Module 2

The Science of Surface and Ground Water

Lesson 2

Runoff and Infiltration

Instructional Objectives

At the end of this lesson, the student shall be able to learn:

1. The importance of runoff and infiltration in the hydrologic cycle.
2. What is the difference between overland flow, interflow and base flow components contributing to stream flow generation.
3. What are hydrograph and hyetographs.
4. Methods to separate infiltration from rainfall hyetographs effective rainfall.
5. Methods to separate base flow from stream hydrograph to find out the Direct Runoff Hydrograph.

2.2.0 Introduction

The amount of precipitation flowing over the land surface and the evapotranspiration losses from land and water bodies were discussed in Lesson 2.1. This water ultimately is returned to the sea through various routes either overland or below ground. Evaporation from the ocean, which is actually a large water body, contributes to the bulk of water vapour to the atmosphere, driven by the energy of the sun. This process completes the ***hydrologic cycle*** (Figure 1), which keeps the water content of the Earth in a continuous dynamic state.

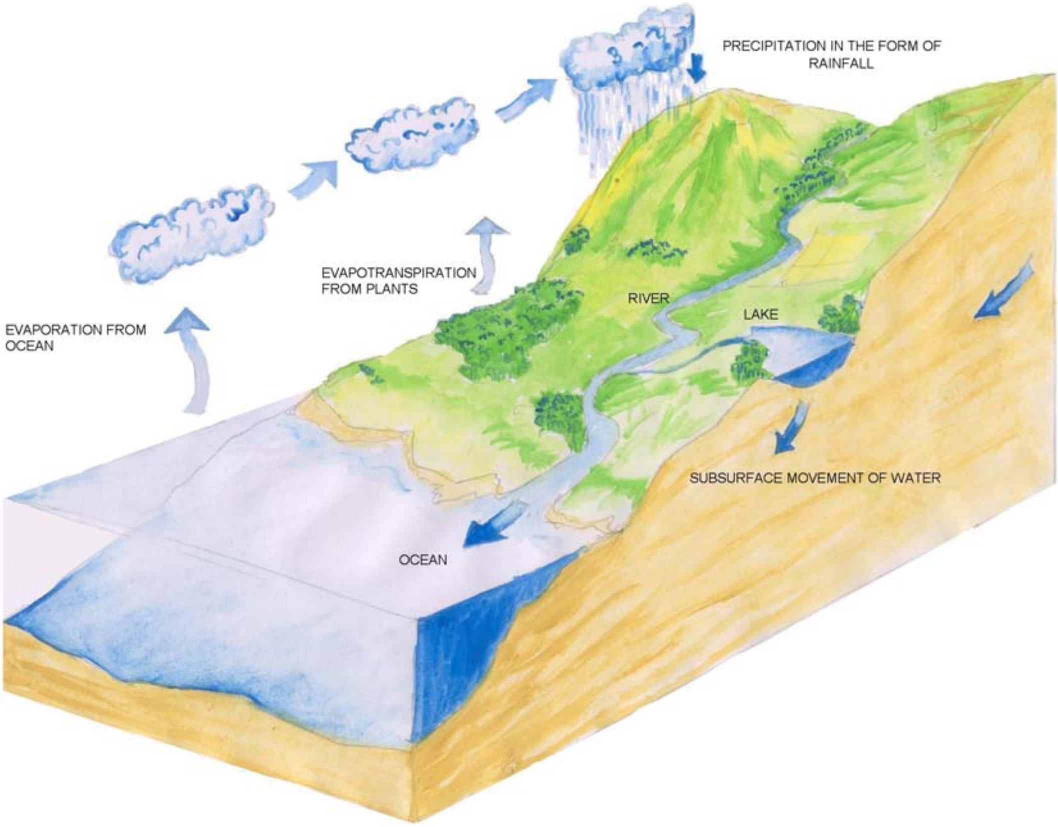

FIGURE 1. HYDROLOGIC CYCLE

In this lesson, we would study the fate of the raindrops as they fall on the earth and flow down the land surface to meet streams and rivers. Part of the water, as it flows down the land surface, infiltrates into the soil and ultimately contributes to the ground water reserve.

