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Module – 3: Runoff and Hydrographs

Introduction:

- Runoff is the portion of rainfall which flows through the rivers, streams etc. or runoff is the portion of the precipitation making its way towards stream channels, lakes or oceans as surface flow. Basically there are three types of runoff:

Surface Runoff:

- It is that portion of rainfall (after all the losses such as interception, infiltration, depression, storage, etc. are met) that enters streams immediately after the rainfall.
- After a lapse of time, overload flow joins streams.
- Sometime known as prompt runoff.

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Module – 3: Runoff and Hydrographs

Introduction:

Subsurface Runoff:

- Certain amount of rain water enters the soil and hence flows laterally towards the stream without joining water table.
- Also takes little time to reach the stream.

Base Flow:

- It is also known as delayed flow.
- This water meets the ground water table and joins the stream or ocean.
- The movement of this flow is very slow and may take months or years to reach the stream.

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Module – 3: Runoff and Hydrographs

Factors Affecting Runoff:

- Climate Factors
- Type of Precipitation
- Rainfall Intensity
- Duration of Rainfall
- Rainfall Distribution
- Direction of Prevailing Wind
- Other Climatic Factors
- Physiographic Factors

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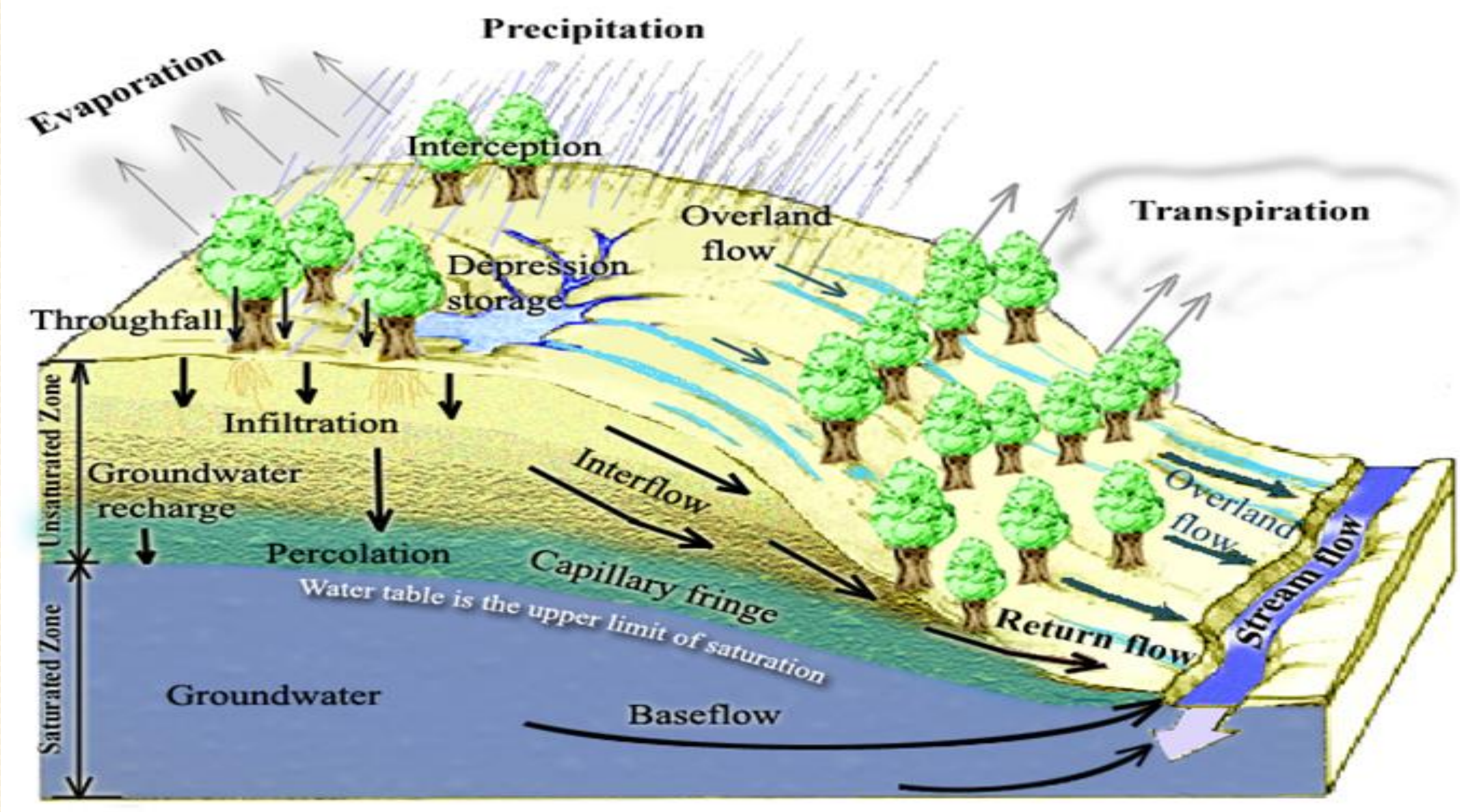

