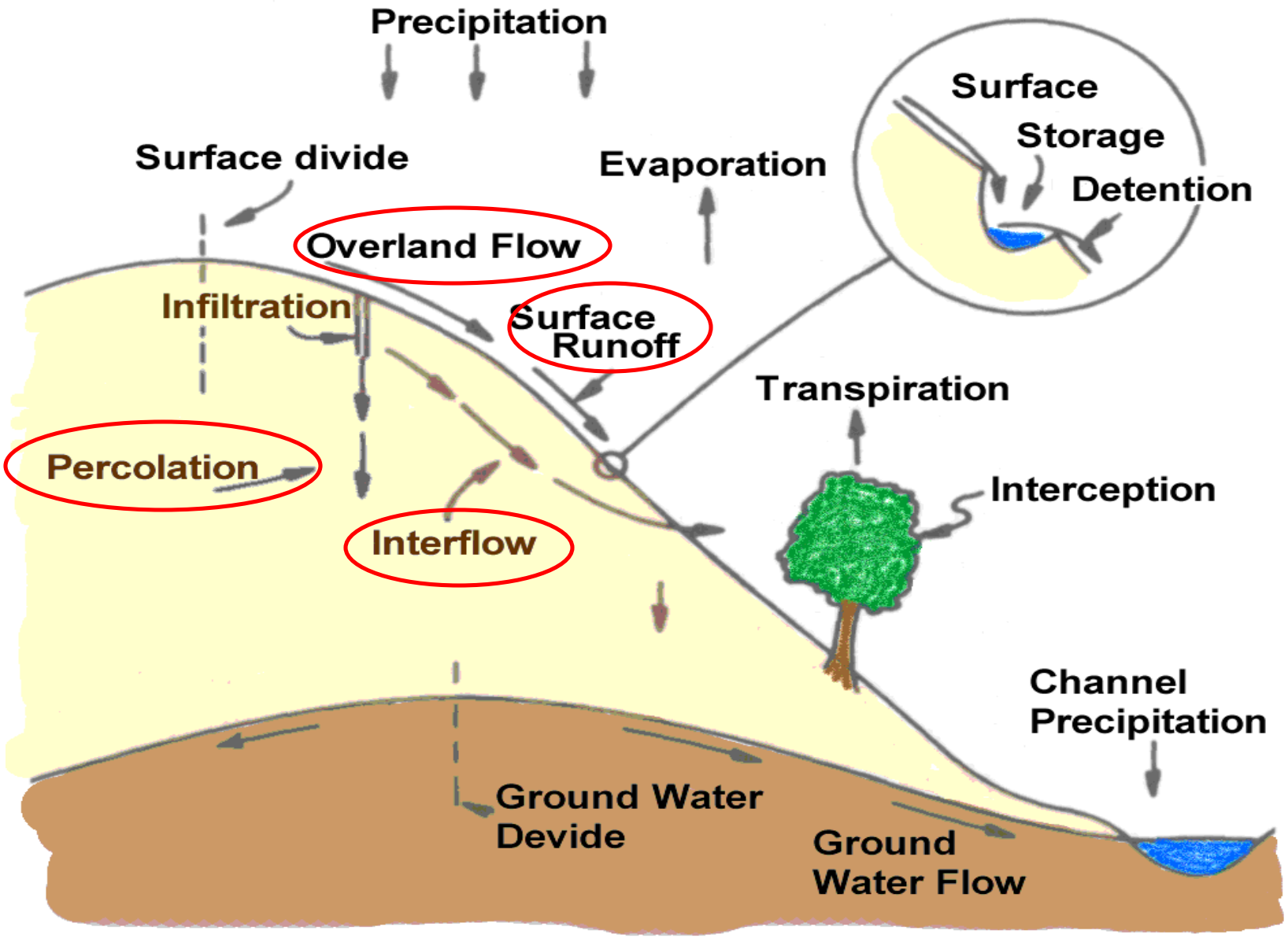
Runoff


Precipitation
Surface divide
Evaporation
Surface
Storage
Detention
Overland Flow
Infiltration
Surface
Runoff
Transpiration
Percolation
Interception
Interflow
Channel
Precipitation
Ground Water
Devide
Ground
Water Flow

Runoff

Runoff is that part of the precipitation that appears in streams, rivers or drains.