2.2.1 Overland flow and inter flow

During a precipitation event, some of the rainfall is intercepted by vegetation before it reaches the ground and this phenomenon is known as ***interception***. At places without any vegetation, the rain directly touches the land surface. This water can infiltrate into the soils, form puddles called the ***depression storage***, or flow as a thin sheet of water across the land surface. The water trapped in puddles ultimately evaporates or infiltrates. If the soil is initially quite dry, then most of the water infiltrates into the ground. The amount of rainfall in excess of the infiltrated quantity flows over the ground surface following the land slope. This is the ***overland flow***. The portion that infiltrates moves through an unsaturated portion of the soil in a vertical direction for some depth till it meets the water table, which is the free surface of a fully saturated region with water (the ground water reserve). Part of the water in the ***unsaturated zone*** of the soil (also called the ***vadose zone***) moves in a lateral direction, especially if the ***hydraulic conductivity*** in the horizontal direction is more than that in vertical direction and emerges at the soil surface at some location away from the point of entry into the soil. This phenomenon is known as ***interflow***. Figure 2 illustrates the flow components schematically.

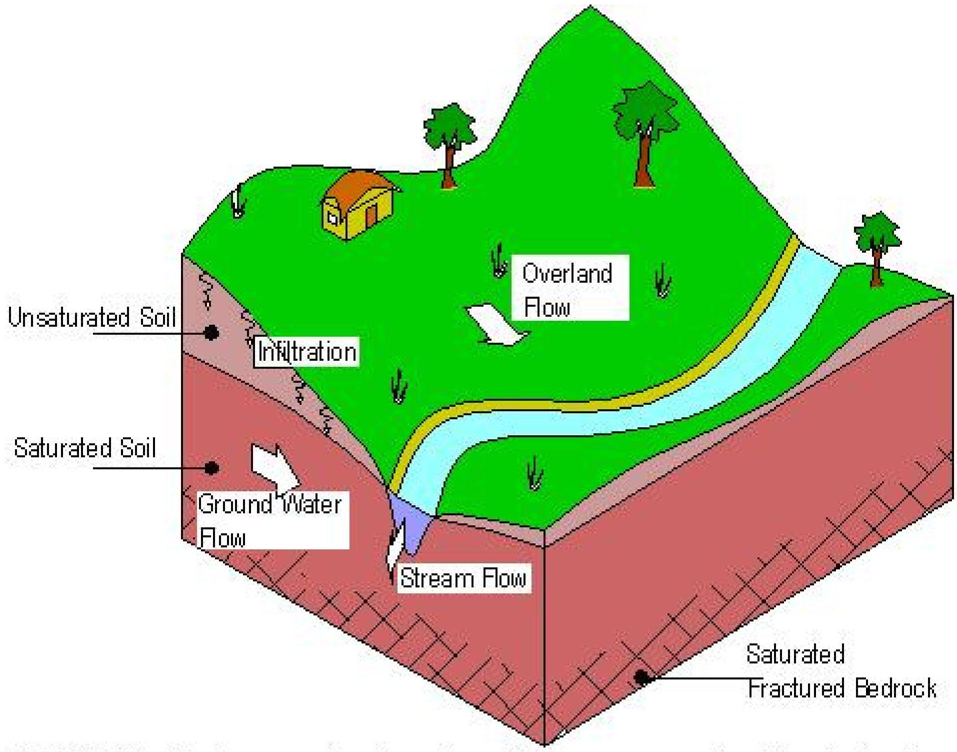

FIGURE 1. Surface and sub-surface flow components of hydrologic cycle

Please note the meaning of the term ***Hydraulic conductivity:***

Hydraulic conductivity is a measure of the ability of a fluid to flow through a porous medium and is determined by the size and shape of the pore spaces in the medium and their degree of interconnection and also by the viscosity of the fluid. Hydraulic conductivity can be expressed as the volume of fluid that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

2.2.2 Stream flow and groundwater flow

If the unsaturated zone of the soil is uniformly permeable, most of the infiltrated water percolates vertically. Infiltrated water that reaches the ground water reserve raises the water table. This creates a difference in potential and the inclination of the water table defines the variation of the ***piezometric head*** in horizontal direction. This difference in energy drives the ground water from the higher to the lower head and some of it ultimately reaches the stream flowing through the valley. This contribution of the stream flow is known as Base flow, which usually is the source of dry-weather flow in perennial streams.