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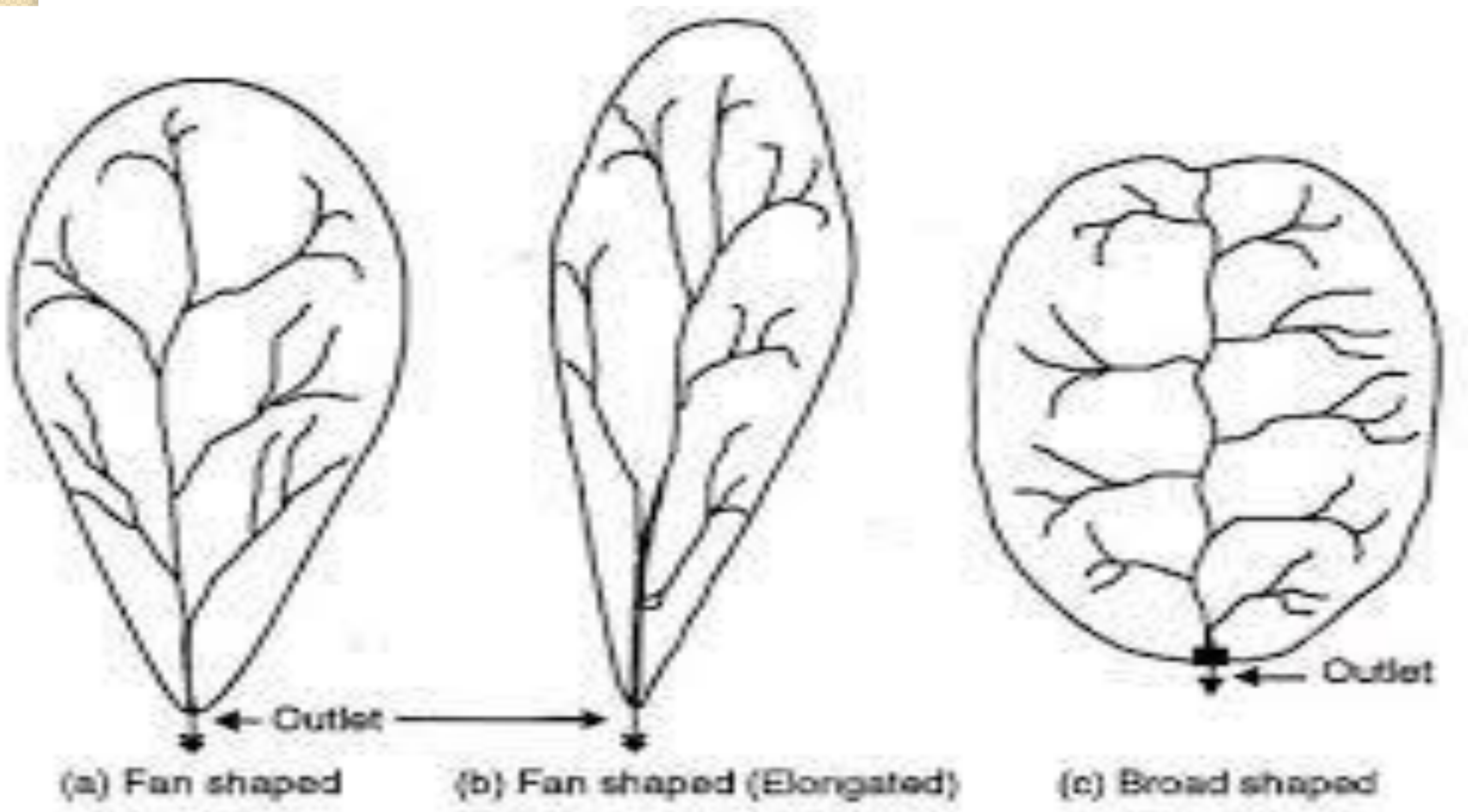
Module – 3: Runoff and Hydrographs



