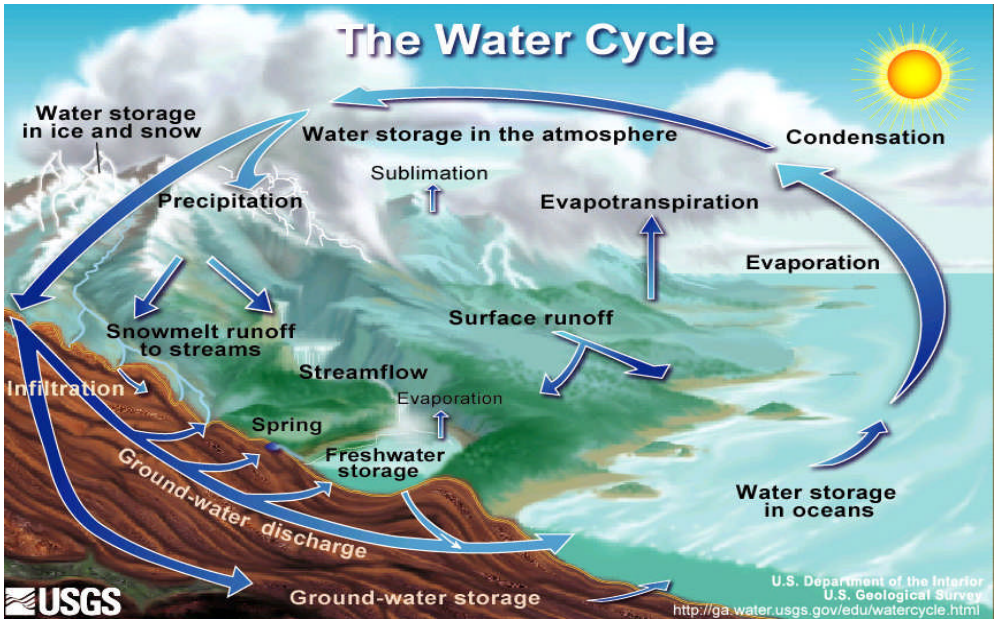
RUNOFF AND RUNOFF RELATIONS

INTRODUCTION:

The water reaching the surface of the earth in the form of **precipitation** reaches the stream ultimately. From the point where precipitation reached the earth surface, it may take different paths on its way to the stream. Some part of the water flows over the land surface and reaches the stream immediately after the precipitation. The other part of the precipitation infiltrates through the soil surface to reach the stream.



Water Cycle

Precipitation:

Precipitation is the general term for all forms of moisture emanating from the cloud and falling on the ground.



Hail



Rain



Snow



Sleet



Frozen Rain

Infiltration:

Infiltration is the process by which, water on the ground surface enters the unsaturated layer of soil.

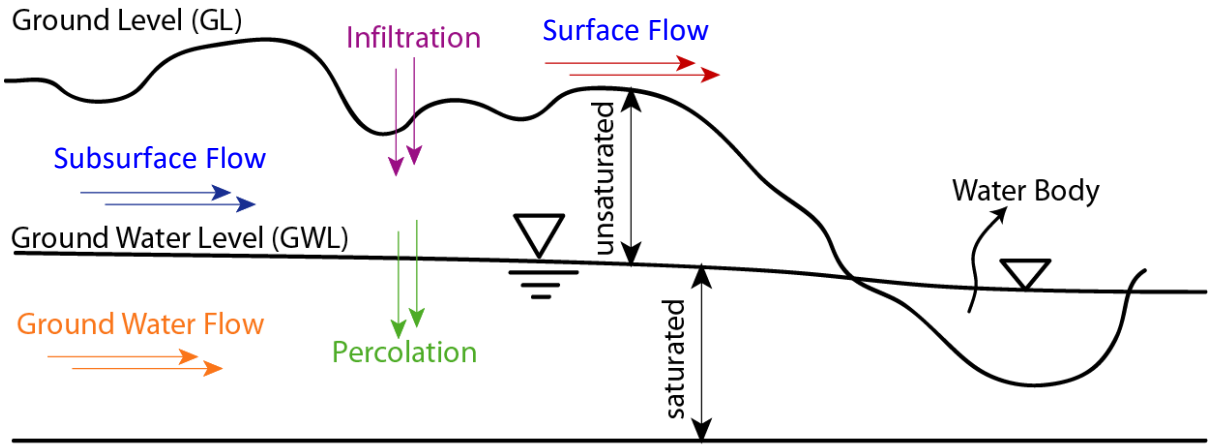
Percolation:

Percolation is the process by which, water moves downward from one layer of soil to another layer of soil.

Precipitation that reached the earth surface may take different paths on its way to the stream.

Note:

- **What is the difference between infiltration and percolation?**



Note:

- **Why the precipitation water has the tendency to reach a stream?**

  or

- **Why does water flow?**

Some part of the water flows over the land surface and reaches the stream immediately after the precipitation.

