INFILTRATION

Water is constantly evaporated from the earth, and is precipitated back on the earth, mainly in the form of rainfall. One part of this rainfall sinks into the ground, forming groundwater reservoir; second major part flows as runoff in the form of rivers; and the rest is lost in evaporation and transpiration. The part of the rainfall which sinks into the ground is discussed in this chapter.

Infiltration Process

It is well-known that when water is applied to the surface of a soil, a part of it seeps into the soil. This movement of water through the soil surface is known as infiltration and plays a very significant role in the runoff process by affecting the timing, distribution and magnitude of the surface runoff. Further, infiltration is the primary step in the natural groundwater recharge.

Infiltration is the flow of water into the ground through the soil surface and the process can be easily understood through a simple analogy. Consider a small container covered with wire gauze, if water is poured over the gauze, a part of it will go to container and a part overflows. Further, the container can hold only a fixed quantity and when it is full no more flow into the container can take place. This analogy, though a highly simplified one, underscores two important aspects, viz., the maximum rate at which the ground can absorb water, the infiltration capacity and the volume of water that it can hold, the field capacity.

Factors Affecting Infiltration Rate

The major factors affecting the infiltration of water into the soil are,

1. Initial moisture content
2. Condition of the soil surface
3. Hydraulic conductivity of the soil profile
4. Texture
5. Porosity
6. Degree of swelling of soil colloids
7. Organic matter
8. Vegetative cover
9. Duration of irrigation or rainfall
10. Viscosity of water

The antecedent soil moisture content has considerable influence on the initial rate and total amount of infiltration, but decreasing as the soil moisture content rises. The infiltration rate of any soil is limited by any restraint to the flow of water into and through the soil profile. The soil layer with the lowest permeability, either at the surface or below it, usually determines the infiltration rate. Infiltration rates are also affected by the porosity of the soil which is changed by cultivation or compaction. Cultivation influences the infiltration rate by increasing the porosity of the surface soil and breaking up the surface seals. The effect of tillage on infiltration usually lasts only until the soil settles back to its former condition of bulk density because of subsequent irrigations. Infiltration rates are generally lower in soils of heavy texture than in soil of light texture. It has been established that in surface irrigation, increased depth increases initial infiltration slightly but the depth of application has negligible effect after prolonged irrigation. Infiltration rates are also influenced by the vegetal cover. Infiltration rates on grassland are subsequently higher than bare uncultivated land. Addition of organic matter increases infiltration rate substantially. The hydraulic conductivity of soil profile often change during infiltration, not only because of increasing moisture content, but also because of the puddling of the surface caused by reorientation of surface particles and washing of finer materials into the soil. Viscosity of water influences infiltration. The high rates of infiltration in the tropics under otherwise comparable soil conditions are due to the low viscosity of warm water.

Measurement of Infiltration

Information about the infiltration characteristics of the soil at a given location can be obtained by conducting controlled experiments on small areas. The experimental set-up is called an infiltrometer. There are two kinds of infiltrometers:

1. Flooding-type infiltrometer
2. Rainfall simulator

1 Flooding-Type Infiltrometer

This is a simple instrument consisting essentially of a metal cylinder, 30 cm diameter and 60 cm long, open at both ends. This cylinder is driven into the ground to a depth of 50 cm (Fig.14.1). Water is poured into the top part to a depth of 5 cm and a pointer is set to mark the water level. As infiltration proceeds, the volume is made up by adding water from a burette to keep the water level at the tip of the pointer. Knowing the volume of water added at different time intervals, the plot of the infiltration capacity vs lime is obtained. The experiments are continued till a uniform rate of infiltration is obtained and this may take 2-3 h. The surface of the soil is usually protected by a perforated disk to prevent formation capacity vs time is obtained. The experiments are continued till a uniform rate of infiltration is obtained and this may take 2-3 h.