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Rainfall – Runoff Relationships Using Regression Analysis:

- Regression analysis is a method of developing a relationship between parameters.
- In practice linear regression analysis is carried out using the principle of Least Squares developed by Snedecor and Cochran in 1967.
- Considering the two variables X and Y, the linear regression equation would be of the form.

$$Y = a + b X$$

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Rainfall – Runoff Relationships Using Regression Analysis:

- Where
- a = Y intercept
- b = slope coefficient
- Usually Runoff (R) would be the Y variable and Rainfall (P) X variable.
- The total number of observations (n) is known as length of the record.

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Rainfall – Runoff Relationships Using Regression Analysis:

- The normal equations for solving are.

$$\Sigma Y = na + b\,\Sigma X$$

$$\Sigma' XY = a\,\Sigma' X + b\,\Sigma' X2$$

- The sums Σ'X, Σ'Y, Σ'X2 and Σ'Y2 are considered over the length of the record (n).
- It is fact that the analytical method gives more reliable values of the constants a and b than the graphical procedure.
- In spite of the fact that the procedure of solving normal equations is simple another method by name performance testing is found to be more useful.

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Rainfall – Runoff Relationships Using Regression Analysis:

- In performance testing method, the arithmetic mean of the two series (X' and Y') is first estimated.
- In next step, the series of deviations X and Y represented as x and y where x = (X' – X') and y = (Y' – Y') are obtained. Hence,

$$b = \Sigma(xy) / \Sigma x2$$

$$a = Y' - bx \text{ are determined.}$$

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Hydrographs:

Definition:

- A hydrograph is a graphical representation of any hydrological parameter (like discharge, stage etc.) on Y axis with time on X axis.