The other part of the precipitation infiltrates through the soil surface and flows through the soil to reach the stream.

COMPONENTS OF THE TOTAL FLOW:

Visualization of the three main routes of travel is very easy. These are:

1. Surface Flow or Overland Flow (in the direction of flow)
2. Subsurface Flow or Interflow
3. Ground Water Flow

Surface Flow:

It is the part of water which travels over the ground surface to the channel without infiltrating or percolating to the water table.

The term channel, as used here, indicates all sorts of depressions which is capable of holding water for a short period of time after the rainfall.

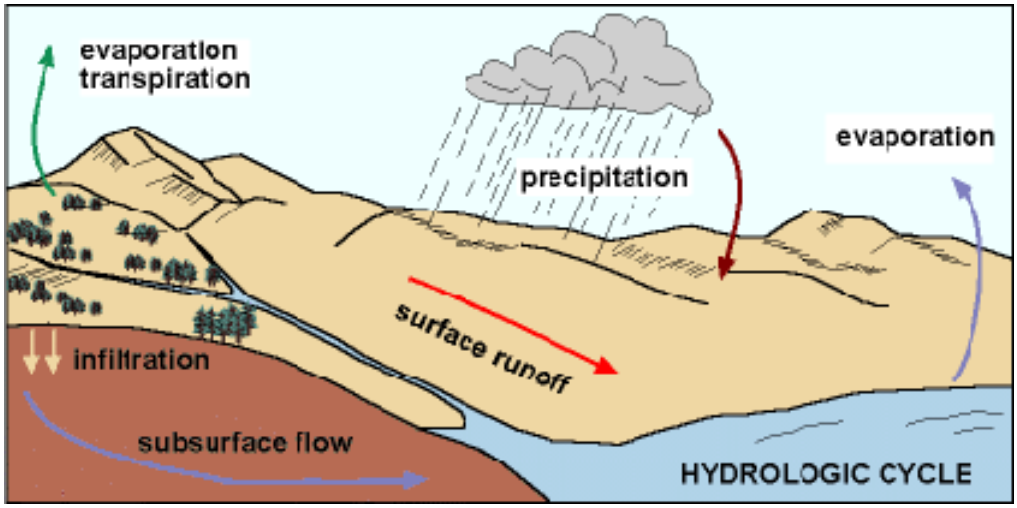
It is the fastest of the three components as it does not have to face any resistance.



Surface Flow

Subsurface Flow:

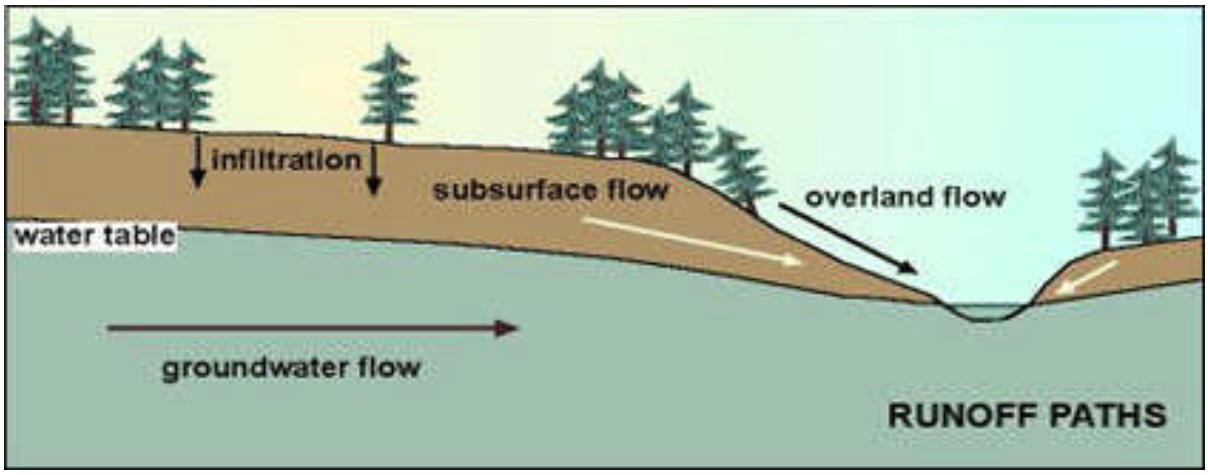
It is the portion of the total flow which, after infiltrating the soil surface, moves laterally through the unsaturated upper soil layer until it enters the channel. Subsurface flow reaches channel more slowly than the surface runoff and hence reaches the stream later.



Water Cycle: Subsurface flow

Ground Water Flow:

Some portion of the precipitation percolates downwards until it reaches the ground water table. The ground water storage may discharge into the stream if the water table intersects the stream channels of the basin. This discharge is called the ground water flow. This is the slowest component as it takes time to infiltrate and percolate.