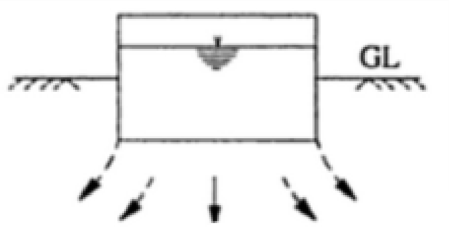


Fig. Simple Infiltrometer

The surface of the soil is usually protected by a perforated disk to preventformation of turbidity and it's settling on the soil surface.A major objection to the simple infiltrometer as above is that the infiltered waterspreads at the outlet from the tube (as shown by dotted lines in Fig. 14.1) and assuch the tube area is not representative of the area in which infiltration takesplace.

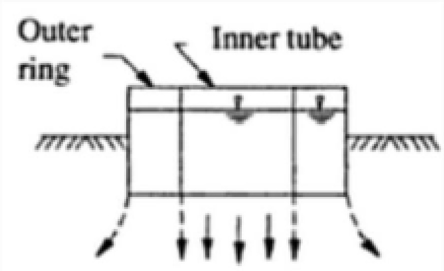


Fig.Ring Infiltrometer.

To overcome this ring infiltrometer consisting of a set of two concentric rings (Fig. 14.2) is used. In this two rings are inserted into the ground and water is maintained on the soil surface, in both the rings, to a common fixed level. The outer ring provides a water jacket to the infiltering water of the inner ring and hence prevents the spreading out of the infiltering water of the inner tube. The measurement of water volume is done on the inner ring only.

The main disadvantages of flooding-type infiltrometer are:

(1) The raindrop-impact effect is not simulated;

(2) The driving of the tube or rings disturbs the soil structure;

(3) The results of the infiltrometer depend to some extent on their size with thelarger meters giving fewer rates than the smaller ones; this is due to the border effect.

Rainfall Simulator

In this a small plot of land, of about 2 m X 4 m size, is provided with a size of nozzles on the longer side with arrangements to collect and measure the surface runoff rate. The specially designed nozzles produce raindrops falling from a height of 2 m and are capable of producing various intensities of rainfall. Experiments are conducted under controlled conditions with various combinations of intensities and durations and the surface runoff is measured in each case. Using the water-budget equation involving the volume of rainfall, infiltration and runoff, the infiltration rate and its variation with time is calculated. If the rainfall intensity is higher than the infiltration rate, infiltration-capacity values are obtained.

Rainfall simulator type infiltrometers give lower values than flooding type infiltrometers. This is due to the effect of the rainfall impact and turbidity of the surface water present in the former.

Infiltration indices

Hydrological calculations involving floods it is found convenient to use a constant value of infiltration rate for the duration of the storm. The average infiltration rate is called infiltration index and two types of indices are in common use.

1 Φ-index

The Φ index is the average rainfall above which the rainfall volume is equal to the runoff volume. The Φ index is derived from the rainfall hyetograph with the knowledge of the resulting runoff volume. The initial loss is also considered as infiltration. The Φ value is found by treating it as a constant infiltration capacity. If the rainfall intensity is less than 0, then the infiltration rate is equal to the rainfall intensity; however, if the rainfall infiltration. TheΦ value is found by treating it intensity is larger than Φ the difference between rainfall and infiltration in an interval of time represents the runoff volume (Fig. 3).

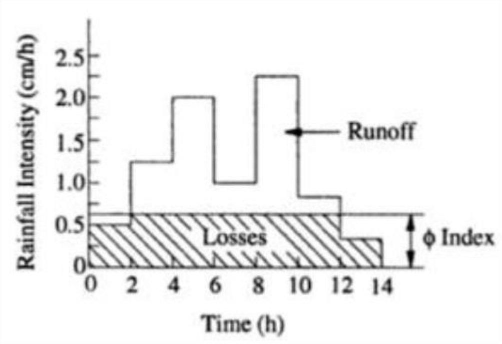


Fig. Φ-index.

The amount of rainfall in excess of the Φ index is called rainfall excess. The Φ -index thus accounts for the total abstraction and enables runoff magnitudes to be estimated for a given rainfall hyetograph.