During a storm event, the overland flow contributes most of the immediate flow of the stream. The total flow of the stream, however, is the sum of overland flow, interflow and ***base flow***. It must be remembered that the rates at which these three components of runoff move varies widely. Stream flow moves fastest, followed by interflow and then ground water flow, which may take months and sometimes even years to reach the stream.

Note that for some streams, the water table lies quite some distance below the bottom of the stream. For these streams, there is a loss of water from the river bed percolating into the ground ultimately reaching the water table. The reason for a low water table could possibly be due to natural geographic conditions, or a dry climate, or due to heavy pumping of water in a nearby area.

2.2.3 The hydrograph and hyetograph

As the name implies, Hydrograph is the plot of the stream flow at a particular location as a function of time. Although the flow comprises of the contributions from overland flow, interflow and groundwater flow, it is useful to separate only the groundwater flow (the base flow) for hydrograph analysis, which is discussed in Lesson 2.3.

In Lesson 2.1, precipitation was discussed. The hyetograph is the graphical plot of the rainfall plotted against time. Traditionally, the hyetograph is plotted upside down as shown in Figure 3, which also shows a typical hydrograph and its components. Splitting up of a complete stream flow hydrograph into its components requires the knowledge of the geology of the area and of the factors like surface slope, etc. Nevertheless, some of the simpler methods to separate base flow are described subsequently.

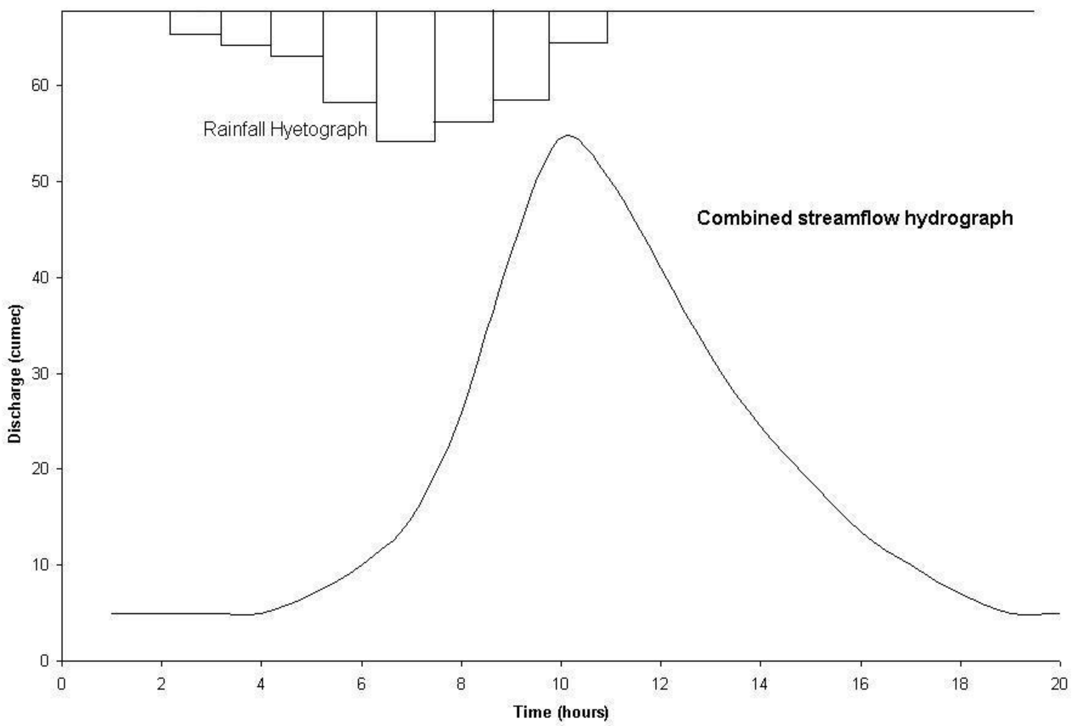

FIGURE 2. Rainfall hyetograph and corresponding flow hydrograph

The combined hydrograph can be split up into two parts: The base flow (Figure 4) and the overland flow added to interflow (Figure 5)