Groundwater Flow

Runoff:

Runoff is the collective term which refers to all the three components of the total flow, i.e., surface runoff, subsurface runoff and ground water flow.

In practice, it is customary to consider the total flow to be divided into 2 parts:

1. Direct Runoff
2. Base Flow

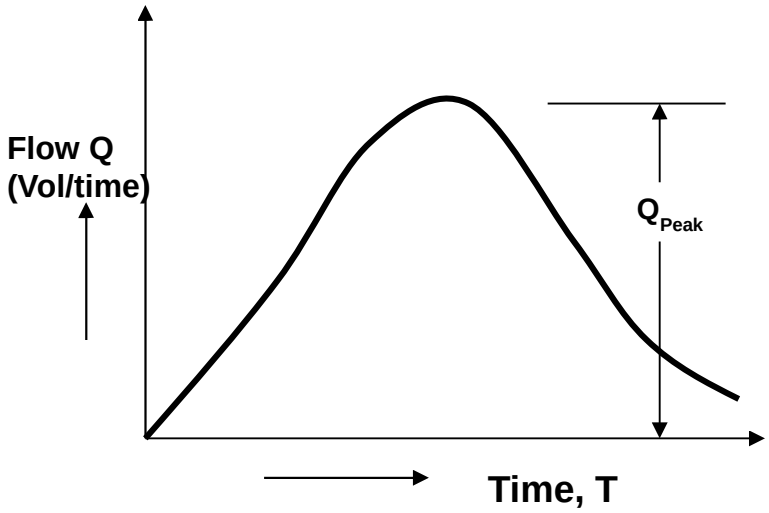
Direct runoff is presumed to consist mainly of overland flow and a substantial portion of surface runoff whereas the base flow is considered to be consisting of the ground water flow.

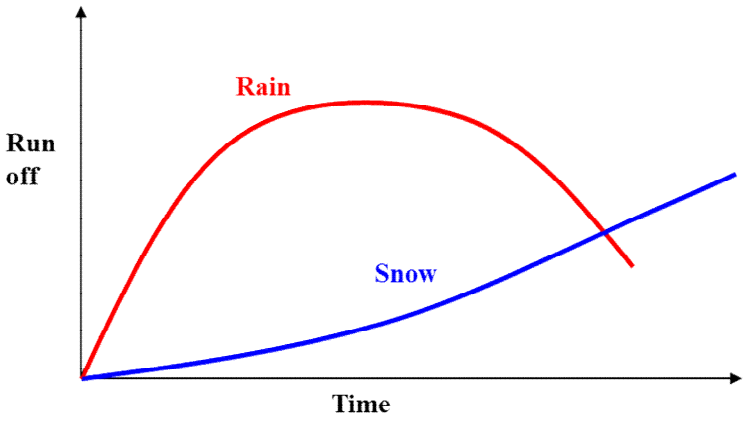
FACTORS AFFECTING RUNOFF:

1. Characteristics of Precipitation:

a. Type of Precipitation:

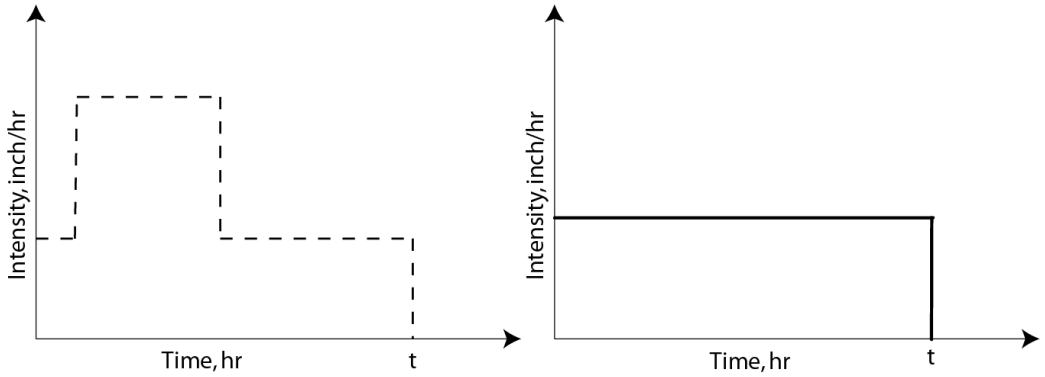
Precipitation generally occurs in the form of rain or snow, depending on which, the drainage pattern varies. Rain produces immediate runoff whereas that in the form of snow produces runoff at a slower rate.