2 W- Index

In an attempt to refine the Φ-index the initial losses are separated from the total abstraction and an average value of infiltration rate called the W index is defined as

$$W = \frac{P - R - I_a}{t_e}$$

Where, P is total precipitation (cm), R is total storm runoff (cm), I_a is initial losses (cm), t_e is the duration of the rainfall excess, i.e. the total time in which the rainfall intensity is greater than W (in hours) and W is the average rate of infiltration (cm/h).

Since I_a values are difficult to obtain, the accurate estimation of the W index is ratger difficult. The minimum value of the W index obtained under very wet soil conditions, representing the constant minimum rate of infiltration of the catchment, is known as $W_{min.}$ Both theW-index and Φ index vary from storm to storm.

Ponding Time

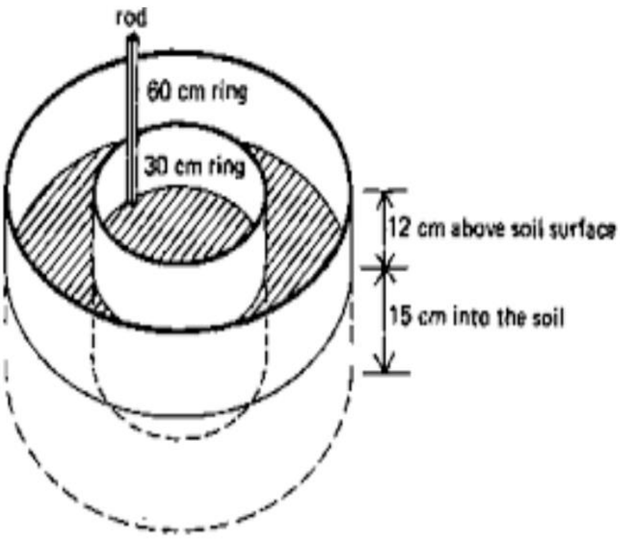
A crucial time for determining runoff is the time to ponding. The ponding time tp is the elapsed time between the time rainfall begins and the time water begins to pond on the soil surface (after which rainfall intensity exceeded the potential infiltration rate). Prior to the ponding time (t < tp), the rainfall intensity is less than the potential infiltration rate and the soil surface is unsaturated. Ponding begins when the rainfall intensity exceeds the potential infiltration rate. At this time (t = tp), the soil surface is saturated. As rainfall continues (t > tp), the saturated zone extends deeper into the soil and overland flow occurs from the ponded water.

The **infiltration rate** is the velocity or speed at which water enters into the soil. It is usually measured by the depth (in mm) of the water layer that can enter the soil in one hour. An infiltration rate of 15 mm/hour means that a water layer of 15 mm on the soil surface, will take one hour to infiltrate.

In dry soil, water infiltrates rapidly. This is called the **initial infiltration** rate. As more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a steady rate. This is called the basic **infiltration rate.** The infiltration rate depends on soil texture (the size of the soil particles) and soil structure (the arrangement of the soil particles)

Double ring infiltrometer The double ring infiltrometer is a widely used method of infiltration test used in many applications; i.e. design of land drainage pipes, design of sports surfaces, golf courses, isolation layers of the communal waste, etc.
The infiltrometer consists of two concentric metal rings (see Fig 1), which are driven into the soil, and of a perforated metal plate.

Equipment



RUNOFF

Runoff is one of the important hydrological processes, which influence the various soil and water conservation and development programs in a watershed. Several attempts have been made in the past to estimate rainfall-runoff volume using mathematical models. Runoff is the drainage of precipitation from catchments, which flows out through its natural drainage system. After the occurrence of infiltration and other losses from the precipitation, the excess rainfall flows out through the small natural channels on the land surface to the main drainage channel. Most environmental process show complicated interrelations, both time and space, leading to numerical models with a complex mathematical structure. Also environmental models require huge amount of data often coming from many sources like remote sensing. Knowledge of runoff that depends upon many factors like precipitation, recharge of the basin, type of soil etc. is one such important parameter.

Components of Runoff

Runoff means the draining or flowing off of precipitation from a catchment area through a surface channel enters into a stream channel. It represents the output from catchment in a given unit of time. Fig. 1 shows components of runoff.