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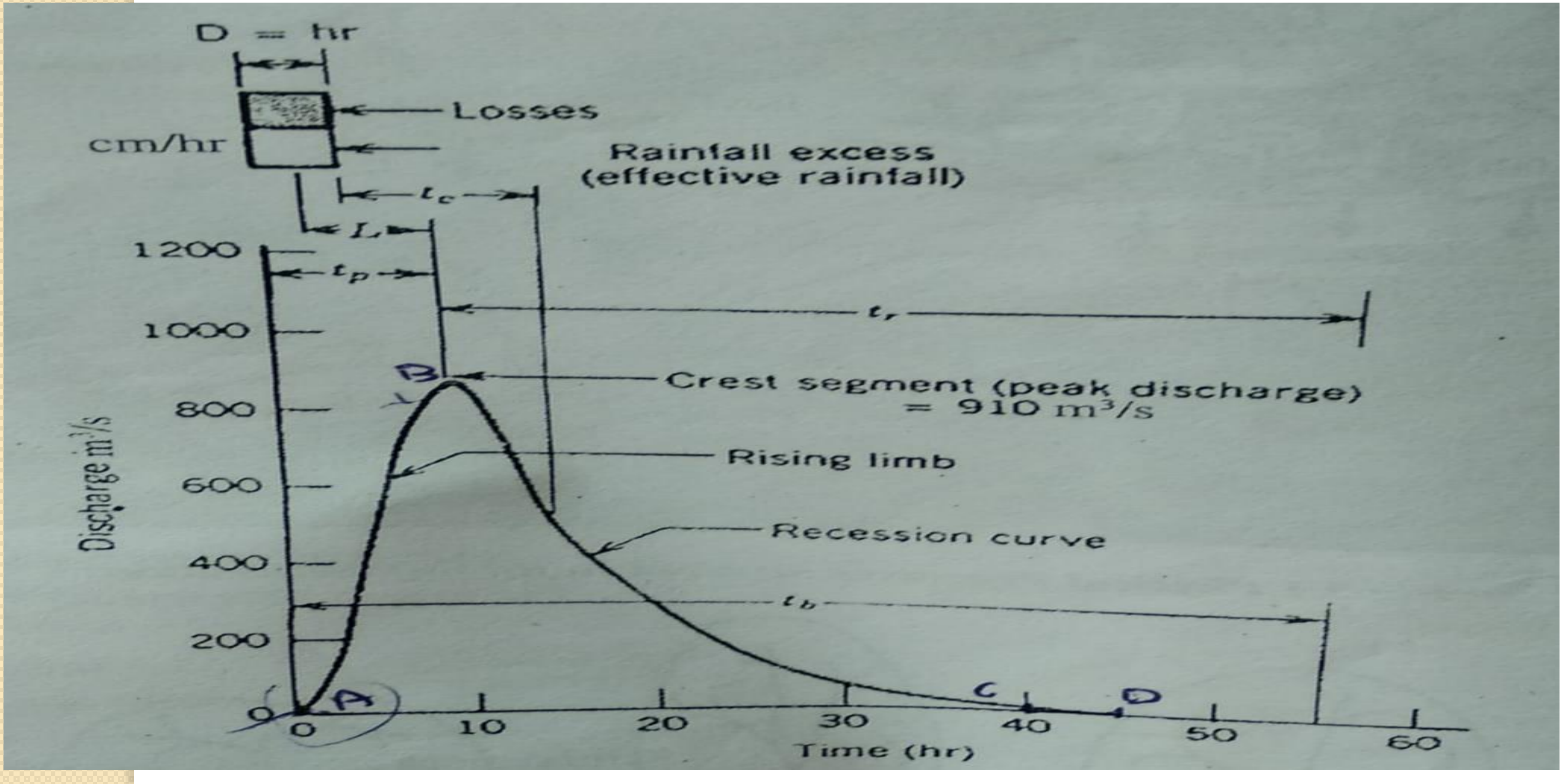
Module – 3: Runoff and Hydrographs

Components of Hydrograph:



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Module – 3: Runoff and Hydrographs

Hydrographs:

Components of Hydrograph:

- **Rising Limb or Concentration Curve (AB):** it is the curve or line joining the starting point A of the rising curve and the point of inflection B. the shape of the rising limb is influenced mainly by the storm or rainfall characteristics.
- **Peak or Crest (BC):** it represents the highest portion of the hydrograph. Its duration also depends on the intensity and duration of the rainfall.

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Hydrographs:

Components of Hydrograph:

- **Falling Limb or Depletion Curve (CD):** it is the descending portion of the hydrograph beyond the point of centraflexure. The point of inflexion represents the time at which the surface inflow into the channel ceases. The shape of the falling limb is mainly a function of the physical features of the channel alone and is independent of the storm characteristics. The shape of the curve CD depends entirely on the basin characters.
- **The Time to Peak (t_{pk}):** it is the time to peak (P) from the starting point of the hydrograph (A).

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Hydrographs:

Components of Hydrograph:

- **Lag Time (T_L):** the time interval from the center of mass of rainfall to the centre of mass hydrograph is the lag time.
- **Time Base (T_B):** it is the total duration or time elapsed between the starting and ending of the hydrograph i.e. the time between A and D.

