LECTURE 5

RAINFALL–RUNOFF PROCESS

OBJECTIVES

This lecture would provide proper understanding of the rainfall-runoff process. The participants would also be able to know about various factors affecting runoff. Computation of direct surface runoff hydrograph and excess rainfall hyetograph are explained with the help of illustrative examples.

5.1 INTRODUCTION

Runoff is defined as the portion or the precipitation flowing off from a catchment through surface channel or channels as a surface or sub-surface flow. Runoff is an important component of the hydrological cycle. While it is made up of flow from all sources, rainfall is the single parameter which influences runoff directly as overland flow or indirectly as sub-surface flow and ground water flow. Fig. 5.1 shows the thematic diagram showing rainfall, runoff process. Chow (1964) visualized the diagram as runoff cycle dependent on the nature of supply. Before going to dicuss the factors affecting the runoff and the estimations for runoff, let us first understand the rainfall-runoff process in brief.

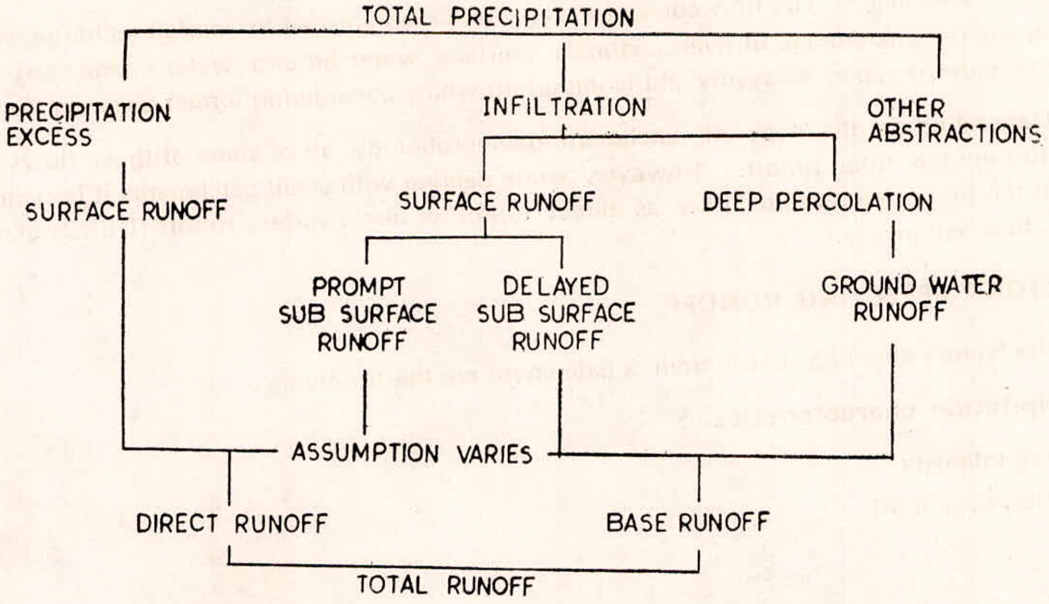


Fig. 5.1 Thematic Diagram Showing Rainfall-Runoff Process

Consider a catchment area receiving precipitation. A part of it is intercepted by vegetation. Some of it is stored in depression on the ground surface and is known as the depression storage which later infiltrates or evaporates. Some of the precipitation is absorbed by the soil depending upon the soil moisture conditions existing at the time of precipitation. If the rain continues further and the soil moisture content within the root zone depth reaches at field capacity, then the additional amount of precipitation drains below the root zone due to gravity and percolates to join the ground water table. At the same time, if the rate of rainfall reaching the ground exceeds the infiltration rate, then this excess water starts collecting on the surface as surface detention and this water flows as overland flow and joins the neighbouring streams through which it travels to the catchment outlet. This flow is known as the surface runoff. The underground water adjacent to the stream flows as sub-surface flow and joins the stream. This part of the runoff is known as sub-surface flow and is considered as a part of surface runoff. On the other hand, the water that percolates in the ground water table and later after long times joins the river stream, is known as ground water flow or base flow. Moreover, during the above process some portion of rainfall also gets lost due to evaporation and evapotranspiration.

Thus the total runoff appearing at the outlet of a basin or catchment consists of various components of runoff as shown in Fig. 5.1. Four principal components of runoff could be identified.

(i) Channel Runoff : This occurs due to rain falling directly on a flowing stream or on the impervious surface of a stream flow measuring installation. It is generally a negible quantity.

(ii) Surface runoff : This is the most important component of runoff especially in small catchments. It occurs when the rainfall rate is greater than the infiltration rate. Its magnitude during the storm varies and ends during or soon after the cessation of storm. Surface flow down deep channels is reduced by transmission losses which may be sometimes large enough to eliminate the surface flow entirely.

(iii) Sub-surface flow : When infiltrated rainfall meets an underground zone of low permeability, the water travels above the zone along the slope and appears over surface as a spring.

(iv) Base flow : The flow comes from an aquifer replenished by rainfall recharge, surface runoff seepage or bank storage of river channels (surface water-ground water interaction). This type of flow appears rather delayedly and is important while considering longer duration flows.

Depending on the type of catchment geomorphology all or some of these flows might combine to form the total runoff. However, while dealing with small catchments it is customary to treat all the first three types of flow as direct runoff or direct surface runoff (DSRO) and deal with base flow separately.

5.2 FACTORS AFFECTING RUNOFF

The factors affecting runoff from a catchment are the following :

(a) **Precipitation characteristics**

(i) Rainfall intensity

(ii) Duration of rainfall

(iii) Distribution of the rainfall over the basin

(iv) Direction of storm movement

(v) Type of precipitation and type of storm

(i) Rainfall intensity : For a given duration, an increase in intensity of rainfall will increase the peak discharge and volume of runoff provided of course the infiltration rate of the soil is exceeded. Uniform intensity storms of given duration but with varying intensity will produce varying stream rises. However, the time during which surface runoff is taking place will be almost the same in all cases. Short time variations in intensity during a storm may significantly affect the shape of the hydrogrph for small basins but generally they will have little noticable effect on hydrographs from a large basin.

(ii) Duration of rainfall : If the two storms with the same uniform intensity alternatively fall over a basin, the hydrograph resulting due to large duration-storm will have both, the rise time and peak discharge, more than the shorter duration storm.

(iii) Dtsiribution of the rainfall over the basin : The areal distribution of rainfall can cause variations in runoff hydrograph shape. If the heavy rainfall falls over the area nearer to the basin outlet, a rapid rise, sharp peak and rapid recession of the hydrograph usually result. If a larger amount of rainfall occurs in the upper reaches of a basin, the hydrograph exhibits a lower and broader peak. An intense thunder storm may be able to produce, highest peak hydrograph in the case of small basin. However, this may not be true for the large basin, the storm with less intensity but covering large areas will be decisive.

(iv) Duration of storm movement : The direction of storm movement with respect to orientation of the basin affects both the magnitude of the peak flow and the duration of surface runoff. Storm direction has the considerable effect over the elongated basin. The storms that move upstream tend to produce lower peaks and broader time base of surface runoff than storms that move down stream on these basins.

(v) Type of precipitation and storm : Different shapes of runoff hydrographs resulted due to snowmelt and excess rainfall. By comparison, the rate at which runoff is generated from snowmelt is usually rather sluggish, because of the lag effects in the snow pack, the local distribution of the source areas of runoff and diurnal fluctuations in temperature. As a result the snowmelt hydrograph tends to exhibit a lower and broadar runoff pattern than the rainfall hydrograph.

The type of storm also effects the shape of the hydrograph. The thunder storm produces the peak flows on small basins, whereas large cyclonic or frontal type storms are generally important for the flood prediction on large basins.

(b) Physiographic factors

(i) Area of the catchment

(ii) Shape of the catchment

(iii) Distribution of water courses

(iv) Slope of the main stream

(v) Slope of valley sides or general land slope

(vi) Orientation

(*i*) *Area of the catchment* : With increase in catchment area, the peak ordinate of the runoff hydrograph for a given rainfall excess will decrease end the time base of the hydrograph will increase.

(*ii*) *Shape of the catchment* : The shape of the catchment will have the significant effect over the shape of the runoff hydrograph. For example, a semicircular basin, on which flow converges from all points to the outlet, produces a shorter time to peak than long, narrow basin of equal size.

(*iii*) *Distribution of water courses* : The efficiency of the drainage system depends upon the pattern and arrangement of the natural stream channels. A well defined drainage system reduces the time of concentration of runoff which causes reduction in time to peak of the outflow.

(*iv*) *Slope of main stream* : When a flood wave reaches the main stream, the time required for the flood wave to reach at the outlet depends on the length of travel and the slope of the stream. For a stream of given length the increase in stream slope causes an increase in the slope of the recession limb of the hydrograph as a result time base of the hydrograph decreases.

(*v*) *Slope of valley sides or General land slopes* : The general land slope has a complex relationship to the surface runoff phenomena because of its influences on infiltration, soil moisture content and vegetal growth. Period of overland flow is affected by the general land slope. On large watershed, the time involved in overland flow is small in comparison with the time of flow in the stream channel. However, on smaller areas, the overland flow is predominant and has a dominant effect on the time relationships and the peak of the hydrograph. With increasing land slope, the time elements of the hydrograph decrease.

(*vi*) *Orientation* : Orientation of a catchment is general direction of the catchment slope. The flood hydrographs of the catchment are affected by the catchment orientation with respect to the directions of storm movement, prevailing winds and the sun's position.

(c) Other factors

(i) Catchment storage

(i i) Pondage of artificial reservoirs

(iii) Cultivation

(iv) Forests influence

(v) Geological factors

(*i*) *Catchment storage* : The shape of the hydrograph at catchment outlet depends upon the catchment capacity to absorb and detain the water which falls over it as a rain or snowmelt. Infiltration capacity of the catchment is the maximum rate at which a soil in any given condition is capable of absorbing water.

(*ii*) *Pondage or artificial reservoirs* : Lakes. reservoirs, swamps etc. are able to reduce the flood peak and increase the time to peak due to pondage action. There is a substantial increase in water loss due to evaporation from the lakes and reservoirs surface.

(*iii*) *Cultivation* : Due to cultivation the percolation, transpiration and interception losses are more as a result the surface runoff tends to decrease.

(*iv*) *Forest influence :* It has been recognised for some time that ihe forest cover influences a number of components in the hydrologic cycle. These components include direct interception of a part of precipitation by vegetation, reduction of evaporation from soil, increase of infiltration by opening up soil channels through development of roots, depletion of soil moisture by evapotranspiration, trapping and shading of snow pack, binding the soil against erosion, factors affecting the hydraulic characteristics of overland flow, and so forth. However, with a saturated soil an intense rainfall of several days duration and many mm depths will cause a large part of the precipitation to be runoff over the surface into streams irrespective of the ground cover. Though for small catchment and short storms, thick vegetation may be able to retard the surface runoff to some extent. But for large catchment and storms of longer duration, there may not be significant influence of forest cover on flood hydrograph.

(*v*) *Geological factors* : The geological factors which affect the shape of the runoff hydrograph are primarily those which govern the flow of ground water and interflow to a stream. For exampla, an impervious formation close to the surface would affect the amount of interflow, hence the resulting runoff hydrograph.

5.3 BASEFLOW

As could be seen from the flow chart at Fig. 5.1 and the hydrograph at Fig. 5 2 the total runoff not only comprises the overland flow due to instantaneous runoff but also delayed flow contribution from sub-surface and ground water-flow.

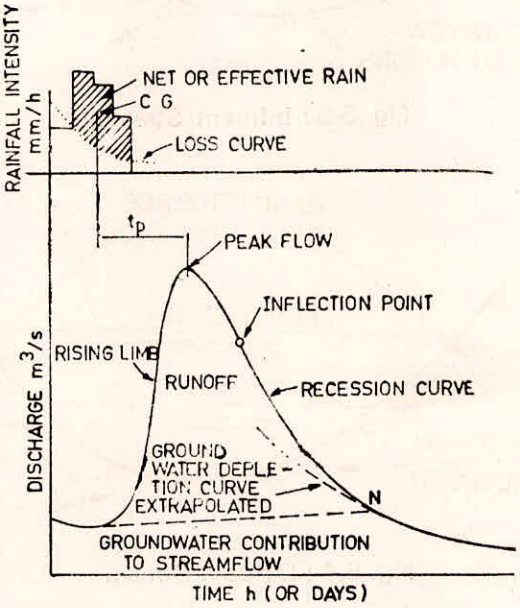


Fig. 5.2 : Component Parts of a Natural Hydrograph

The *'base flow'* or *'base runoff'* is defined as the sustained or fair weather runoff. Since baseflow represents the discharge of aquifers, changes occur slowly and there is a lag between cause and effect which may extend to periods of days or weeks. The amount of baseflow increases after a recharge of ground water storage and it gradually diminishes during periods of no recharge. Fluctuation of baseflow contribution to a stream mainly depends on fluctuation of water level in the stream during and after a storm. Thus, contribution of base flow to the stream runoff depends on the condition of the stream whether it is influent or effluent.

A broad distinction shall be made between an influent and effuent stream. An *'influent stream'* is one where the baseflow is negative, i.e. the stream feeds the groundwater instead of receiving from it as in Fig. 5 3

An *'Effluent Stream'* on the other hand is fed by the ground water (Fig. 5.4) and acts as a drain for borderieg aquifers.

An *'Intermittent streams'* are those which act as both influent and effluent streams either at different reaches or at the same location. During flood, river stage rises more rapidly than the ground water level, under such conditions stream becomes influent and water percolates from stream into the banks. During recession water level of stream may go below the water table and

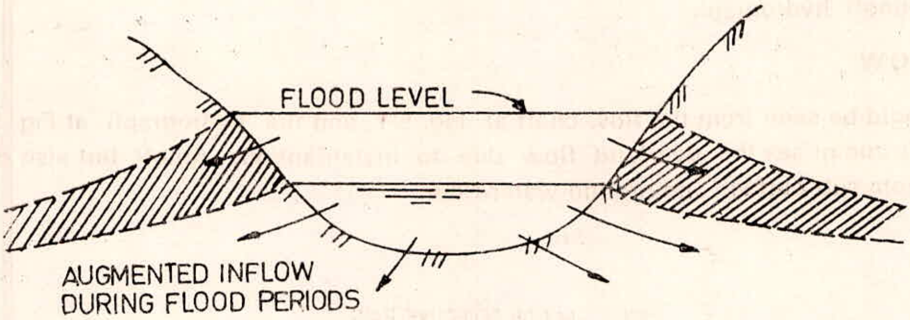


Fig. 5.3 : Influent Stream

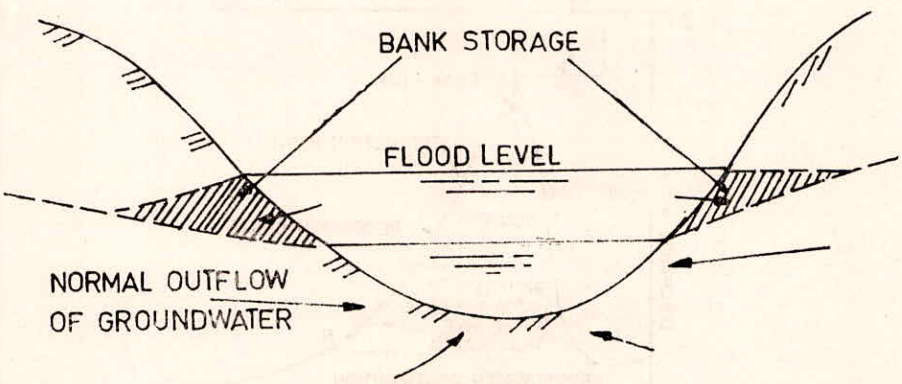


Fig. 5.4 : Effluent Stream

the stream will become effluent. This is shown in Fig. 5.5 when an influent stream during high flood becomes effluent after the flood a bank storage is created on both sides as shown in Fig. 5.6

In many natural rivers, depending on bank permeability and the slope of the phreatic surface the variation in baseflow will be less than indicated in Fig. 5.7 and will only cause a slight dip from the extrapolation of the depletion curves followed by a gradual rise to a higher than initial value as indicated in Fig. 5 8

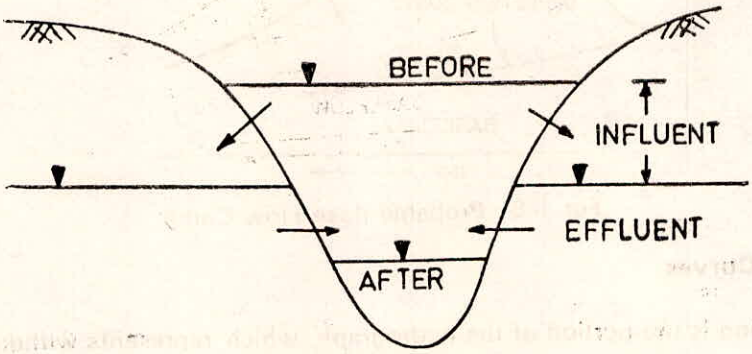


Fig. 5.5

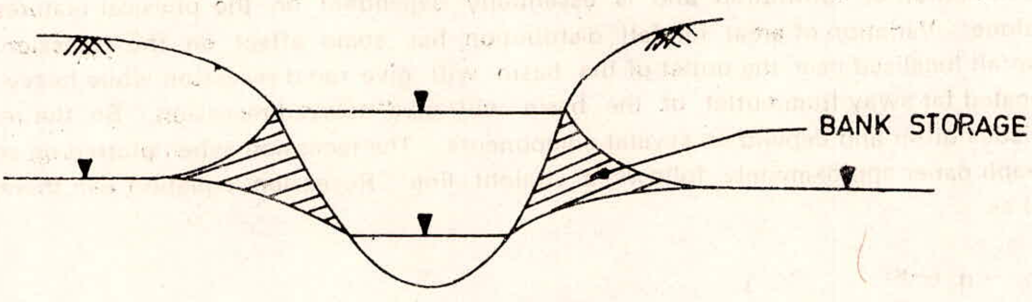


Fig. 6.6

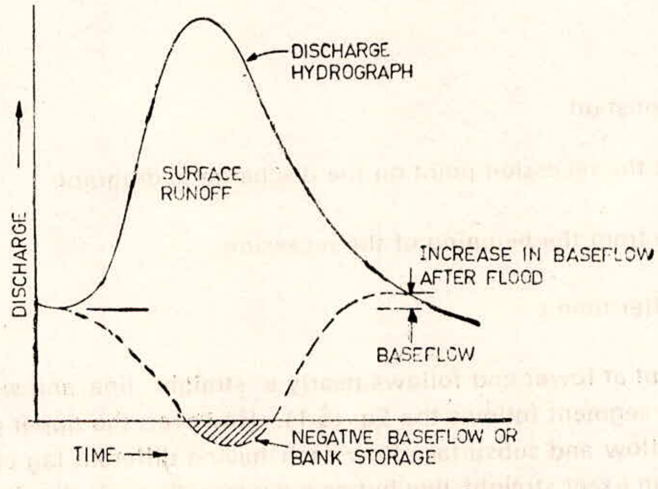


Fig. 5.7 : Negative Baseflow

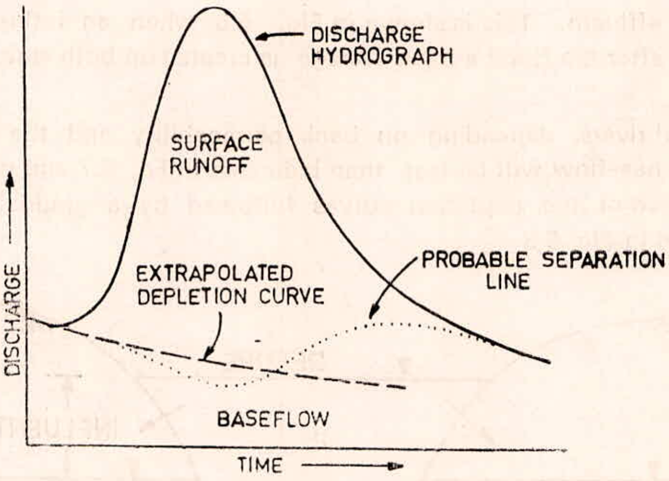


Fig. 5.8 : Probable Base Flow Curve

5.3.1 Recession Curves

The recession is the portion of the hydrograph which represents withdrawal of water from storage after all inflow to the channel has ceased (Fig 5.2). Recession is independent of time variations in rainfall or infiltration and is essentially dependent on the physical features of the channel alone. Variation of areal rainfall distribution has some effect on the recession shape. Heavy rainfall localised near the outlet of the basin will give rapid recession while heavy rainfall mainly located far away from outlet of the basin will give delayed recession. So, the recession characteristics differ and depend on several components. The recession when plotted on semilogrithmic graph paper approximately follows a straight line. Recession equation can therefore be expressed as

$$q_t = q_o e^{-Kt} \quad \text{or} \quad \log q_t = \log q_o - kt \qquad (5.1)$$

where

k = Recession constant

q_o = Discharge at the recession point on the discharge hydrograph

t = elapsed time from the begining of the recession

q_t = Discharge after time t

Recession segment at lower end follows nearly a straight line and signifies ground water recession. This recession segment follows the Eq. (5.1). However, the upper part of the recession segment contains surface flow and subsurface flow each having different lag characteristics, therefore, it does not show as an exact straight line but as a curve with gradually decreasing slope.

5.3.2 Normal Recession Curve

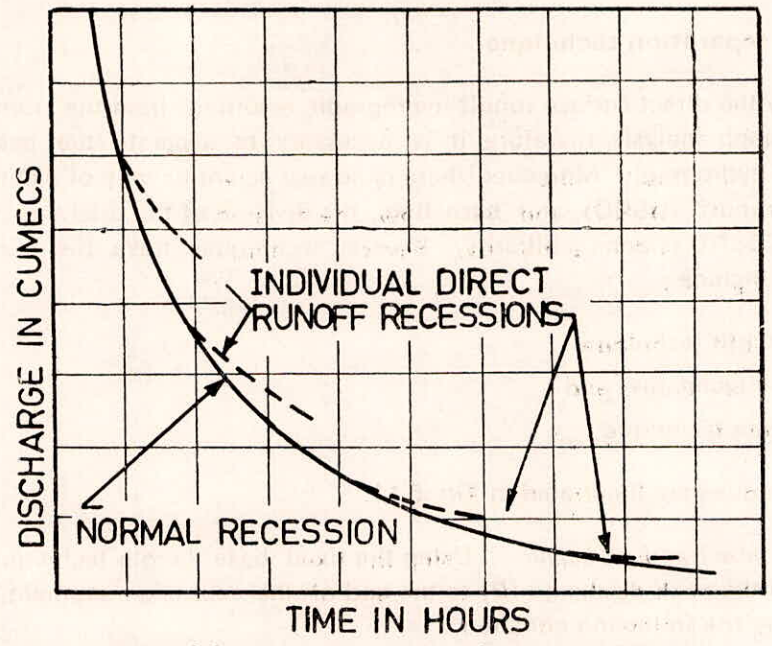
In hydrograph analysis the observed hydrographs are usually corrected to eliminate runoff from rainfall falling prior to or after the main rain event. A normal direct runoff recession curve is generally used for this purpose. Normal direct runoff recession curve is generally known as normal recession curve. Such curve can also be used to separate hydrograph of single rainfall event from complex hydrograph developed due to two or more distinct periods of intense rainfall at close interval of time.

Normal recession curve of a basin is drawn from number of hydrographs of isolated single rainfall event by fitting together recession segments of a number of hydrographs of direct runoff so that the various segments coincide in their upper part. Segments of several hydrographs may be required to cover a desired range of flow.

A smooth curve is drawn joining the individual direct runoff recession of various storms as shown in the Fig. 5.9 which gives normal recession curve.

5.3.3 Master Base Flow Recession Curve

The lower most portion of the recession limb of a hydrograph represents contribution as base flow from underground storage. Master base flow recession curve of a base flow recession from several floods until a curve covering the necessary range in discharge is complete, This is shown in Fig. 5.10



CONSTRUCTION OF NORMAL DIRECT RUNOFF RECESSION CURVE

Fig. 5.9

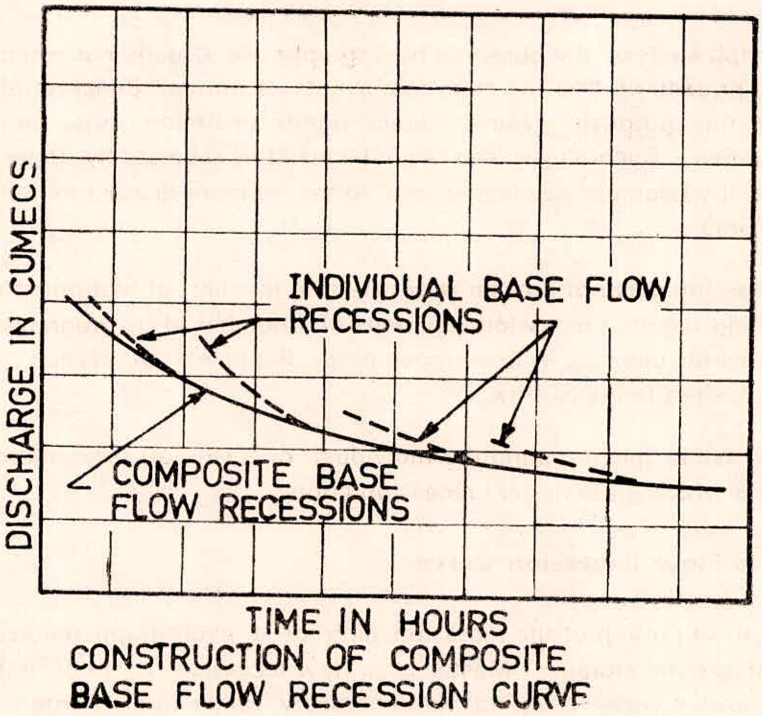


Fig. 5.10

5.3.4 Base flow separation technique

Since only the direct surface runoff hydrograph resulting from the storm event is required for the unit hydrograph analysis, therefore it is necessary to separate the base flow component from the discharge hydrograph. Moreover, there is no real scientific way of distinguishing between the direct surface runoff (DSRO) and base flow, the division of the total streamflow hydrograph into base flow and DSRO is done arbitrarily. Several techniques have been evolved to separate base flow. These include :

(i) Fixed base length technique
(i i) A straight line technique, and
(iii) A variable slope technique

Each techniques are illustrated in Fig. 5.11.

(*i*) *Fixed base length technique :* Using the fixed base length technique the time interval from a point below the peak discharge (B) to the end of the recession segment of the hydrograph (C) is determined by the following equation :

$$N = A^{0.2} \qquad (5.2)$$

where

A = area of watershed in square miles

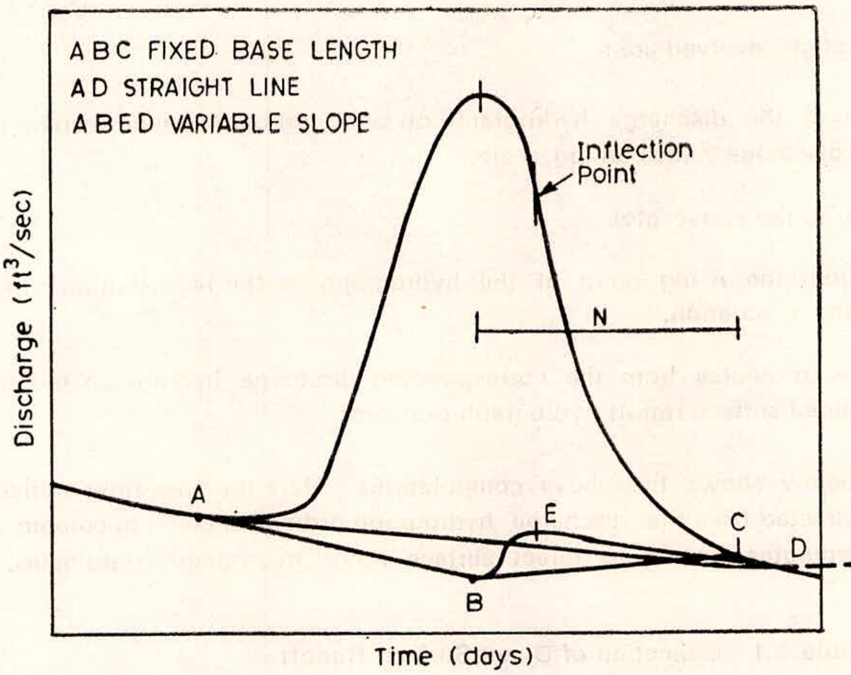


Fig. 5.11 : Base Flow Separation Techniques

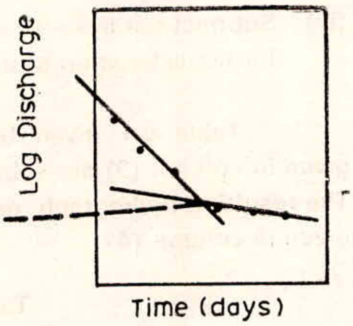


Fig. 5.12 Determination of Recession Point

A line is drawn connecting point C and point B which was found by extending the line defining the groundwater flow prior the beginning of the direct runoff.

(*iii*) *Straight line technique* : The eassier base flow separation techniques is to connect the points indicating the beginning (A) and the ending (D) of direct runoff with a straight line. Point D is generally determined as the point of separation of groundwater flow and the recession segment of the hydrograph from the semilog plot of discharge versus time (Fig. 5.12),

Example 5.1 given below illustrates the separation of baseflow by straight line technique from the discharge hydrograph of a typical storm of a catchment.

Example 5.1. The ordinates of discharge hydrograph for a typical storm of e catchment are given below :

Time (hrs)	0	6	12	18	24	30	36	42
Discharge (m³/s)	10	30	87.5	111.5	102.5	85	71	59
Time (hrs)	48	54	60	66	72	78	84	90
Discharge (m³/s)	47.5	39	31.5	26	21.5	17.5	15.0	12.5
Time (hrs)	96	192						
Discharge (m³/s)	12	12						

Find out the ordinates of direct surface runoff hydrograph using straight line technique for base flow separation.

Solution :

The computational steps involved are :

(i) Plot the recession limb of the discharge hydrograph on semi log graph paper keeping time on arithetic scale and discharge values on log scale.

(ii) Locate recession point on the above plot.

(iii) Draw straight line from the rising point of the hydrograph to the recession limb of the hydrograph for base flow separation.

(iv) Subtract the base flow ordinates from the corresponding discharge hydrograph ordinates for the estimation of direct surface runoff hydrograph ordinates.

Table 5.1 given below shows the above computations. Here the base flow ordinates. given in column (3) are subtracted from the discharge hydrograph ordinates, given in column (2). The resulting hydrograph ordinates known as direct surface runoff hydrograph coordinates, are given in column (4).

Table 5.1 Estimation of Direct Surface Runoff

Time (hrs) (1)	Discharge Hydrograph (m^3/s) (2)	Base flow (m^3/s) (3)	Direct surface Runoff (m^3/s) (4) = (2) — (3)
0	10	10	0
6	30	10	20
12	87.5	10.5	77
18	111.5	10.5	101
24	102.5	10.5	92
30	85.0	11	74
36	71.0	11	60
42	59.0	11	48
48	47.5	11.5	36
54	39.0	11.5	27,5
60	31.5	11.5	20.0
66	26.0	12	14.0
72	21.5	12	9.5
78	17.5	12	5.5
84	15.0	12.5	2.5
90	12.5	12.5	0
96	12.0	12.0	0
102	12.0	12.0	0

(iii) Variable slope technique : In this technique, the baseflow following the peak is extended back in time to the point directly below the recession inflection point on the hydrograph. This point (E) is connected to the extension of the baseflow preceeding the rising limb of the hydrograph to the time of peak discharge, (Point B). The variable slope precedure for separating the baseflow from direct surface runoff in many cases, more realistically reflects tha actual physical processes, however, the increased accuracy in separating baseflow from maximum runoff using this method is almost negligible when compared to the fixed base length or straight line approach.

5.4 SEPARATION OF COMPLEX HYDROGRAPH

The discussion so far has been restricted to only analysis with simple hydrographs without considering effects of subsequent rainfall until after direct runoff had left the basin. Often, however, one might have to deal with hydrographs of the form shown in Fig. 5.13. In these cases, it becomes necessary to separate the runoff caused by individual bursts in a rainfall event by projecting the small segment of recession between peaks in a complex hydrograph along line A B as in Fig. 5.13. Base flow is then seperated as in the above case.

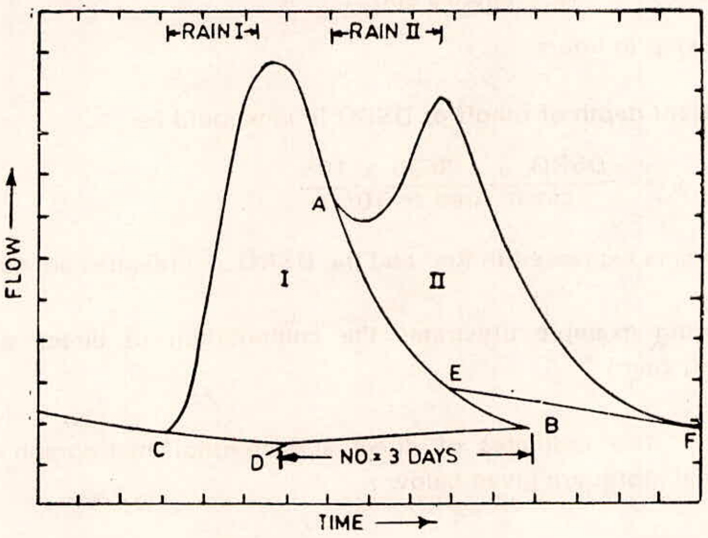


Fig. 5.13 : Seperation of complex Hydrograph Using Recession Curve

5.5 COMPUTATION OF DSRO VOLUME AND EQUIVALENT RUNOFF DEPTH

After separation of the baseflow from the total runoff, the remainder is the Direct Surface runoff (DSRO) which is supposed to be the resultant of the effective rainfall after all losses are accounted for from the rainfall over the catchment. For the purpose of estimating loss rate parameters it would be necessary to compute the volume of DSRO and express it in depth units so as to facilitate comparison with the rainfall for the determination of the loss parameters.

Though method like planimetering and counting of Squares or Solomon's method could be used fot estimating the volume of DSRO, a simple method is described below for estimating total volume of direct runoff and finding its equivalent depth.

For first time step, the beginning and end segments of a DSRO graph could be assumed to approximate to triangles and the remaining sections as trapezoids.

The cumulative volume of DSRO could therefore be considered as :

$$DSRO_{vol} = \frac{DSRO_1 \times \triangle t}{2} + \frac{DSRO_1 + DSRO_2}{2} \times \triangle t + \dots\dots\dots\dots$$

$$\frac{DSRO_{n-1} + DSRO_n}{2} \triangle t + \frac{DSRO_n \triangle t}{2} \qquad (5.3)$$

which could be written as

$$DSRO_{vol} = \triangle t \sum_{i=1}^{n} DSRO_i \qquad (5.4)$$

where

n is number of DSRO ordinates and

$\triangle t$ is time step in hours.

The equivalent depth of runoff of DSRO in mm could be

$$DSRO_{depth} = \frac{DSRO_{vol} \times 3630 \times 10^3}{\text{catch. Area} \times 10^6} \qquad (5.5)$$

where catchment area is expressed in Km^2 and the $DSRO_{vol}$ ordinates are cumec-hour.

The following example illustrates the computation of direct surface runoff volume in equivalent depth unit (mm).

Example 5 2. The ordinates of direct surface runoff hydrograph resulted at a catchment outlet due to a typical storm are given below :

Time from start (hr)	0	6	12	18	24	30	36
Direct Surface Runoff (m^3/s)	0	8	21	16	11	7	4
Time from start (hr)	42	48					
Direct Surface Runoff (m^3/s)	2	0					

If the catchment area is 27 Km^2, find out the direct surface runoff in the depth unit (mm)

Solution :

(i) Compute $DSRO_{vol}$ in cumec — hour as :

$$DSRO_{vol} = \triangle t \sum_{i=1}^{n} DSRO_i$$

For the above example, $\Delta t = 6$ hours, $n = 9$

$$DSRO_{vol} = 6\ (0 + 8 + 21 + 16 + 11 + 7 + 4 + 2 + 0)$$

$$= 414 \text{ cumec hour.}$$

(ii) Compute $DSRO_{depth}$ in mm as

$$DSRO_{depth} = \frac{DSRO_{vol} \times 3600 \times 10^{3}}{\text{Catch Area} \times 10^{6}}$$

$$= \frac{414 \times 3600 \times 10^{6}}{27 \times 10^{8}}$$

$$= 55.2 \text{ mm}$$

Therefore the required DSRO volume expressed in depth unit will be 55.2 mm for the above example.

5.6 HYDROLOGIC ABSTRACTIONS

When the rain falls over the catchment, not all the rain contribute to the runoff at the catchment outlet. A part of it is lost and the remainder of the rainfall, termed as excess rainfall, is the driving force causing runoff hydrographs. A good understanding of these factors that preclude rainfall from running off is necessary from point of view of engineering hydrology in order to fully use the capabilities of hydrographs. These include interception, depression storage, infiltration, evaporation and evapotranspiration etc. Since the portion of the precipitation involved in these processes are not available for surface runoff, these process represents, the hydrologic abstractions. Although a portion of infiltrated water may join the ground water which may contribute later to the stream as base flow.

Much of the rain falling during the first part of a storm is stored on the vegetal cover as interception and in surface depressions (puddles) as depression storage. As rain continues, the soil surface is covered with water and runoff starts towards the channel. Thus, that part of the storm rainfall which does not appear either as infiltration or as surface runoff is known as surface retention.

Interception due to vegetal cover is relatively unimportant in moderate to severe floods though it may be considerable over a period of time.

Almost immediately after the beginning of rainfall excess, the smallest depression become filled and overland flow begins. While some of the flow fills up larger depressions, the larger portions of overland flow contribute to the streams.

Infiltration is the phenomenon of water penetration from the surface of the ground to the sub-surface layers. By far, infiltration is the factor responsible for greater portion of the losses from rainfall which does not appear as runoff in the stream immediately. Rain will infiltrate unit it exceeds the infiltration capacity of the soil.

For a given soil the infiltration capacity will vary depending upon whether the soil was initially dry when rainfall started or already wet from a previous rain. Depending on the condition of the soil, the streamflow resulting from a storm could be a moderate flow or a severe flood.

5.6.1 Computatian of Excess Rainfall

Although number of techniques for separating the losses from rainfall hyetograph are available, but the ϕ-index method is one of the simple and most commonly used technique available for this purpose. It involves a trial and error procedure which does not differentiate between type of losses e.g. interception, depression, infiltration. Since other losses than infiltration for heavy storms are small, the ϕ-index must be interpreted for all practical purposes as a constant infiltration capacity method. It is a well known fact that the infiltration capacity decreases with time. Therefore, the ϕ-index method is not that realistic. It under estimates the infiltration early in time and over estimates it later. In addition, one does not know how to extrapolate the ϕ-value determined for a storm to different storm. Inspite of so many draw backs and limitations, this method is very much used for computing the excess rainfall hyetograph.

The ϕ-index or constant loss rate is defined as the rate of rainfall above which the rainfall volume equals the runoff volume (Fig. 5.14). Mathematically, the ϕ-index can be expressed as :

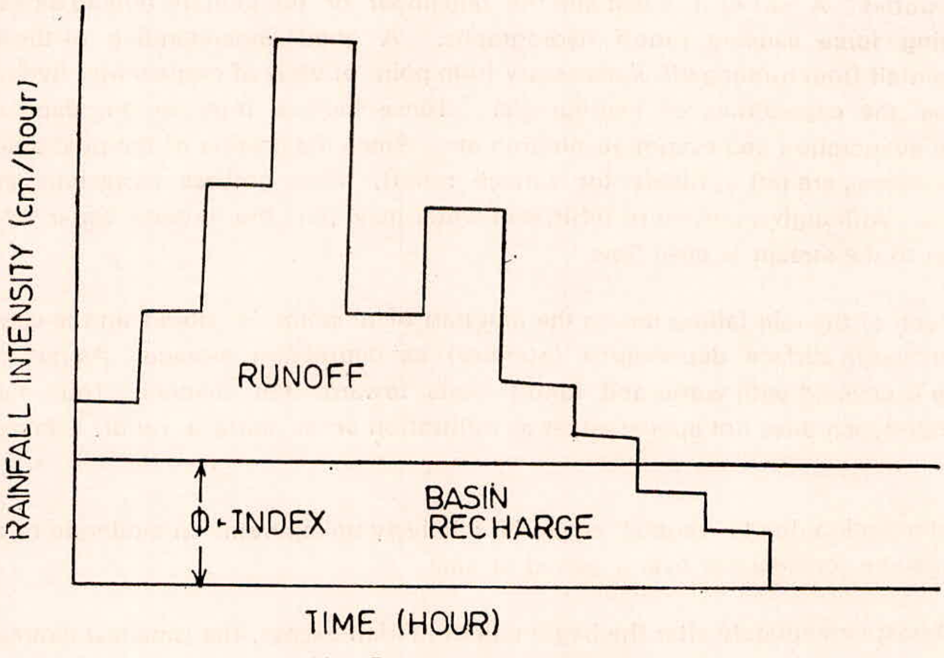


Fig. 5.14 : Index method

$$\phi = \frac{P-R}{t_e} \qquad (5\ 6)$$

where

P = total storm precipitation (mm or cm)

R = total direct surface runoff (mm or cm)

t_e = duration of the excess rainfall i.e. the total time in which the total intensity is greater than ϕ (in hours) and

ϕ = uniform rate of infiltration (mm/h or cm/h)

If antecedent condition of the catchment is such that the other losses due to intetception, depression and evaporation etc. are considerable in the beginging of the storm, then those losses are subtracted from the rainfall occurred in the begining periods of the storm, before applying the uniform loss rate method (ϕ-index) for computing the excess rainfall.

The derivation of ϕ-index is simple, and the approach is described here with the help of an example.

Example 5.3

A storm with 10 cm precipitation produced a direct surface runoff of 5.8 cm equivalent in depth unit. The time distribution of the storm is given below. Estimate the ϕ index of the storm and excess rainfall hyetograph

Time from start (hrs)	1	2	3	4	5	6	7	8
Incremental Rainfall in each hour (cm)	0.4	0.9	1.5	2.3	1.8	1.6	1.0	0.5

Solution :

(i) Compute total infiltration i.e.

Total infiltration = Total rainfall — Direct surface runoff

$$= 10 - 5.8$$

$$= 4.2 \text{ cm.}$$

(ii) Assume time of rainfall excess (t_e) equal to the total duration of the storm for the first trial i.e.

$$t_e = 8 \text{ hour}$$

(iii) Compute the first trial value of ϕ as

$$\phi = \frac{P - R}{t_e} = \frac{4.2}{8}$$

$$= 0.525 \text{ cm/hour}$$

(iv) Compare the above value of ϕ with individual blocks of rainfall. This value of ϕ makes the rainfall of the first hour and eighths hour in-effective as their magnitudes are less than 0.525 cm/hr. The value of time of rainfall excess (t_e) is therefore modified.

(v) Assume $t_e = 6$ hour in the second trial and modified value of total rainfall for 6 hour duration will be 10-0.4-0.5 = 9.1 cm.

(vi) Compute modified value of infiltration i.e.

$$\text{Infiltration} = 9.1 - 5.8$$

$$= 3.3 \text{ cm.}$$

(vii) Compute second trial value of ϕ i.e.

$$\phi = \frac{3.3}{6} = 0.55 \text{ cm/hour}$$

This value of ϕ is satisfactory as it gives

$t_e = 6$ hour

(viii) Calculate the rainfall excess subtracting the uniform loss from each block. The excess rainfall hyetograph is given below:

Time from start (hour)	1	2	3	4	5	6	7	8
Rainfall excess (cm)	0	0.35	0.95	1.75	1.25	1.05	0.45	0

Note that the total rainfall excess = 5.8 cm.
= Direct surface runoff (cm)

5.7 SUMMARY

(i) Proper understanding of the rainfall runoff process is prerequisite for developing the deterministic hydrologic models.

(ii) While developing the regional relationships for runoff computation, it is always advantageous to have the knowledge about the factors affecting the runoff. Such regional relationships are used for the estimation of runoff for ungauged catchments in the region. Further more, various factors affecting the runoff should always be considered for deciding the form of rainfall-runoff relationships.

(iii) For unit hydrograph studies the direct surface runoff and excess rainfall are required. The direct surface runoff hydrograph may be obtained after separating the base flow from discharge hydrograph using the techniques already described in the lecture. On the other hand, the excess rainfall hyetograph is computed after accounting the losses from rainfall using the uniform loss rate procedure.

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