Consider a catchment area receiving precipitation. For a given precipitation, when the evapotranspiration, initial loss, infiltration and detention storage requirements are satisfied, the excess precipitation moves over the land surfaces to reach smaller channels. This portion of runoff is called overland flow and involves building up of storage over the surface and draining off the same. Flows from several small channels join bigger channels and flows from these in turn combine to form a larger stream, and so on, till the flow reaches the catchment outlet. The flow in this mode, where it travels all the time over the surface as overland flow and through the channels as open-channel flow and reaches the catchment outlet is called surface runoff.

A part of the precipitation that infilters moves laterally through upper crusts of the soil and returns to the surface at some locations away from the point of entry into the soil. This component of runoff is known variously as interflow, through flow, storm seepage, subsurface flow or quick return flow.

Depending upon the time delay between the infiltration and the outflow, the interflow is sometimes classified into prompt interflow, i.e. the interflow with the least time lag and delayed interflow.

Another route for the infiltered water is to undergo deep percolation and reach the groundwater storage. The time lag, i.e. the difference in time between the entry into the soil and outflows from it is very large, being of the order of months and years. This part of runoff is called groundwater runoff or groundwater flow.

Based on the time delay between the precipitation and the runoff, the runoff is classified into two categories; as (a) Direct runoff (b) Base flow.

a) Direct runoff

It is the part of runoff which enters the stream immediately after the rainfall. It includes surface runoff, prompt interflow and rainfall on the surface of the stream. In the case of snow-melt, the resulting flow entering the stream is also a direct runoff. Direct storm runoff and storm runoff are also used to designate direct runoff.

b) Base flow

The delayed flow that reaches a stream essentially as groundwater flow is called base flow.

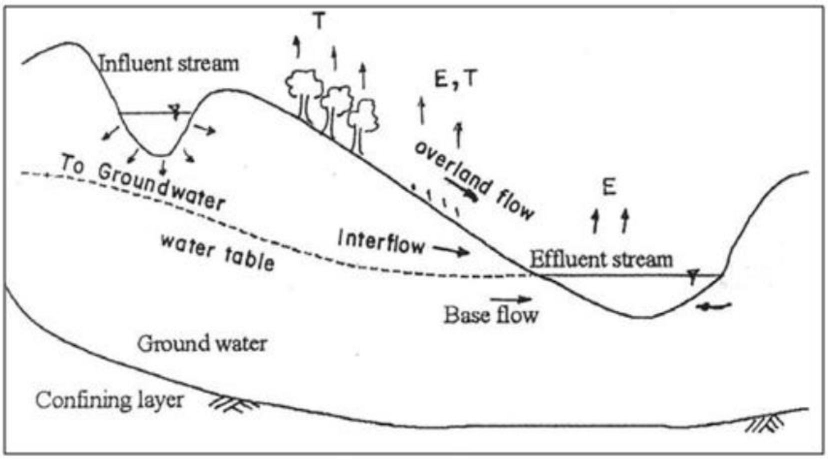


Fig. Components of runoff.

Physical characteristics affecting runoff:

- Land use
- Vegetation
- Soil type
- Drainage area
- Basin shape
- Elevation
- Topography, especially the slope of the land
- Drainage network patterns
- Ponds, lakes, reservoirs, sinks, etc. in the basin, which prevent or delay runoff from continuing downstream

Factors Affecting Runoff

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

a) Precipitation characteristics
b) Shape and size of catchment
c) Topography
d) Geologic characteristics
e) Meteorological characteristics
f) Storage characteristics of a catchment

1. Precipitation Characteristics

Precipitation is the most important factor, which affects runoff. The important characteristics of precipitation are duration, intensity and areal distribution.

Duration Total runoff depends on the duration of rainstorm. For a given rainfall intensity and other conditions, a longer duration rainfall event will result in more runoff.

Intensity Rainfall intensity influences both rate and volume of runoff. The runoff volume and also runoff rate will be greater for an intense rainfall event than for less intense event.

Areal Distribution It also influences both the rate and volume of runoff. Generally, the maximum rate and volume of runoff occurs when the entire watershed contributes.