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Module – 3: Runoff and Hydrographs

Factors Affecting The Shape of The Flood Hydrograph:

The factors affecting the shape of the flood hydrograph can mainly due to:

Climatic Factors

Physical Factors

- For a given duration, the peak and volume of the surface runoff are essentially proportional to the rainfall intensity.
- Duration of the rainfall of given intensity directly effects the volume of rainfall.
- If the storm moves in the downstream direction, flow will be quicker at the basin.

Module – 3: Runoff and Hydrographs

Factors Affecting The Shape of The Flood Hydrograph:

- Shape of a catchment has great influence on the shape of the hydrograph with regards to the period of concentration, maximum flood intensity and curves of rising and falling flood.
- Smaller catchment yields a more rapid and intense flood per unit area. It gives a high and narrow hydrograph which becomes lower as the catchment area increases.
- The slope of the main stream controls the velocity of flow in the channel. The basin slope is important in small catchments where the overland flow is relatively more important. In such cases steeper slope of the catchment results in larger peak discharges.

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Factors Affecting The Shape of The Flood Hydrograph:

- A large drainage density creates situation conductive for quick disposal of runoff down the channel.
- Vegetation and forests increases the infiltration and storage capacities of the soils, vegetal cover reduces the peak flow.

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Unit Hydrograph:

- A unit hydrograph is defined as the hydrograph of direct runoff resulting from one centimeter depth of excess rainfall (effective rainfall) occurring uniformly over the basin and at a uniform rate for a specified duration (D hours).

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Assumptions made in deriving the unit hydrograph are:

- The effective rainfall is uniformly distributed within the specified period of time or within its duration.
- The time or base duration of the hydrograph of direct runoff due to an effective rainfall of unit duration shall be constant.
- The effective rainfall is uniformly distributed throughout the area of the drainage basin.
- The direct runoff or ordinates of common base line are proportional to the total amount of direct runoff represented by each hydrograph.

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Assumptions made in deriving the unit hydrograph are:

- The hydrograph of runoff due to a given period of rainfall for a drainage area, shows all the combined physical characteristics.

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Module – 3: Runoff and Hydrographs

Practical Problems:

- The choice of the unit period.
- Determination of the base length and base flow.
- The effect of non-uniformity of rainfall over the catchment and intensity variation within the unit period.
- The effect of storm movement and the applicability of the unit hydrograph theory to large basins.
- Unit hydrograph is well suited for areas between 200 Hectares to 5000 km^2.

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Derivation of Unit Hydrograph:

- Few unit periods of intense rainfall duration corresponding to an isolated storm uniformly distributed over the area are collected from the past rainfall records. (the unit storm is a storm of such duration that the period of surface runoff is not much less for any other storm of shorter duration).
- Form the collected past records of the drainage (rivers) discharge for the storms prepare the storm hydrograph for some days after and before the rainfall of that unit duration (i.e. select a flood hydrograph which has resulted from a unit storm as specified in step 1).

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Derivation of Unit Hydrograph:

- Draw the line separating the ground water flow (base flow) and direct runoff by any of the standard base flow separation procedures.
- From the ordinates of the total runoff hydrograph (at regular time intervals) deduct the corresponding ordinates of base flow to obtain the ordinates of direct runoff.
- Divide the volume of direct runoff by the area of the drainage basin to obtain the net precipitation depth (X) over the basin.
- Divide each of the ordinate of direct runoff by the net precipitation depth to obtain the ordinates of the unit hydrograph.

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Derivation of Unit Hydrograph:

Ordinate of Unit Hydrograph (UHG) = {Ordinate of direct runoff (FHG) / Depth of net precipitation(X)}

UHG = {FHG / X} x 1

FHG = UGH x X

- Plot the ordinates of the unit hydrograph against time since the beginning of direct runoff, which is the unit hydrograph for the basin for the duration of the storm (producing the flood hydrograph).