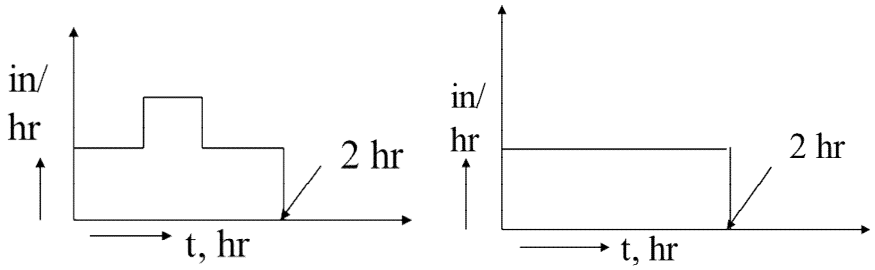
b. Rainfall Intensity:

If the rainfall intensity increases the runoff also increases.



An intense rain as shown in first figure will definitely produce much more runoff than that produced by the uniform rainfall as shown in the second figure, provided the infiltration capacity remains the same throughout the storm period.

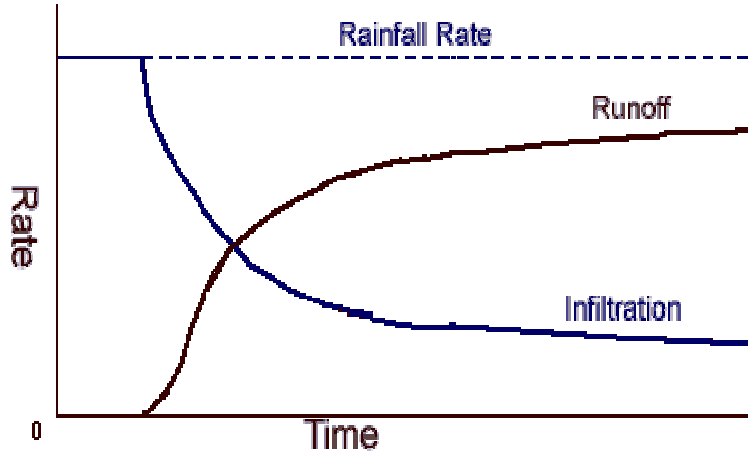
- For example, if the rainfall intensity increases by four times the runoff may increase by nine times if the infiltration capacity remains the same throughout the storm period.



Case 1 **Case 2**

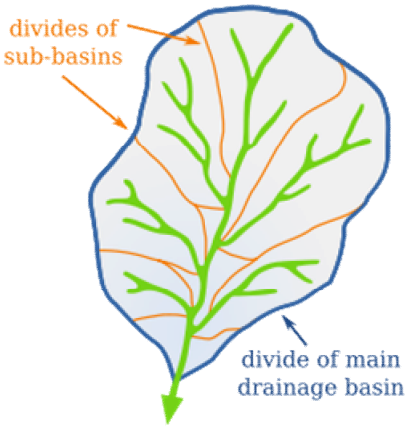
c. Duration of Rainfall:

Duration of rainfall is important regarding the fact that the infiltration capacity of the soil goes on decreasing as the rainfall continues for longer duration. As the infiltration decreases the surface runoff increases. Thus rain of a longer duration may produce a considerable runoff even when the intensity is mild.



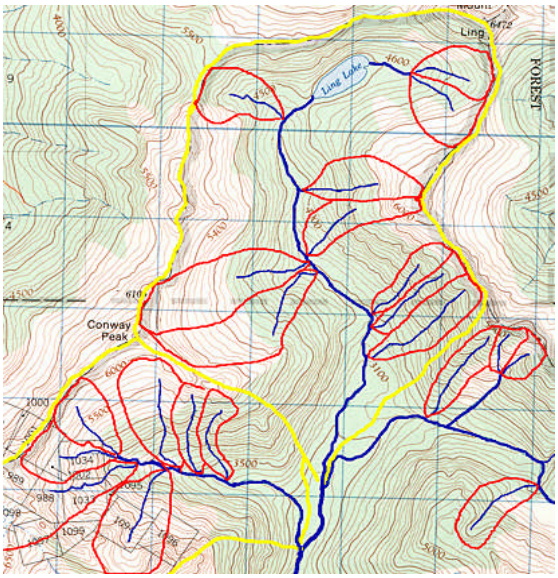
d. Rainfall Distribution:

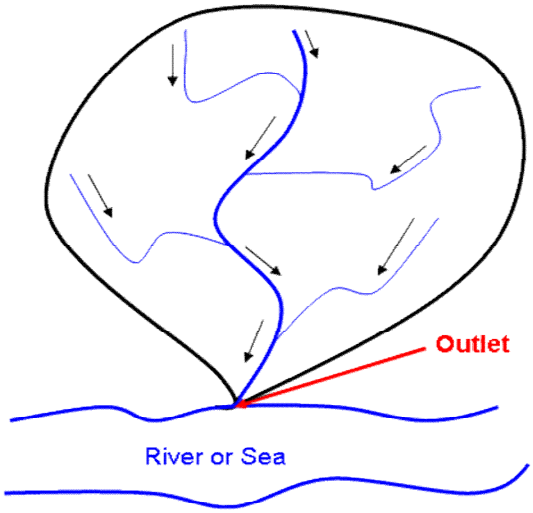
All the above discussion is made based on the assumption that the rainfall is evenly distributed over the whole catchment area which does not happen in reality. In reality, rain falls on a small part of the whole basin. For small drainage basins the peak flow are the results of intense rain falling over the small areas whereas for the large basins the peak flows are results of storms of less intensity but covering a large area.