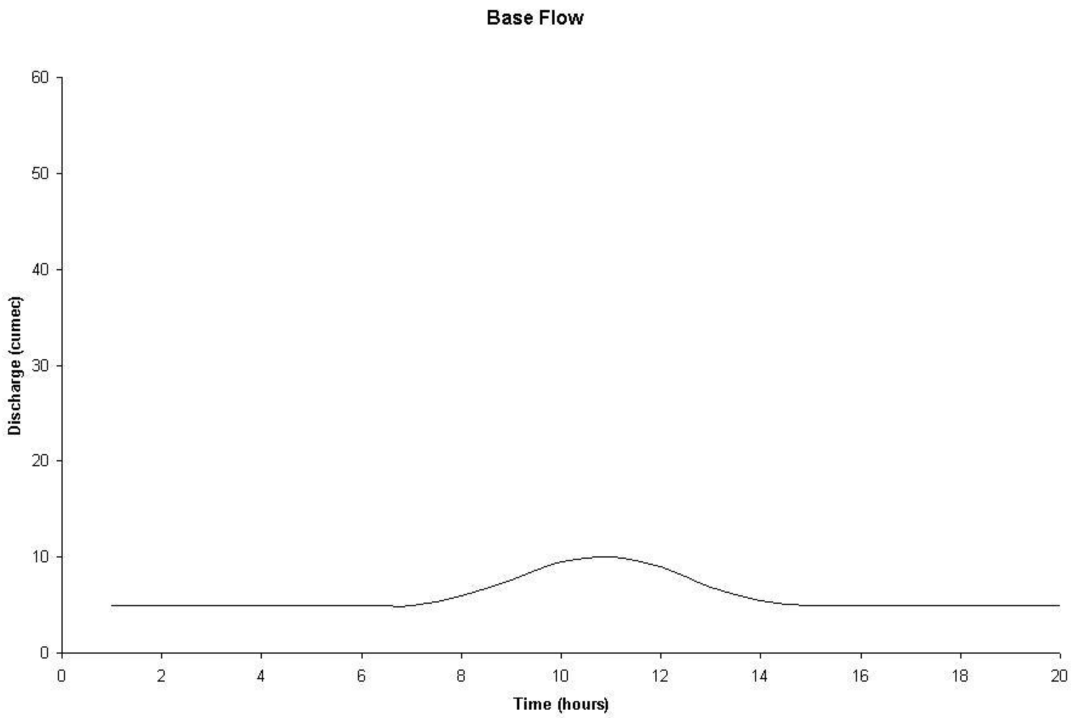

FIGURE 3. Typical baseflow discharge hydrograph

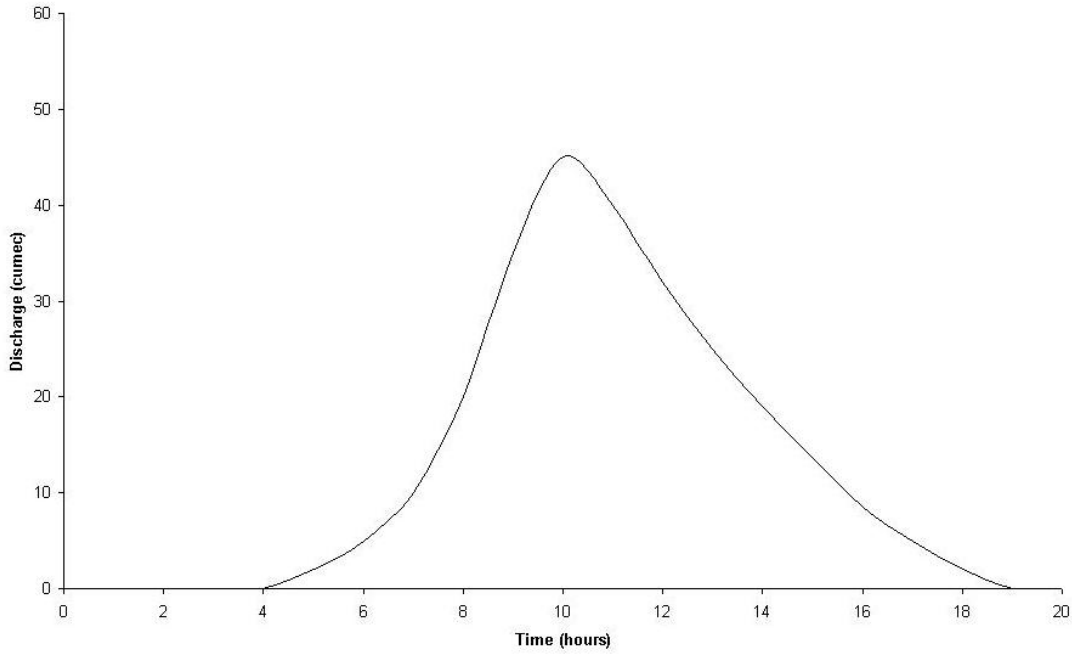

FIGURE 5. Overland flow and interlfow combined hydrogrph

2.2.4 Effective rainfall

A part of the rainfall reaching the earth's surface infiltrates into the ground and finally joins the ground water reservoirs or moves laterally as interflow. Of the interflow, only the quick response or prompt interflow contributes to the immediate rise of the stream flow hydrograph. Hence, the rainfall component causing perceptible change in the stream flow is only a portion of the total rainfall recorded over the catchment. This rainfall is called the effective rainfall.

The infiltration capacity varies from soil to soil and is also different for the same soil in its moist and dry states. If a soil is initially dry, the infiltration rate (or the infiltration capacity of the soil) is high. If the precipitation is lower than the infiltration capacity of the soil, there will be no overland flow, though interflow may still occur. As the rainfall persists, the soil become moist and infiltration rate decreases, causing the balance precipitation to produce surface runoff. Mathematical representation of the infiltration capacity and the methods to deduct infiltration for finding effective rainfall is described later in this lesson.