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Limitations of Unit Hydrograph Theory:

- It is a fact that similar rainfall distribution from storm to storm over a large area is quite rate. Hence this theory is limited to catchments not exceeding 5000 km2.
- The rainfall distribution over an odd shaped catchment, especially very long and having narrow width would be uneven. Therefore unit hydrograph for such a catchment may not be suitable.
- In mountainous catchments, where orographic precipitation is common, aerial distribution is more or less uneven, but the pattern tends to remain the same from storm to storm and hence unit hydrograph theory may not be successful.

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Limitations of Unit Hydrograph Theory:

- When the precipitation is mostly of snowfall, the unit hydrograph theory would not yield accurate results.
- The linear relationship fails when the catchment has large storage reservoirs, lakes and low areas. Thereby, unit hydrograph theory fails.
- Unit hydrograph theory is not acceptable when the base period and peak flow very more than ±20% and ±10% respectively.

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Applications of Unit Hydrograph Theory:

- Unit hydrograph theory can be used for flood forecasting and warning.
- It is fact that the unit hydrograph is a linear model of the catchment, the theory can be adopted for determining the runoff hydrograph of the catchment even for extreme magnitude to determine peak flow for design of hydraulic structures.
- Unit hydrographs proves to be more helpful for the extension of flood records, along with the help of rainfall data.

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Module – 3: Runoff and Hydrographs

Base Flow Separation:

I – Method:

- Generally the method of base flow separation should be such that time base of the direct runoff remains relatively constant, from storm to storm.
- This is usually achieved by terminating the direct runoff at the fixed time after the peak of the hydrograph.
- As the thumb rule the value of N can be obtained from the relation.

$$N = \{A^{0.2} / 1.21\}$$

Where A = drainage or catchment area in km2

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Base Flow Separation:

I – Method:

- But, the value of N can also be determined by inspection of a number of hydrographs, keeping in mind that the total base should not be excessively long and the rise of the ground water should not be too large.
- In figure portion of the curve above PQ is direct (surface) runoff and that below is the base flow (sub-surface flow).

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Base Flow Separation:

II – Method:

- In this method the base flow curve (i.e. falling limb of the hydrograph after the point of inflexion existing prior to the commencement) of the surface runoff is extended till it intersect the ordinate drawn at the peak point (R) as shown in figure.
- This point is joined to point Q by a straight line segments PR and RQ demarcate the base flow and surface runoff.
- This is probably the most widely used base flow separation procedure.

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Base Flow Separation:

III – Method:

- In this method the base flow separation is achieved by projecting backwards the ression curve, (after the depletion of the flood water) till it intersects the ordinate at the point of inflection as shown by line MN in figure.
- Points P and N are joined by an arbitrary smooth curve.
- This method may give better results where the ground water contribution are significant and reach the stream quickly.