Note: Catchment area/ Drainage basin/ Basin:

A drainage basin is a region of land where water from precipitation drains downhill into a body of water. The drainage basin includes both the streams and rivers that convey the water as well as the land surfaces from which water drains into those channels. The drainage basin acts like a funnel - collecting all the water within the area covered by the basin and channeling it into a waterway. Each drainage basin is separated topographically from adjacent basins by a ridge, hill or mountain, which is known as a water divide or a watershed.

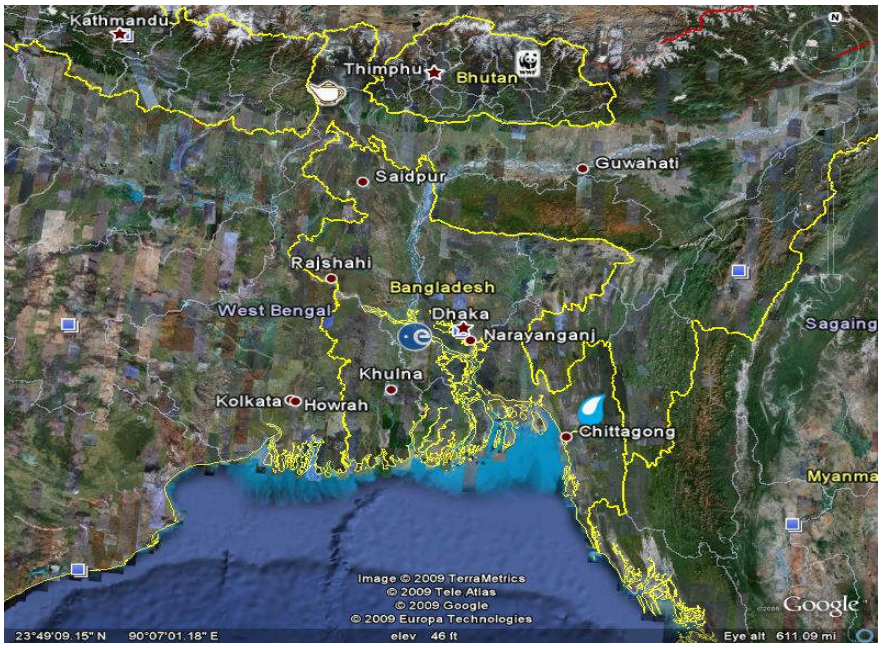




Schematic Diagram of a Drainage Basin
Catchment Area

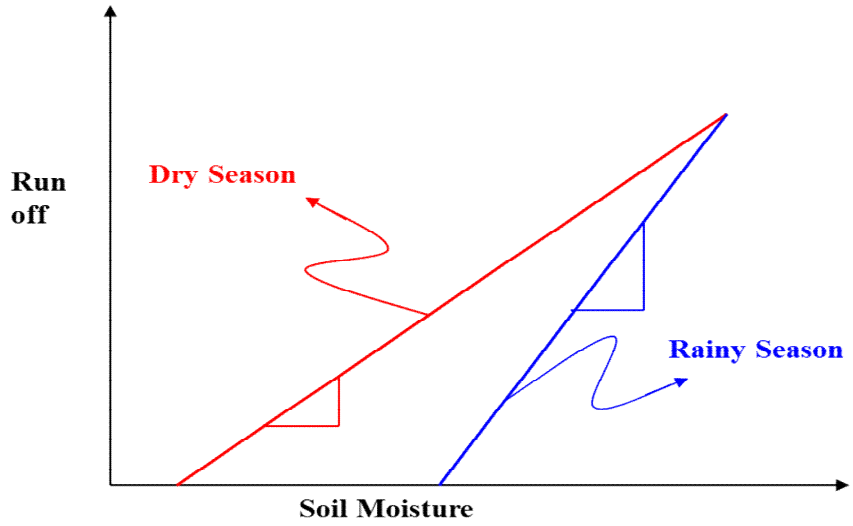
The following image shows the nested nature of drainage basins as determined from a topographic map sheet. The red lines describe the watersheds for the drainage basins of first order streams. The yellow lines define the watersheds for two drainage basins from locations further upstream. Note that the first order basins are components of these much large drainage basins.

Bangladesh as a Catchement area



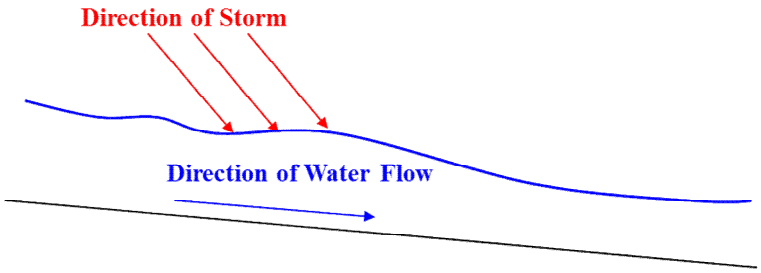
e. Soil Moisture Deficiency:

The runoff depends on the soil moisture present at the time of rainfall. If the rain occurs after a long dry spell of time, the soil is dry and it can absorb huge amount of water and thus intense rain may fail to produce appreciable runoff. On the other hand, if the rain falls after a rainy season, the soil will already be wet and there will be less infiltration and even small rainfall may cause appreciable runoff.

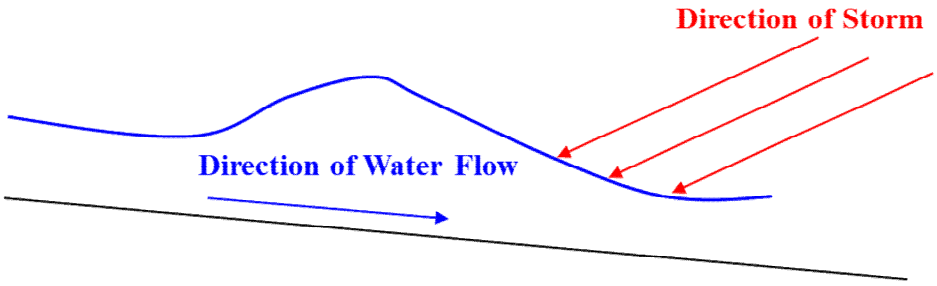


f. Direction of the Prevailing Storm:

If the direction of the storm is in the same direction as the direction of water movement in the drainage basin then the water will stay in the drainage basin for a shorter time. This is due to the fact that runoff will be more compared to that if direction of storm is opposite to that of the direction of water movement.



Water will stay in the drainage basin for a shorter time, runoff more.



Water will stay in the drainage basin for a longer time, infiltration will be more and less runoff.

g. Various Climatological Factors:

Various climatological factors such as temperature, wind, humidity, etc. affect the losses from the drainage basin. If losses are more then runoff will be less.

Total Precipitation = Surface Runoff + Subsurface Runoff + Ground Water Flow + Losses.

2. Characteristics of the Drainage Basin:

a. Size of the Basin:

If the area of the basin is large, then the total flow will take more time to pass the outlet and the peak will be reduced.

b. Shape of the Basin:

The shape of the drainage basin also governs the rate at which water enters the stream. The shape of the basin is usually expressed by the two terms:

- Form Factor
- Compactness Coefficient

Form Factor:

$$\text{Form Factor} = \frac{\text{average width of the basin}}{\text{axial length of the basin}} = \frac{B}{L}$$

The axial length (L) is the distance between the outlet and the most remote point on the basin

The average width (B) is obtained by dividing the total area (A) by the axial length (L). So, B = A/L.

$$\text{Form Factor} = \frac{B}{L} = \frac{A/L}{L} = \frac{A}{L^2}$$

Compactness Coefficient:

$$\text{Compactness coefficient} = \frac{P}{C}$$

Where, P = Perimeter of the Basin

C = Circumference of the circle whose area is the same as the area of the basin.

Shape of the Basin:

If A is the area of the basin and r is the radius of the equivalent circle, then,

$$A = \pi r^2$$

$$or, r = \sqrt{\frac{A}{\pi}}$$

$$Now, C = 2\pi r$$

$$or, C = 2\sqrt{A\pi}$$

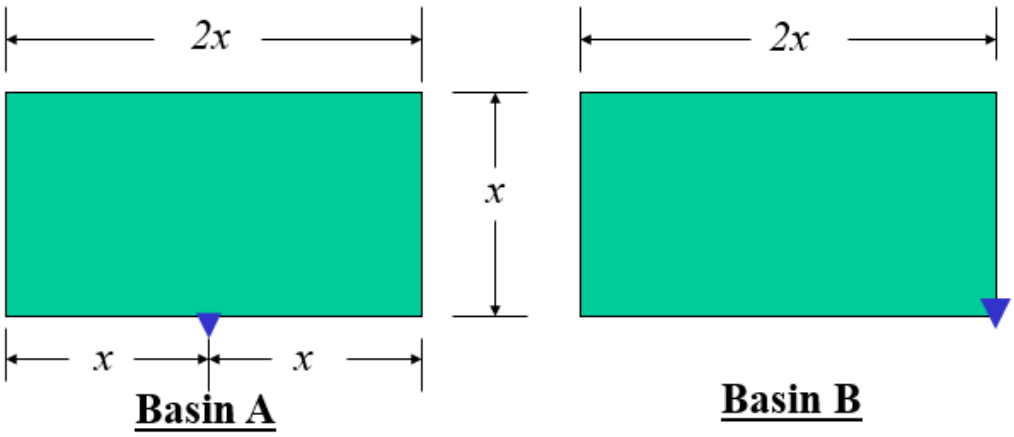
$$So,\ Compactness\ coefficient = \frac{P}{C} = \frac{P}{2\sqrt{A\pi}}$$

Where, P = Perimeter of the Basin

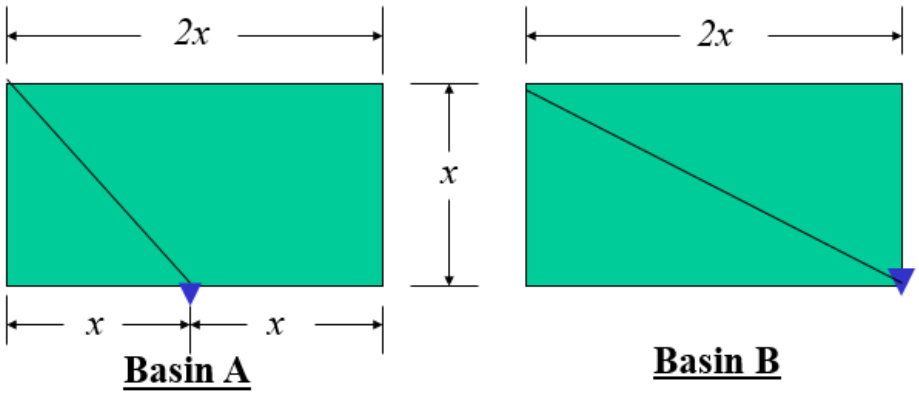
A = Area of the Basin

1.0 Example-

Find out the form factors and compactness coefficient of the following basins.



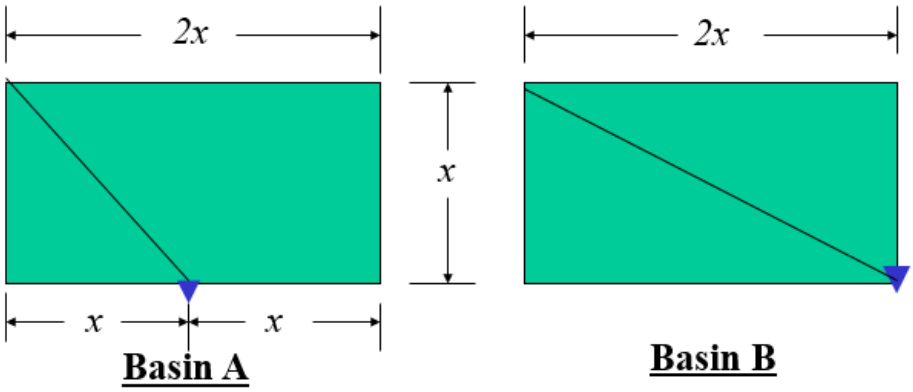
Solution:



Area of both basins = $2x^2$

Axial Length of Basin A, $L_A = \sqrt{2}x$

Axial Length of Basin B, $L_B = \sqrt{5}x$

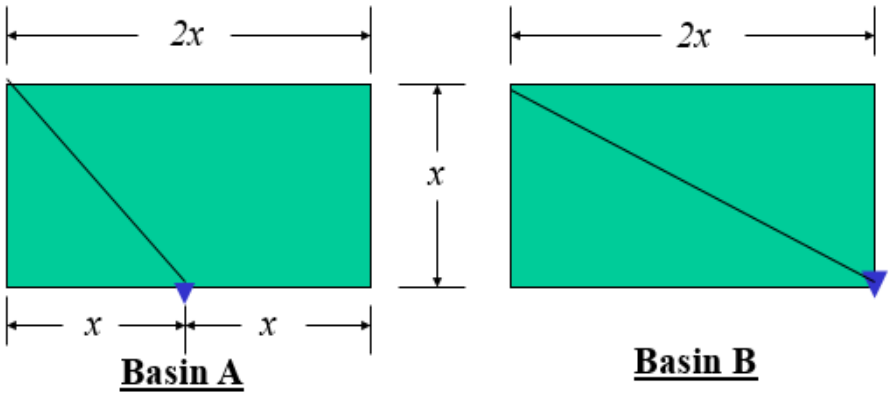


Average width of Basin A, $B_A = 2x^2 / \sqrt{2}x = \sqrt{2}x$

Average width of Basin B, $B_B = 2x^2 / \sqrt{5}x = (2/\sqrt{5})x$

Form factor of Basin A = $(B_A/L_A) = (\sqrt{2}x / \sqrt{2}x) = 1$.

Form factor of Basin B = $(B_B/L_B) = \{(2/\sqrt{5})x / \sqrt{5}x) = 2/5$.



Perimeter of Basin A & B , P_A & $P_B = 6x$

$$Compactness\ coefficient\ of\ Basin\ A = \frac{P}{2\sqrt{A\pi}} = \frac{6x}{2\sqrt{2x^2\pi}} = \frac{3}{\sqrt{2\pi}}$$

$$Compactness\ coefficient\ of\ Basin\ B = \frac{P}{2\sqrt{A\pi}} = \frac{6x}{2\sqrt{2x^2\pi}} = \frac{3}{\sqrt{2\pi}}$$

COMPUTATION OF RUNOFF:

Rational Method:

Introduction:

The Rational Method is an intensity based rainfall method, meaning that it can be used to predict peak flows based on the characteristics of the catchment area and a rainfall event. This makes the Rational Method a popular choice for storm sewer analyses. It is a very simple method as only a few parameters are used.

Objectives of Rational Method:

Many hydrologic design problems require simply an estimation of the peak flow rate generated by a river system under specified conditions, in such problems, the general shape of the flood hydrograph and the time of occurrence of the peak flow rate are no special significance and need not be taken into account. In such cases the Rational Method can be applied to estimate the peak flow rate. *Also when adequate data are not available this method can be applied.*

Assumptions:

- The rainfall is uniform both spatially and temporally.
- The drainage area is small.
- The duration of the rainfall is equal to the catchment's time of concentrations.

  Time of concentration: Time required for water to reach the outlet from the furthest point.
- Peak flow occurs when the entire catchment area is contributing.
- The recurrence interval of the peak discharge is equal to that of the rainfall intensity.

Rational Formula:

$$Q \alpha CIA$$

$$\Rightarrow Q = kCIA$$

Where, Q = Peak Discharge in m^3/s or ft^3/s

A = Area of the catchment (acres or hectares)

I = Rainfall intensity with the selected recurrence interval, T years and the duration equal to the catchment's time of concentration

K = A factor of proportionality

= 0.278 when A in km^2 and I in mm/hr

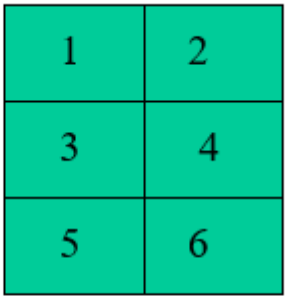
= 0.00278 when A in hectares and I in mm/hr

= 1.0 when A in m^2 and I in m/s

C = coefficient of runoff, which depends on the type of area, soil condition, soil covers, storage, depressions etc. Theoretically it can vary from 0.0 to 1.0

[C = 0 indicates no runoff, i.e., 100% infiltration & C = 1 indicates 100% runoff i.e., no infiltration]

[For composite area, $C = \frac{C_1A_1 + C_2A_2 + ...C_nA_n}{A_1 + A_2 + ... + A_n}$]



$$C = \frac{C_1A_1 + C_2A_2 + C_3A_3 + C_4A_4 + C_5A_5 + C_6A_6}{A_1 + A_2 + A_3 + A_4 + A_5 + A_6}$$

Area Type	Description	C values (experimental)
Business	Downtown	0.07-0.095
	Neighborhood	0.50-0.70
Residential	Single family	0.30-0.50
	Multiunit detached	0.40-0.60
	Multiunit attached	0.60-0.75
	Suburban Resident	0.25-0.40
	Apartment	0.50-0.70
	1.2 acre lots or more	0.30-0.45
Lawns, Heavy Soils	Flat, 2%	0.13-0.17
	Average, 2%-7%	0.18-0.22
	Steep, >7%	0.25-0.35
Industrial	Light	0.50-0.80
	Heavy	0.60-0.90
Lawns, Sandy Soils	Flat, 2%	0.05-0.10
	Average, 2%-7%	0.10-0.15
	Steep, >7%	0.15-0.20
Pavement	Asphalt/ Concrete	0.70-0.95
	Brick	0.70-0.85
	Drives and walks	0.75-0.85

2.0 Example-

Determine the expected runoff by rational method from a bituminous pavement (runoff coefficient 0.75) 2 km long and 200 m wide during a rainfall of 5 in/hr.

$$Given\ data,$$

$$Area,\ A = 2\,km \times 200\,m = (2 \times 0.2) = 0.4\,km^2$$

$$Intensity,\ I = 5\,in/hr = (25.4 \times 5)\,mm/hr = 127\,mm/hr$$

$$Factor\ k = 0.278$$

$$Runoff\ coefficient, C = 0.75$$

$$\therefore Expected\ runoff, Q = kICA = (0.278 \times 127 \times 0.75 \times 0.4) = 2.94 m^3/s$$