2.2.5 Methods of base flow separation

Consider the total runoff hydrograph shown in Figure 3, for which the corresponding effective rainfall hyetograph over the catchment is known. In this example, the flow in the stream starts rising at about 4 hours, and the peak is seen to reach at about 10.5 hours. The direct runoff is presumed to end at about 19.5 hours. Though we have separately shown the base flow and the direct runoff in Figures 4 and 5, it is only a guess, as what is observed flowing in the stream is the total discharge. A couple of procedures are explained in the following sub-sections to separate the two flows. For this, we consider another hydrograph (Figure 6), where the total flow is seen to be reducing initially, and then a sudden rise takes place, probably due to a sudden burst of rainfall.

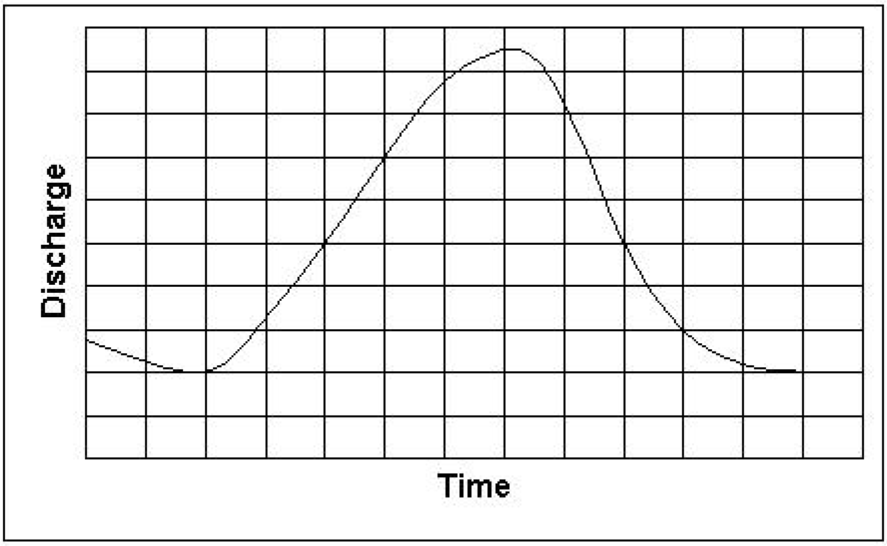

FIGURE 6. A typical hydrograph requiring base flow separation

Method 1

One method to separate the base flow from the total runoff hydrograph is to join points X and Z as shown in Figure 7. This method is considered not very accurate, though.