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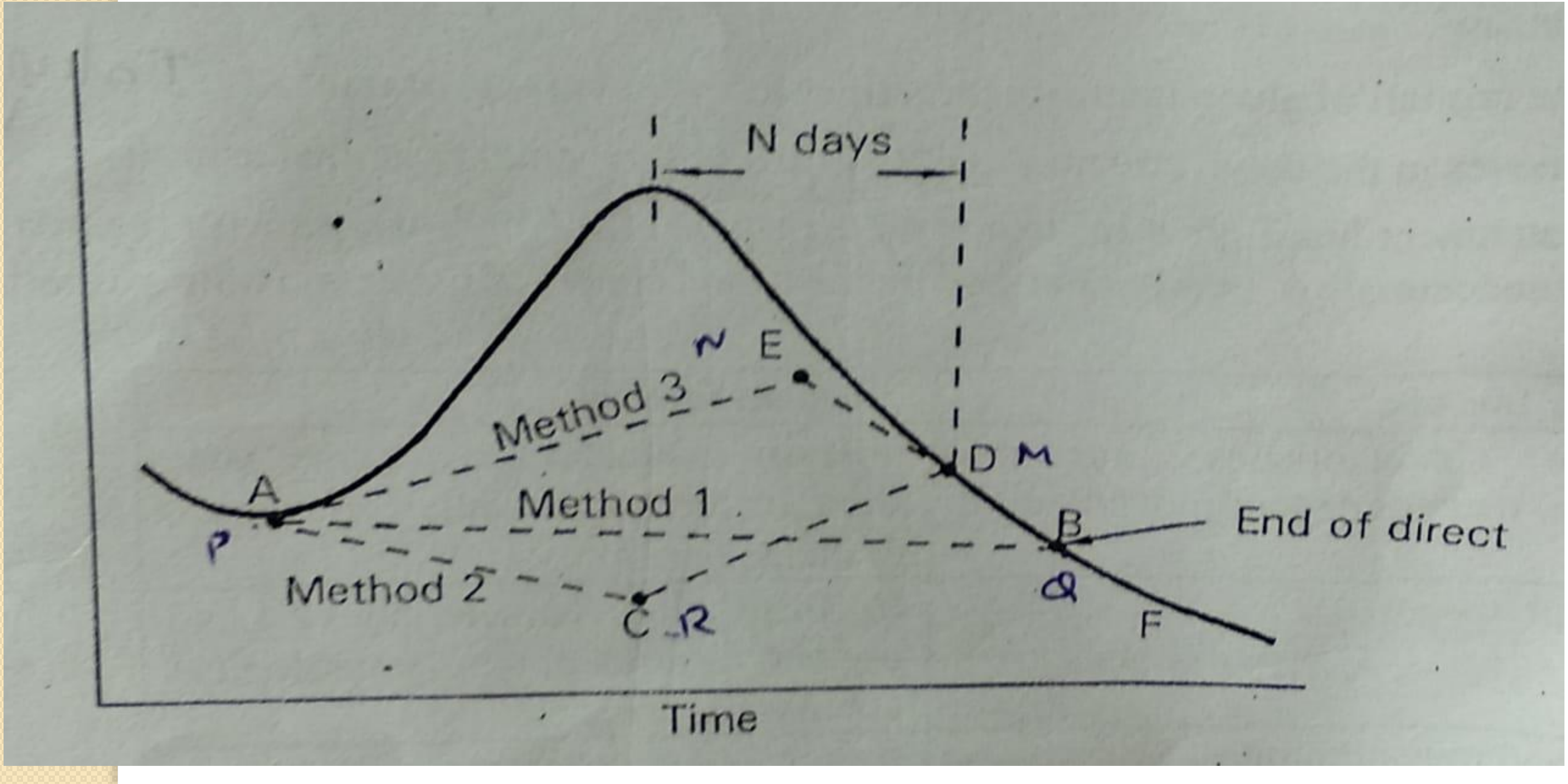
Base Flow Separation:



S – Hydrograph:

- S – Curve or a summation curve is a hydrograph of direct surface discharge that would result from a continuous effective rainfall at a constant rate for an infinite period.
- It is the curve obtained by summation of t – hour's unit hydrographs spaced t – hours apart.
- Figure shows a series of t – hour's unit hydrographs arranged with their starting points t – hours apart.
- At any given time the ordinates of the various curves occurring at that time coordinate are summed up to obtain ordinate of the S – curve.

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Module – 3: Runoff and Hydrographs

S – Hydrograph:

- A smooth curve drawn through these ordinates will be the S – curve.
- This S – curve is due to t – hour's unit hydrograph.
- It has an initial steep portion and reaches a maximum equilibrium discharge at a time equal to the time base of the first unit hydrograph.
- The average intensity of excess rainfall producing the S – curve is l/t cm/hour and the equilibrium discharge is

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Module – 3: Runoff and Hydrographs

S – Hydrograph:

$$Q_e = \{(A/t) \times 10^4\} \text{ meter}^3 / \text{sec}$$

- Where A = catchment area in km2
- t = duration in hours of excess rainfall of the unit hydrograph used in deriving the curve
- Alternatively

$$Q_e = 2.778 \times \{A/t\} \text{ m}^3 / \text{sec}$$

- The S – hydrograph technique is very much useful in deriving a unit hydrograph of one duration knowing an unit hydrograph of other duration.

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S – Hydrograph: