordinate of} \\ \text{UH at any time 't'} \end{array} \right\} = T_0 \left\{ \begin{array}{l} \text{the slope of S-curve derived from } T_0 \\ \text{hour unit hydrograph at time 't'} \end{array} \right\}$

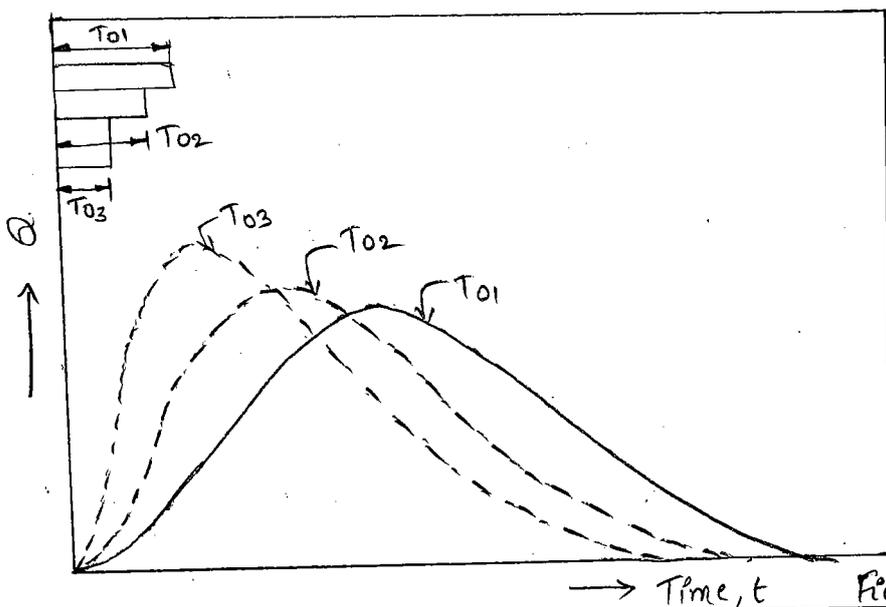


Fig. 3.

In the above expression, R_0 is the intensity of rainfall excess, given by $R_0 = 1/T_0$

If $R_0 = 1 \text{ cm}$, we get

$$u(t) = \frac{ds_t}{dt}$$

Where s_t is the ordinate of S-curve of intensity 1 cm/hr . Thus, the ordinate of IUH at any time 't' is the slope of S-curve of intensity 1 cm/hr .

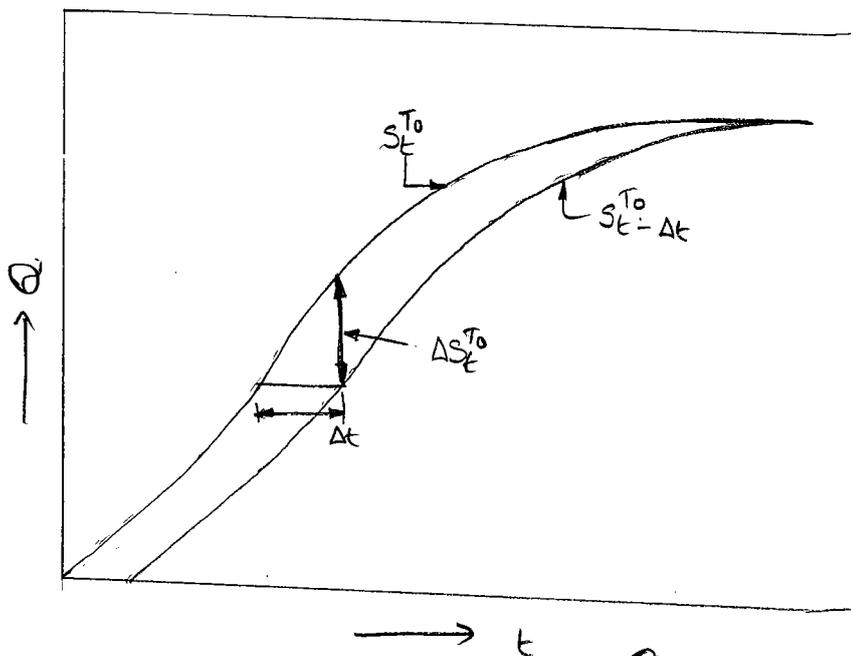


Fig 4.

An IUH, designated by $u(t)$ is a single peaked hydrograph with a finite base width. It has the following properties:

1. $0 \leq u(t) \leq a$ positive value at $t > 0$.

2. $u(t) = 0$ at $t \leq 0$

3. $u(t) \rightarrow 0$ as $t \rightarrow \infty$

4. $\int_0^{\infty} u(t) dt = \text{unit depth of over catchment}$

and 5. (Time to peak) < (Time to Centroid of Curve).

It is interesting to note that IUH is a unique demonstration of a particular Catchment's response to rain, independent of duration, just as unit hydrograph is its response to rain of a particular unit duration. IUH is not time dependant. It is a geographical expression of the integration of the catchment, such as length, shape, slope etc. that control such a response.

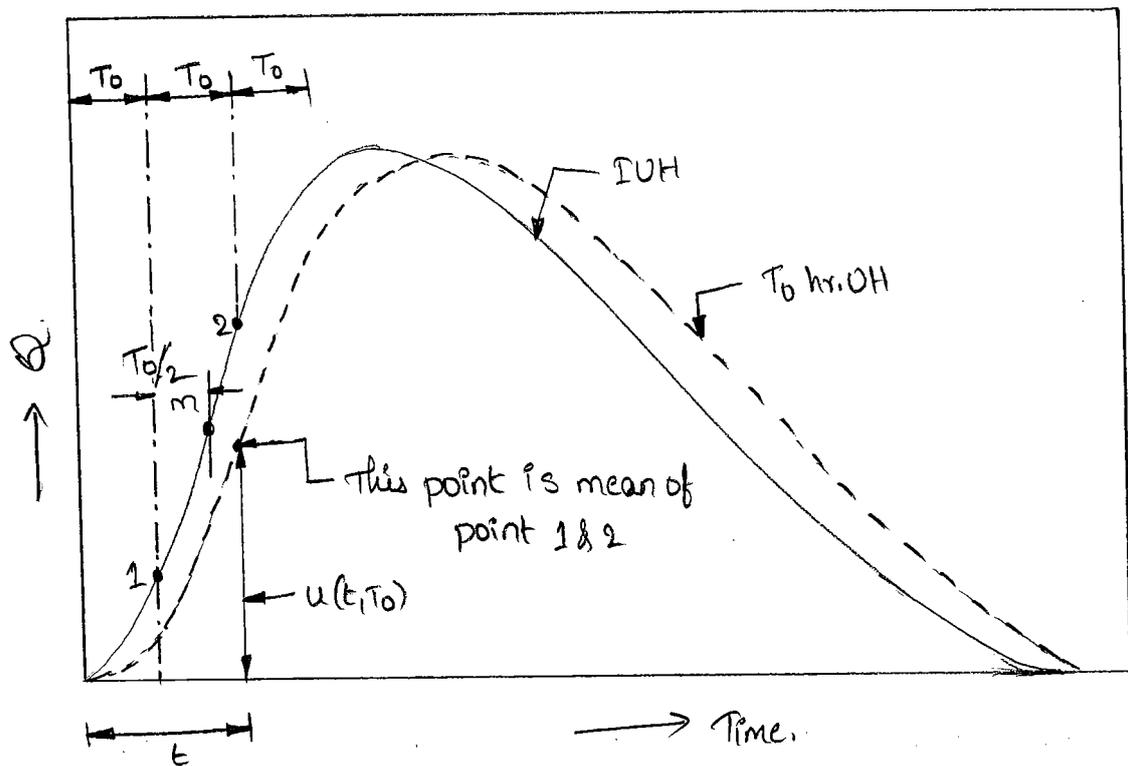


Fig. 5

→ The IUH can be developed either directly from the observed data or by adopting conceptual models.

→ when once IUH is available for a catchment, unit hydrographs of various unit durations can be easily derived.

Let us derive unit hydrograph $u(t, T_0)$ of T_0 unit (hydrograph) duration.

We already know that,

$$u(t, T_0) = S_t - S_{t-T_0}$$

$$(a) \quad u(t, T_0) = \frac{1}{T_0} \left[\int_0^t u(z) dz - \int_0^{t-T_0} u(z) dz \right]$$

$$(a) \quad u(t, T_0) = \frac{1}{T_0} \int_{t-T_0}^t u(z) dz$$

Hence,

$$\left\{ \begin{array}{l} \text{ordinate of U.H. of} \\ T_0 \text{ at any time } t \end{array} \right\} = \frac{1}{T_0} \left\{ \begin{array}{l} \text{area of UH in the limits} \\ \text{between } (t-T_0) \text{ and } t \end{array} \right\}$$

If UH is assumed to be linear between $(t-T_0)$ and t , the above Equation reduces to

$$u(t, T_0) = u\left(t - \frac{T_0}{2}\right).$$

Thus the ordinate of T_0 unit hydrograph at any time t is the average of UH for $(t-T_0)$ hours and that of 't' hours.

From fig 5., it is clear that if UH is divided into T_0 hour time interval, and if the averages of the ordinates at the beginning and the end of each interval are plotted at the end of the interval, we get ordinate of T_0 unit hydrograph.

$$\text{Thus, } u(t, T_0) = \frac{1}{2} [u(t) + u(t-T_0)]$$