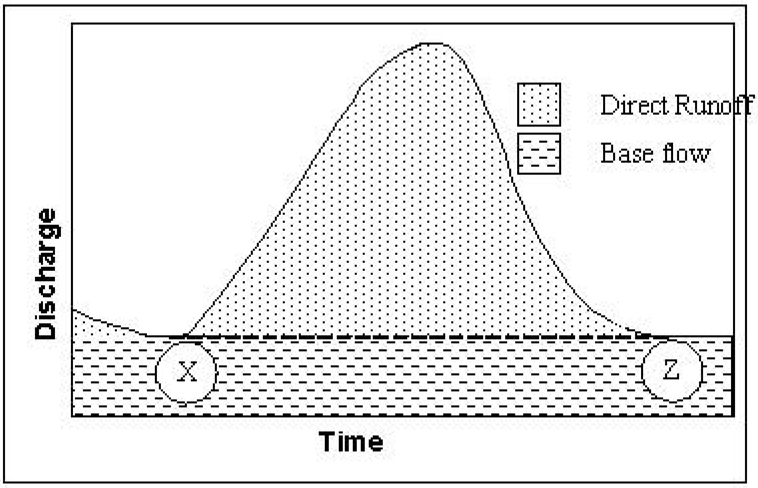

FIGURE 7. Method 1 to separate base flow

Method 2

This method suggests the extension of the base flow graph (Figure 8) along its general trend before the rise of the hydrograph up to a point P directly below the runoff hydrograph peak. From P, a straight line PQ is drawn to meet the hydrograph at point Q, which as separated from P in the time scale by an empirical relation given as:

$$N \text{ (in days)} = 0.862\, A^{0.2} \qquad (1)$$

Where, A is the area of the drainage basin in square kilometers.

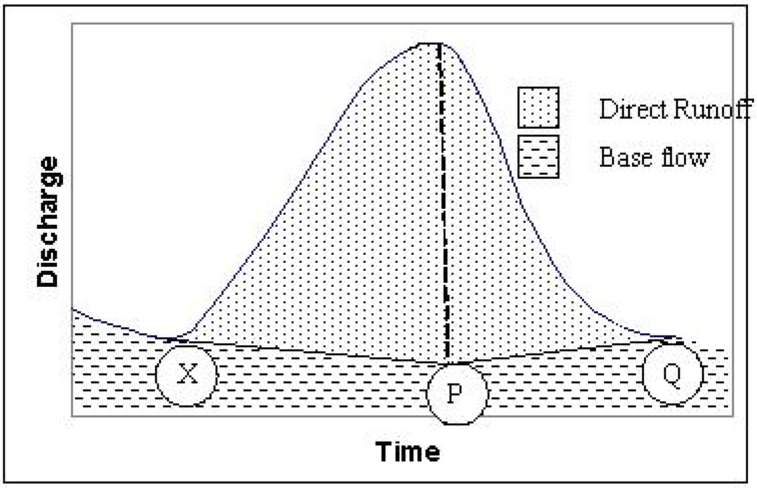

FIGURE 8. Method 2 to separate base flow

Method 3

The third method makes use of composite base flow recession curve, as shown in Figure 9. The following points are to be kept in mind:

X – A follows the trend of the initial base flow recession curve prior to the start of the direct runoff hydrograph
B – Q follows the trend of the later stage base flow recession curve.
B is chosen to lie below the point of inflection (C) of the hydrograph.

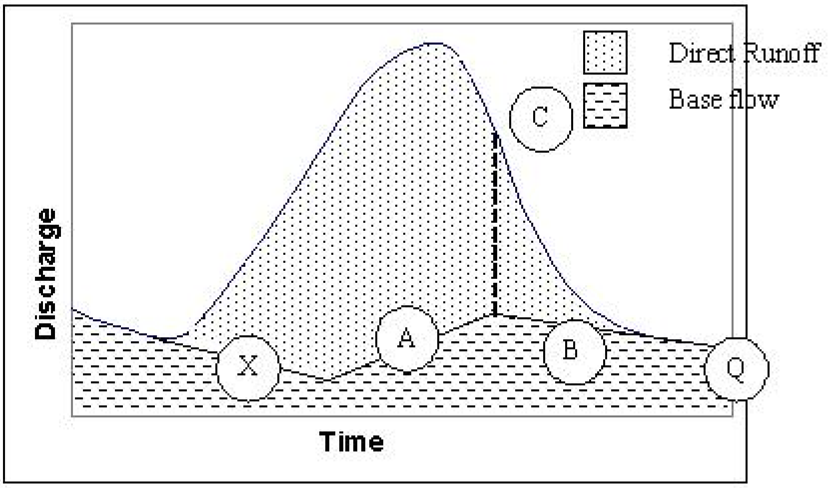

FIGURE 9. Method 3 for base flow separation

The hydrograph after separating and the base flow results in what is called the ***Direct Runoff Hydrograph***.

2.2.6 Estimation of infiltration

The rate at which water infiltrates into a ground is called the ***infiltration capacity.*** When a soil is dry, the infiltration rate is usually high compared to when the soil is moist. For an initially dry soil subjected to rain, the infiltration capacity curve shows an exponentially decaying trend as shown in Figure 10. The observed trend is due to the fact that when the soil is initially dry, the rate of infiltration is high but soon decreases, as most of the soil gets moist. The rate of infiltration reaches a uniform rate after some time.

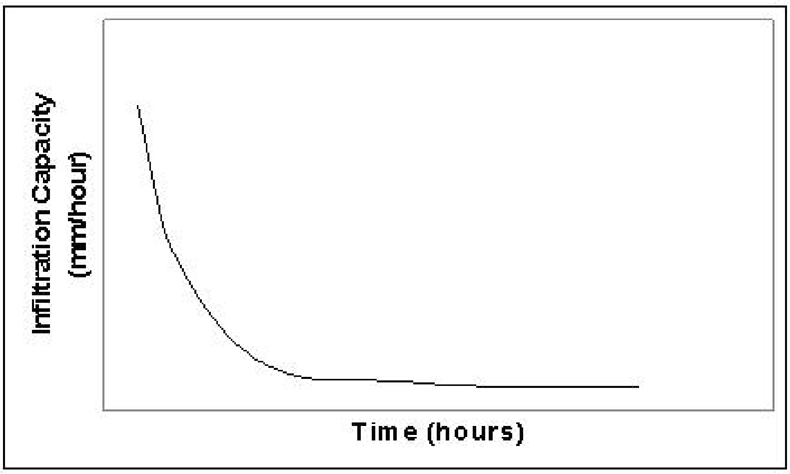

FIGURE 10. Infiltration rate decreasing as more water infiltrates

Interestingly, if the supply of continuous water from the surface is cutoff, then the infiltration capacity starts rising from the point of discontinuity as shown in below.

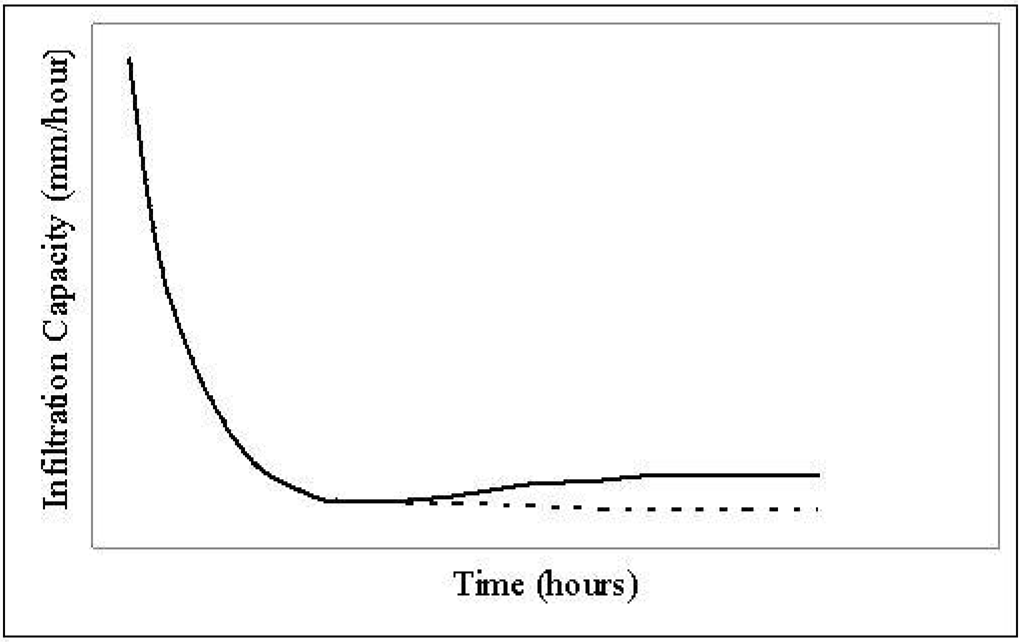

FIGURE 11. Infiltration capacity rising after supply from top is cut off

For consistency in hydrological calculations, a constant value of infiltration rate for the entire storm duration is adopted. The average infiltration rate is called the Infiltration Index and the two types of indices commonly used are explained in the next section.

2.2.7 Infiltration indices

The two commonly used infiltration indices are the following:

***ϕ* – index**

***W* – index**

2.2.7.1 The *ϕ* - index

This is defined as the rate of infiltration above which the rainfall volume equals runoff volume, as shown in Figure 12.

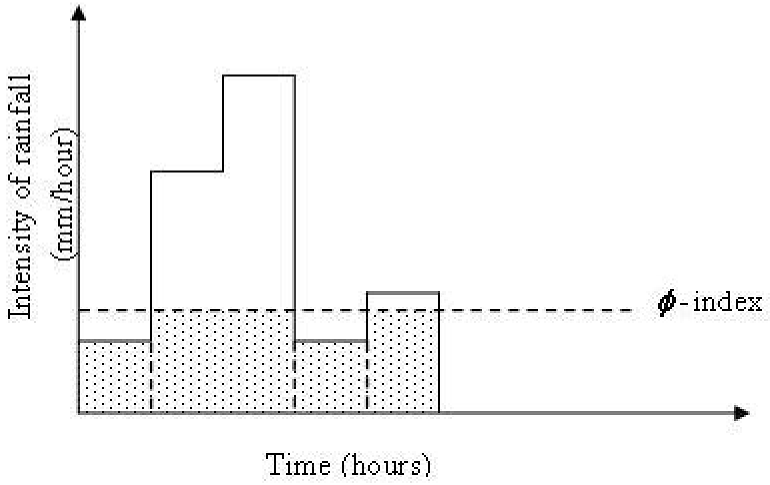

FIGURE 12. Illustrating the ϕ- index

The method to determine the - index would usually involve some trial. Since the infiltration capacity decreases with a prolonged storm, the use of an average loss rate in the form of - index is best suited for design storms occurring on wet soils in which case the loss rate reaches a final constant rate prior to or early in the storm. Although the - index is sometimes criticized as being too simple a measure for infiltration, the concept is quite meaningful in the study of storm runoff from large watersheds. The evaluation of the infiltration process is less precise for large watersheds. The data is never sufficient to derive an infiltration curve. Under the circumstances, the - index is the only feasible alternative to predict the infiltration from the storm.

2.2.7.2 The W – index

This is the average infiltration rate during the time when the rainfall intensity exceeds the infiltration rate.

Thus, ***W*** may be mathematically calculated by dividing the total infiltration (expressed as a depth of water) divided by the time during which the rainfall intensity exceeds the infiltration rate. Total infiltration may be fund out as under:

Total infiltration = Total precipitation – Surface runoff – Effective storm retention

The ***W*** – index can be derived from the observed rainfall and runoff data. It differs from the - index in that it excludes surface storage and retention. The index does not have any real physical significance when computed for a multiple complex watershed. Like the phi-index the - index, too is usually used for large watersheds.