Runoff (RO) may be classified according to speed of appearance after rainfall as direct runoff (DRO) and base flow (BF), and according to source as surface runoff (SRO), interflow (IF) and base flow (groundwater runoff or GRO).

When rain falls, the first drops of water are intercepted by the leaves and stems of the vegetation. This is usually referred to as interception storage.

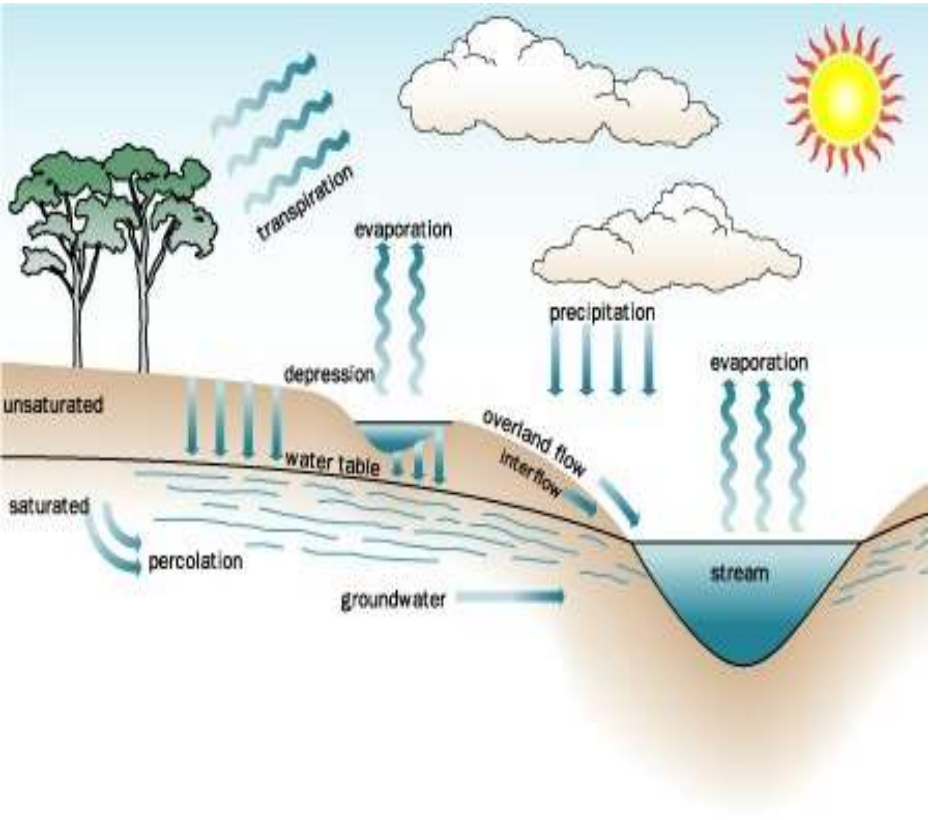
As the rain continues, water reaching the ground surface infiltrates into the soil until it reaches a stage where the rate of rainfall (intensity) exceeds the infiltration capacity of the soil. Thereafter, surface puddles, ditches, and other depressions are filled (which is known as depression storage or surface detention), after which runoff is generated.