2. Shapes and Size of Catchment

The runoff from a catchment depends upon the size, shape and location of the catchment. The following are the general observations:

a) More intense rainfall events are generally distributed over a relatively smaller area, i.e., larger the area lower will be the intensity of rainfall.

b) The peak normally decreases as the area of the basin increase. (peak flow per unit area)

c) Larger basins give a more constant minimum flow than the smaller ones. (effect of local rains and greater capacity of the ground-water reservoir)

d) Fan shaped catchments give greater runoff because tributaries are nearly of same size and hence time of concentration of runoff is nearly same. On the contrary, discharges over fern leaf arrangement of tributaries are distributed over long period because of the different lengths of tributaries.

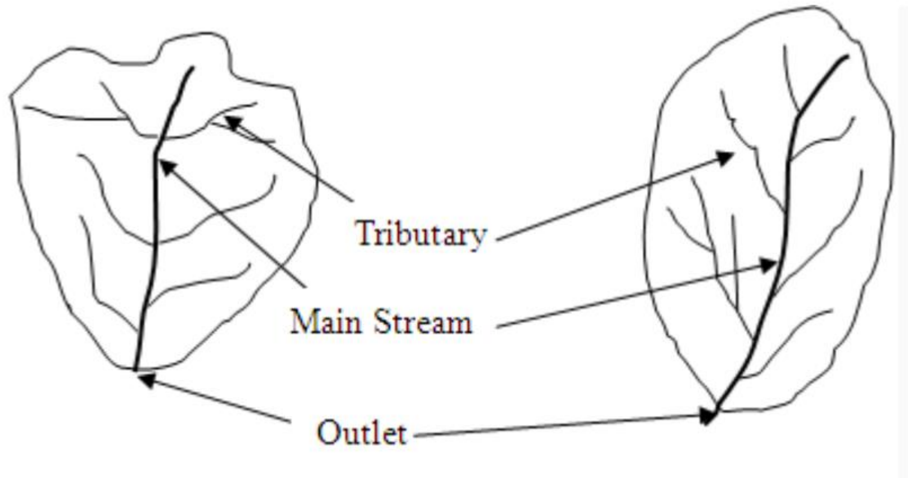


Fig. a.Fan shaped catchment. Fig.b.Leaf shaped catchment.

3. Topography

The runoff depends upon surface condition, slope and land features. Runoff will be more from a smooth surface than from rugged surface. Also, if the surface slope is steep, water will flow quickly and adsorption and evaporation losses will be less, resulting in greater runoff. On the other hand if the catchment is mountainous, the rainfall intensity will be high and hence runoff will be more.

4. Geologic Characteristics

Geologic characteristics include surface and sub-surface soil type, rocks and their permeability. Geologic characteristics influence infiltration and percolation rates. The runoff will be more for low infiltration capacity soil (clay) than for high infiltration capacity soil (sand).

5. Meteorological Characteristics

Temperature, wind speed, and humidity are the major meteorological factors, which affect runoff. Temperature, wind speed and humidity affect evaporation and transpiration rates, thus soil moisture regime and infiltration rate, and finally runoff volume.

Meteorological factors affecting runoff:

- Type of precipitation (rain, snow, sleet, etc.)
- Rainfall intensity
- Rainfall amount
- Rainfall duration
- Distribution of rainfall over the drainage basin
- Direction of storm movement
- Precipitation that occurred earlier and resulting soil moisture
- Other meteorological and climatic conditions that affect evapotranspiration, such as temperature, wind, relative humidity, and season

6. Storage Characteristics of a Catchment

Presence of artificial storage such as dams, weirs etc. and natural storage such as lakes and ponds etc. tend to reduce the peak flow. These structures also give rise to greater evaporation.

Definition of Hydrograph

The hydrograph which results due to an isolated storm is typically singlepeaked skew distribution of discharge and is known variously as storm hydrograph, flood hydrograph or simply hydrograph.

The hydrograph is the response of a given catchment to a rainfall input. It consists of flow in all the three phases of runoff, viz. surface runoff, interflow and base flow and embodies in itself the integrated effects of a wide variety of catchment and rainfall parameters having complex interactions.

Elements of Hydrograph

Hydrograph has three characteristic regions: (i) the rising limb AB, joining point A, the starting point of the rising curve and point B, the point of inflection, (ii) the crest segment BC between the two points of inflection with a peak P in between, (iii) the falling limb or depletion curve CD **starting from the second point of inflection C.**

Rising Limb

The rising limb of a hydrograph, also known as concentration curve represents the increase in discharge due to the gradual building up of storage in channel and over the catchment surface. The initial losses and high infiltration losses during the early period of a storm cause the discharge to rise rather slowly in the initial periods. The basin and storm characteristics control the shape of the rising limb of a hydrograph.

Crest Segment

The crest segment is one of the most important parts of hydrograph as it contains the peak flow. The peak now occurs when the runoff from various parts of the catchment simultaneously contribute amounts to achieve the maximum amount of flow at the basin outlet. Generally for large catchments, the peak flow occurs after the cessation of rainfall, the time interval from the centre of mass of rainfall to the peak being essentially controlled by basin and storm characteristics. Multiple-peaked complex hydrographs in a basin can occur when two or more storms occur in succession. Estimation of the peak flow and its occurrence, being important in flood-flow studies are dealt with in detail elsewhere in this book.

Recession Limb

The recession limb, which extends from the point of inflection at the end of the crest segment (point C)to the commencement of the natural groundwater flow (point D.) represents the withdrawal of water from the storage built up in the basin during the earlier phase of the hydrograph. The starting point of the recession limb, i.e. the point of inflection represents the condition of maximum storage. Since the depletion of storage takes place after the cessation of rainfall, the shape of this part of the hydrograph is independent of storm characteristics and depends entirely on the basin characteristics.

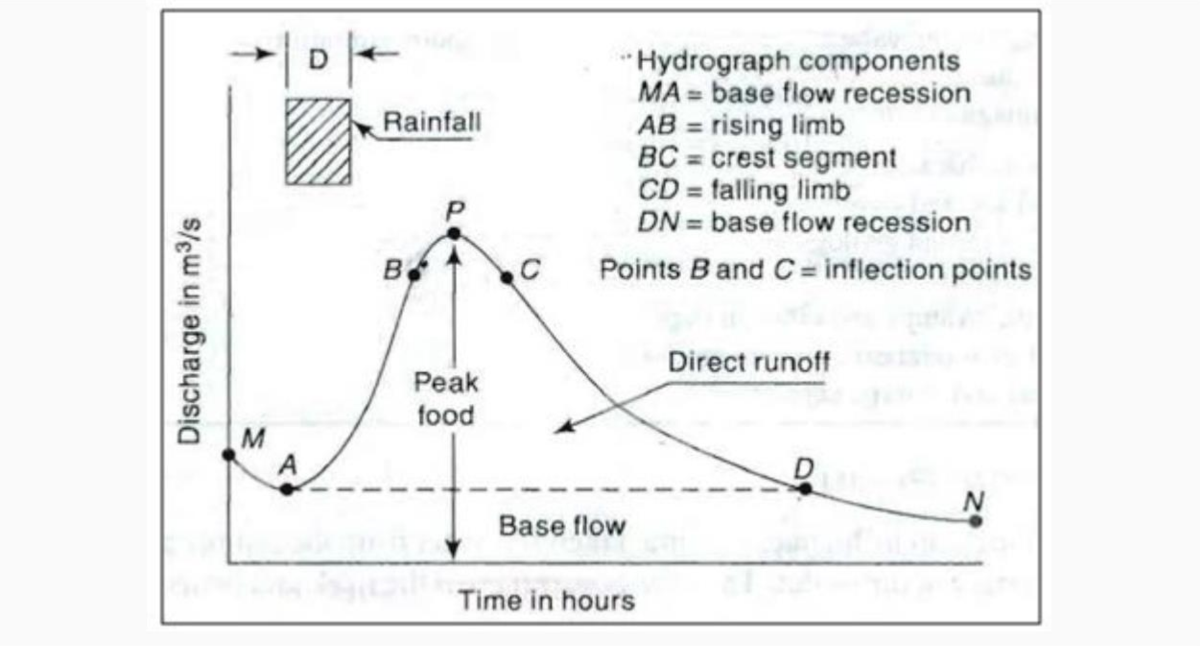


Fig. Elements of a hydrograph.

Stream flow Recession

The storage of water in the basin exists as (i) surface storage, which includes both surface detention and channel storage, (ii) interflow storage, and (iii) groundwater storage, i.e. base-flow storage.

Lag Time (T_L)

It is the difference in time between the center of mass of net rainfall and center of mass runoff.

Time to Peak (T_P)

It is the time difference between the beginnings of direct runoff (point B) to peak.

Rainfall Duration (T_r)

It is the effective rainfall duration, which causes direct runoff. Curve between point M and A represents recession from previous storm.

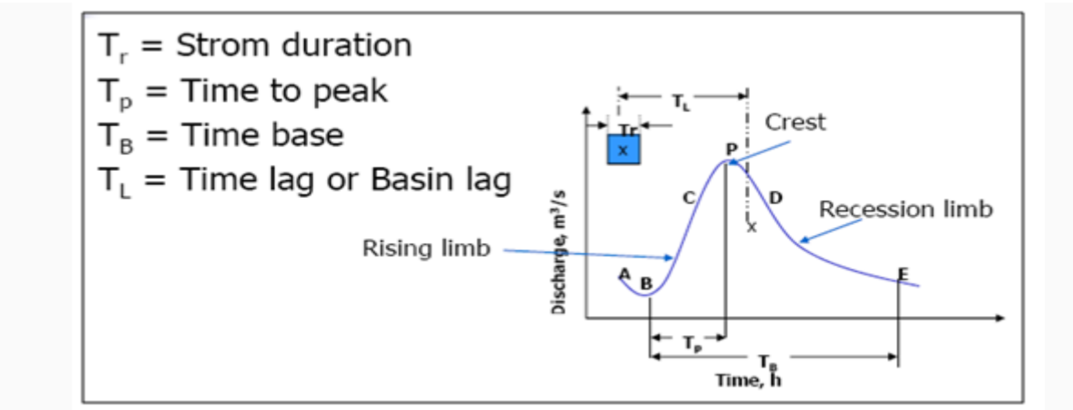


Fig. Hydrograph time characteristics.

Definition of Unit Hydrograph

A unit hydrograph is defined as the hydrograph of direct runoff resulting from one unit depth (1 cm) of rainfall excess occurring uniformly over the basin and at a uniform rate for a specified duration (D hours).

The definition of a unit hydrograph implies the following:

- The unit hydrograph represents the lumped response or the catchment to a limit rainfall excess of D-h duration to produce a direct-runoff hydrograph. It relates only the direct runoff to the rainfall excess. Hence the volume of water contained in the unit hydrograph must be equal to the rainfall excess. As 1 cm depth of rainfall excess is considered the area of the unit hydrograph is equal to a volume given by 1cm over the catchment.
- The rainfall is considered to have an average intensity of excess rainfall (ER) of 1/D cm/h for the duration D-h of the storm.
- The distribution of the storm is considered to be uniform all over the catchment.

Uses of Unit Hydrograph

1. Development of flood hydrograph for extreme rainfall magnitudes for use in the design of hydraulic structures.
2. Extension of flood-flow records based on rainfall records.
3. Development of flood forecasting and warning systems based on rainfall.

Factors Affecting Hydrograph

Physiographic factors	Climatic factors
1. Basin characteristics (a) Shape (b) Size (c) Slope (d) Nature of the valley (e) Elevation (f) Drainage density 2. Infiltration characteristics (a) Land use and cover (b) Soil type and geological conditions (c) Lakes, swamps and other storage 3. Channel characteristics: cross-section, roughness and storage capacity	1. Storm characteristics: precipitation, intensity, duration, magnitude and movement of storm 2. Initial loss 3. Evapotranspiration

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