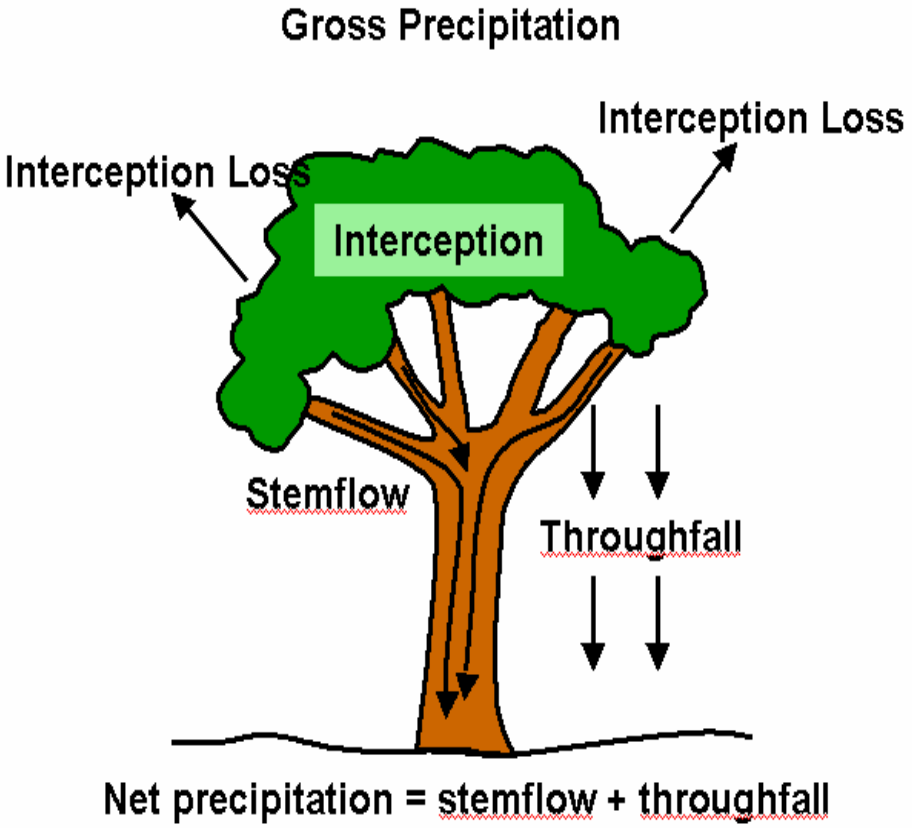
When the precipitation of a storm reaches the ground, it must first fill up all depressions before it can flow over the surface. The volume of water trapped in these depressions is called depression storage (surface detention). This amount is eventually lost through processes of infiltration and evaporation and thus form a part of the initial loss.

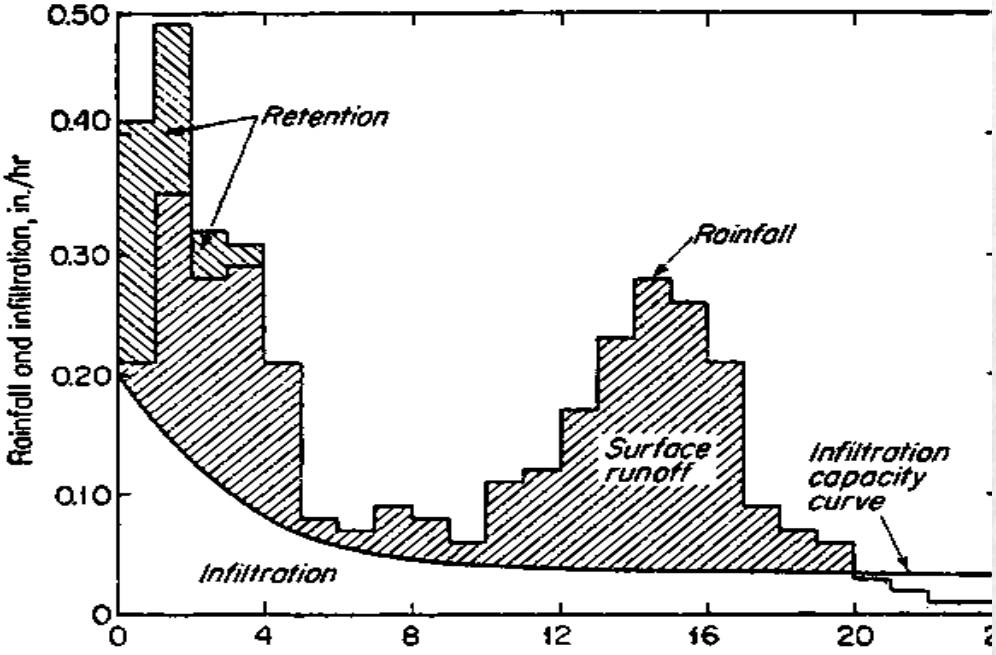
The process of runoff generation continues as long as the rainfall intensity exceeds the actual infiltration capacity of the soil but it stops as soon as the rate of rainfall drops below the actual rate of infiltration.

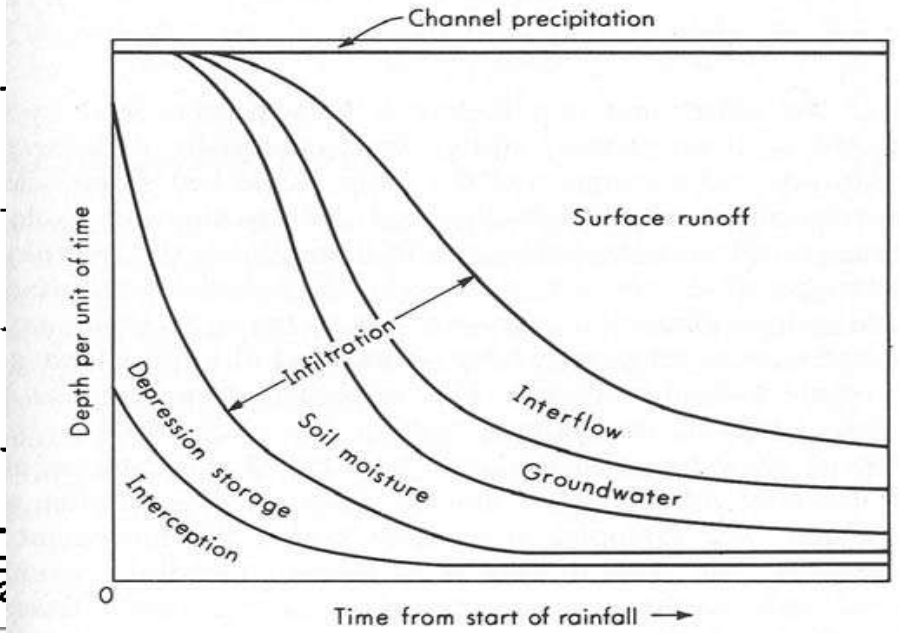
Route of Interception

1. Interception loss: rain water retained by the vegetation as surface storage.
2. Through fall: rain water can drip off the plant leaves to join the ground surface or the surface flow.
3. Stem flow: the rain water may run along the leaves and braches and down the stem to reach the ground surface







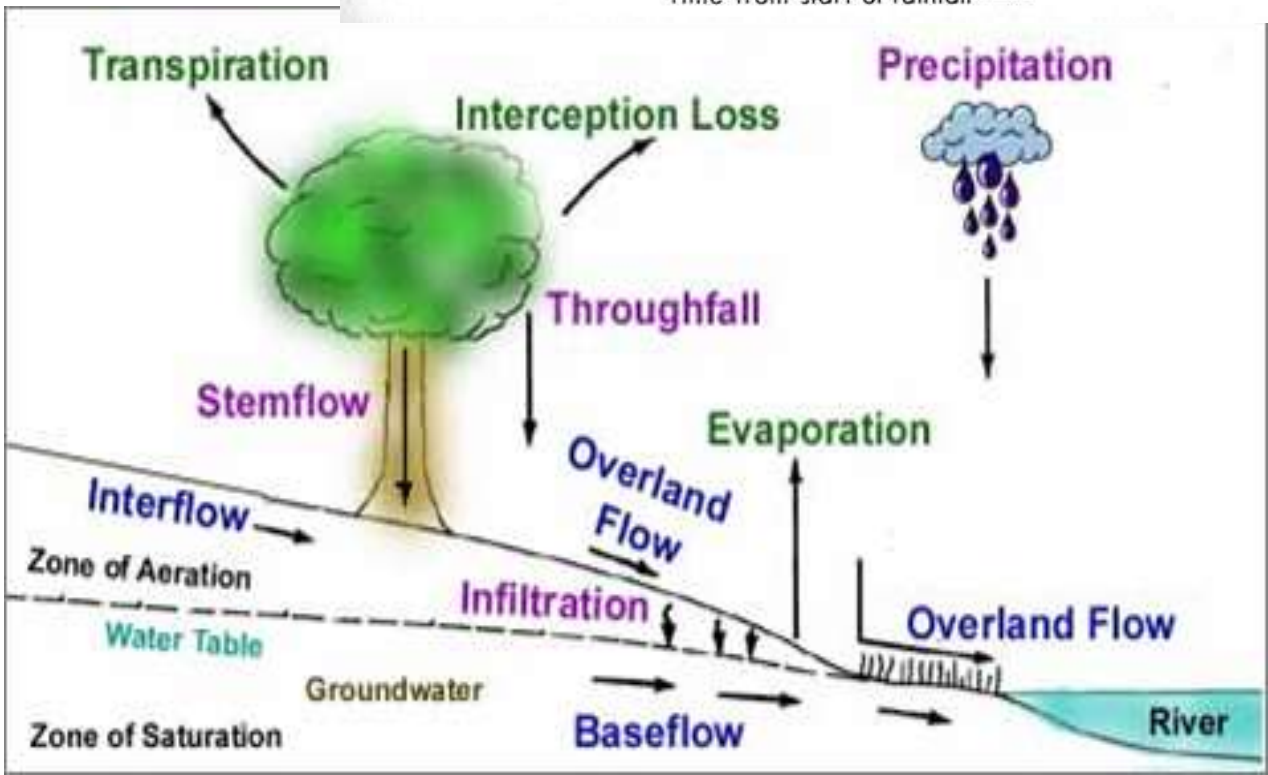


RO = DRO + BF

DRO = OF + IF = SRO + IF

BF = GRO

RO = OF (SRO) + IF + BF



Runoff

Direct Runoff (DRO), which is composed of contributions from *surface runoff (SRO)* and *quick interflow*.

Baseflow (BF), which is composed of contributions from *delayed interflow* and *groundwater runoff (GRO)*.

The division of interflow to quick and delayed is arbitrary.

Surface runoff includes all *overland flow* (OF) as well as all precipitation falling directly onto stream channels.

Surface runoff is generally the same as *overland flow* due to very small contribution of rainfall falling onto the stream.

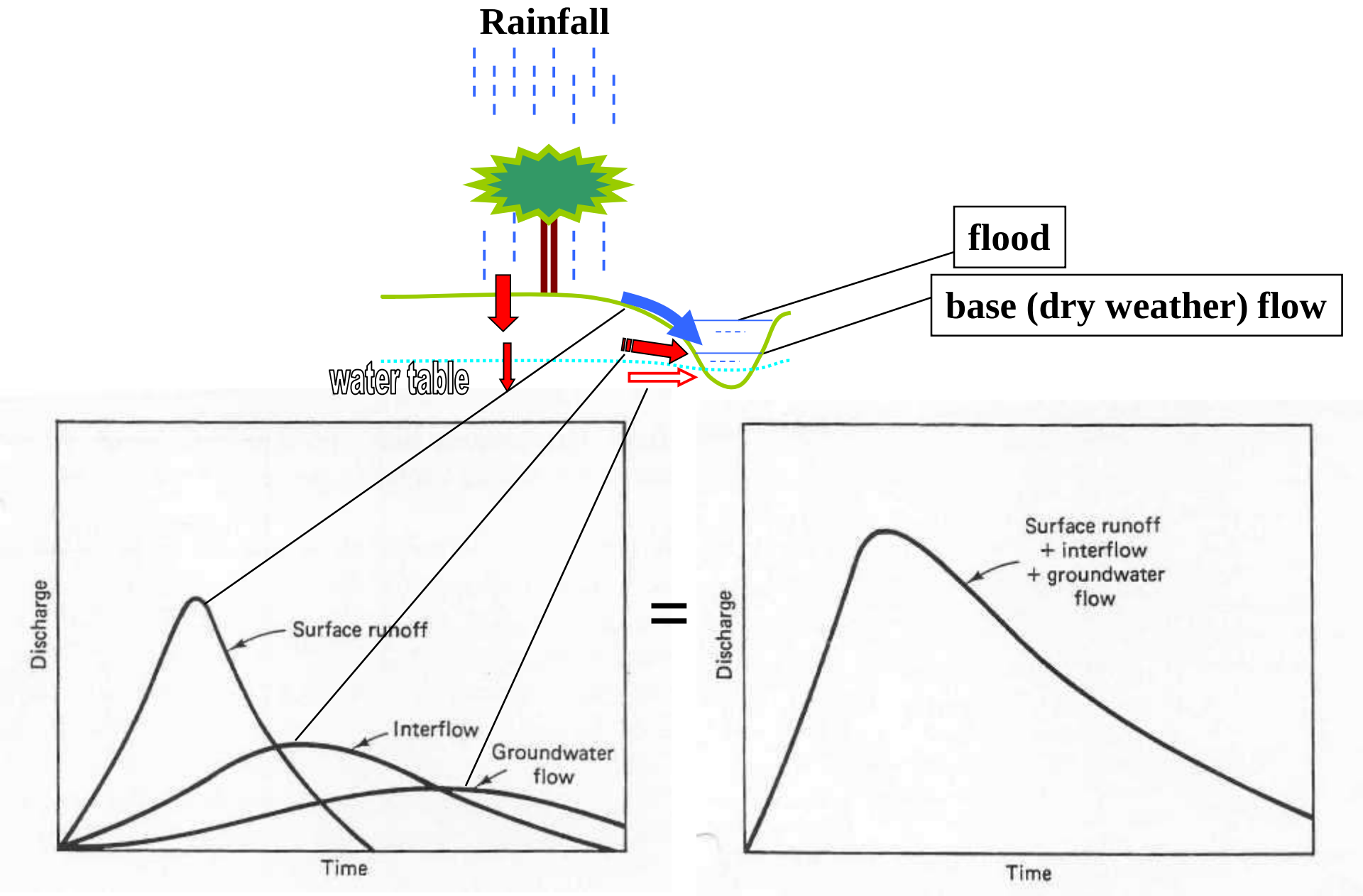
Interflow is the portion of the streamflow contributed by infiltrated water that moves laterally in the subsurface until it reaches a channel. Interflow is a slower process than surface runoff. Interflow travels laterally or horizontally through the zone of aeration (vadose zone) without reaching the water table.

Components of interflow are:

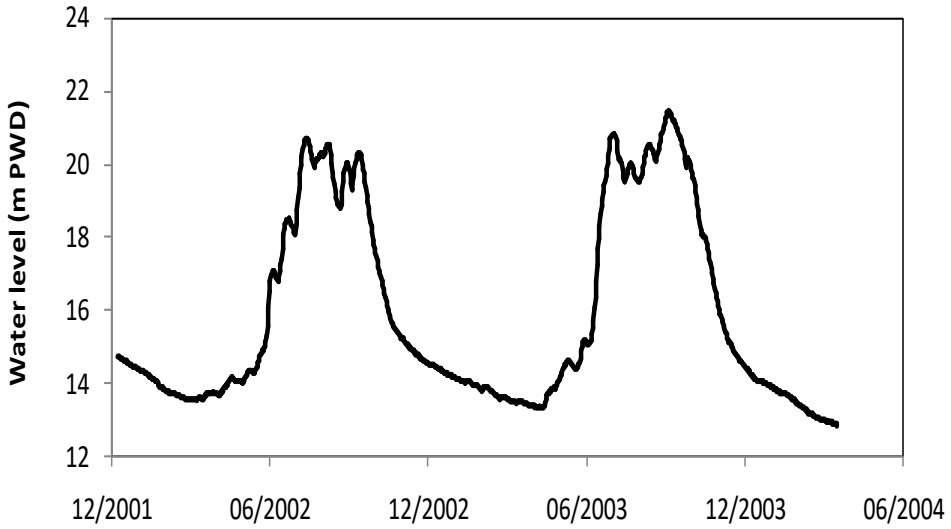
- *quick interflow*, which contributes to direct runoff, and
- *delayed interflow*, which contributes to baseflow.

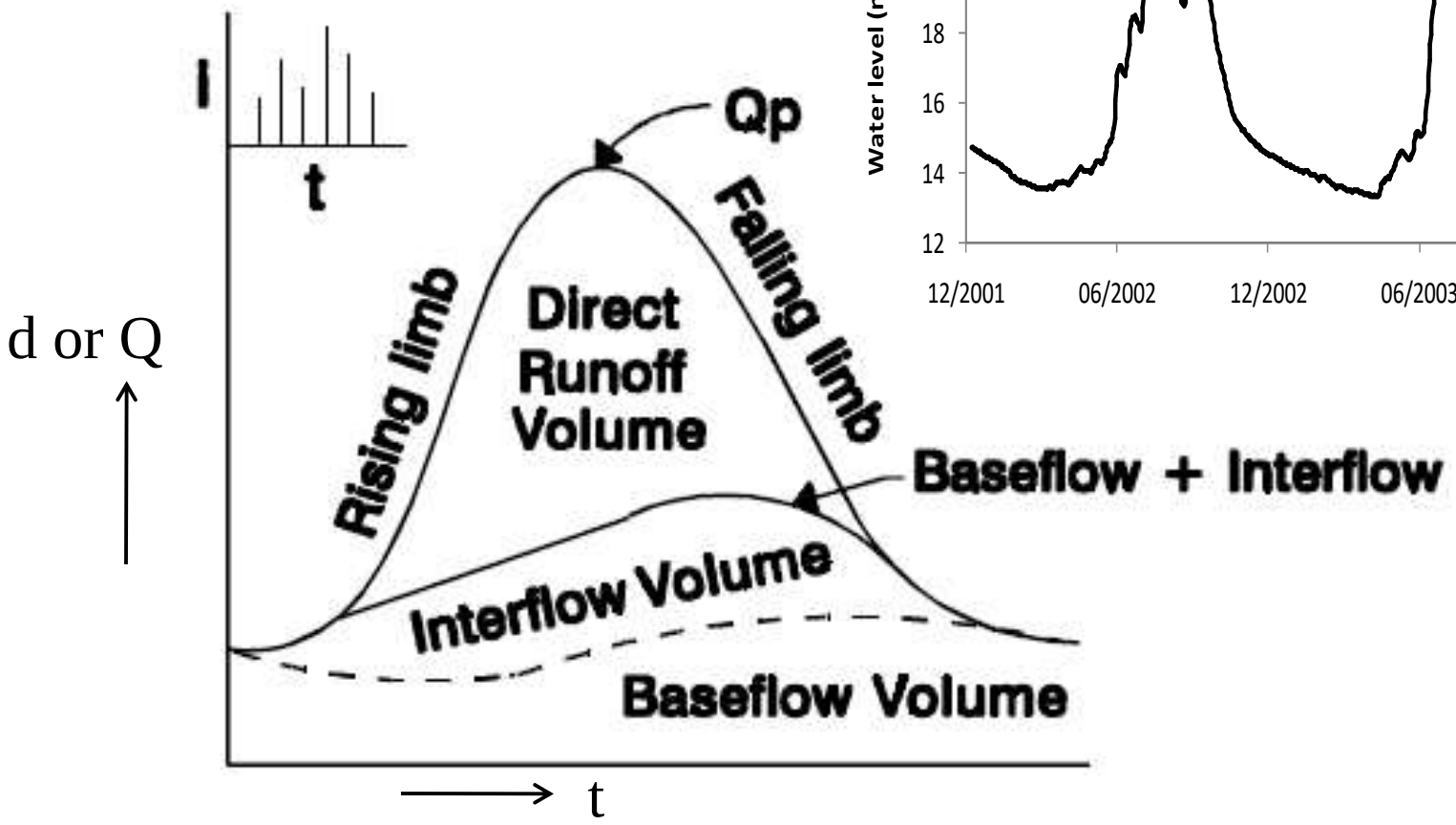
Groundwater runoff is the flow component contributed to the stream by groundwater. This process is extremely slow as compared to surface runoff.

Runoff generation

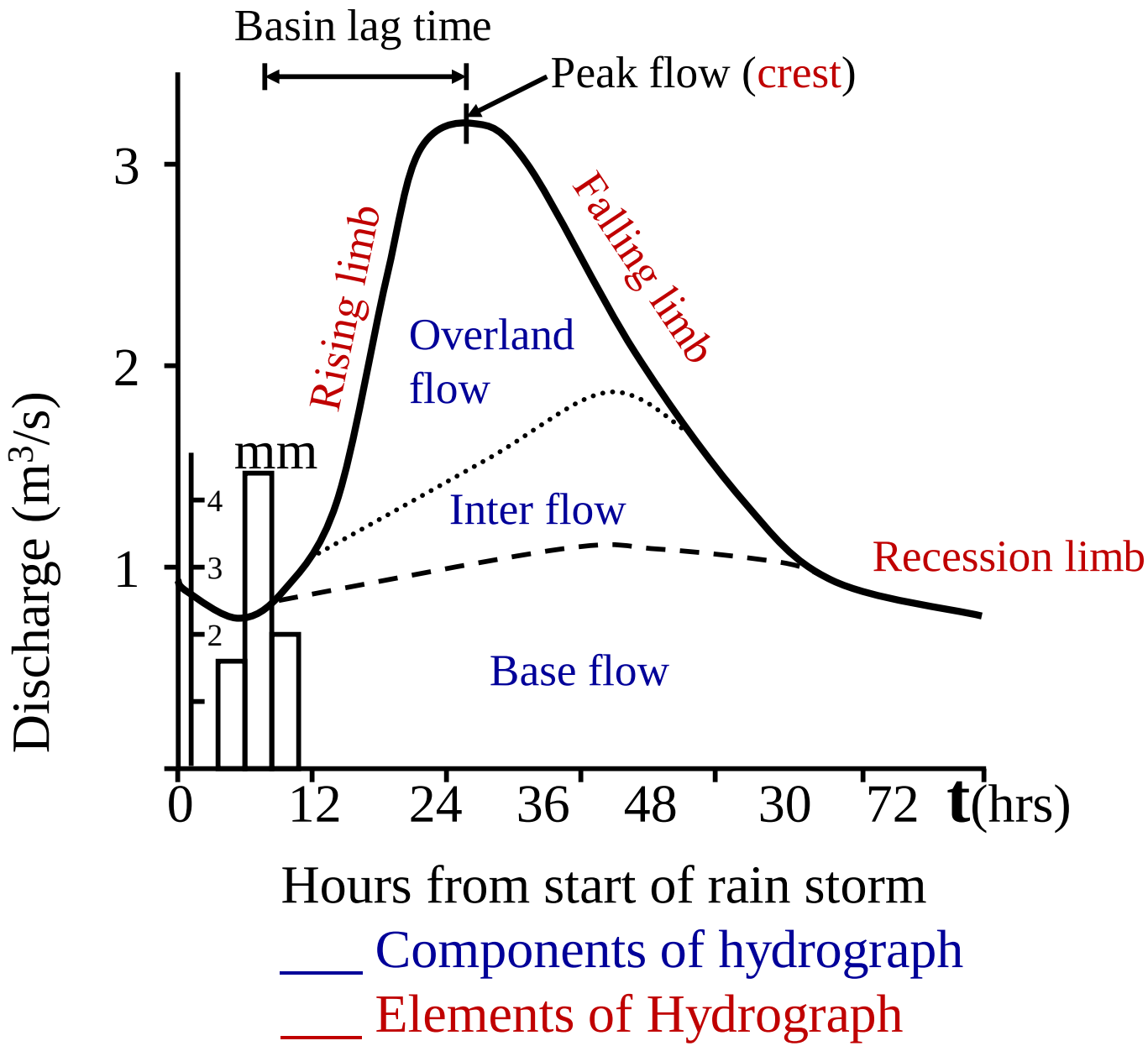


Hydrograph: A plot of stage or water level (d) or discharge (Q) against time is called a hydrograph. Depending upon the unit of time, there is annual hydrograph, seasonal hydrograph, monthly hydrograph or storm hydrograph.





The three important characteristics of a hydrograph are **peak discharge, runoff volume and the duration of runoff.**


Basin lag time
Peak flow (crest)
Rising limb
Falling limb
Overland flow
Inter flow
Base flow
Recession limb
mm
4
3
2
Discharge (m3/s)
3
2
1
0
12
24
36
48
30
72
t(hrs)
Hours from start of rain storm
Components of hydrograph
Elements of Hydrograph

Runoff

Factors affecting runoff

Features that facilitate runoff removal, produce high peaks and short hydrographs. Features that delay runoff removal, produce low peaks and long hydrographs.

The factors affecting the runoff are:

Storm Characteristics

Intensity, amount, duration, frequency and areal extent (distribution).

Runoff from a watershed depends very much on the distribution of rainfall.

Basin Characteristics

Size, shape, slope, soil type, land use, drainage density and antecedent moisture condition

In general, for a given intensity, a large drainage area implies a large peak flow (runoff volume).

For a given rainfall amount, the runoff efficiency (% of rainfall that becomes runoff: runoff/rainfall) increases with the decreasing size of the catchment i.e. the larger the size of the catchment the smaller is the runoff efficiency.

A fan shaped watershed has a higher peak than fern shaped watershed as travel time (time of concentration) is lower in fan shaped than fern shaped.

The slope of the channel affects the magnitude of the peak and the duration of runoff. A steep channel produces greater velocities and allows faster removal of the runoff from the watershed; therefore, shorter times to peak take place.

RAINFALL CHARACTERISTICS AFFECTING DIRECT RUNOFF

- Rainfall Depth
- Rainfall intensity
- Rainfall Duration
- Rainfall areal distribution
- Rainfall Frequency
- Antecedent precipitation

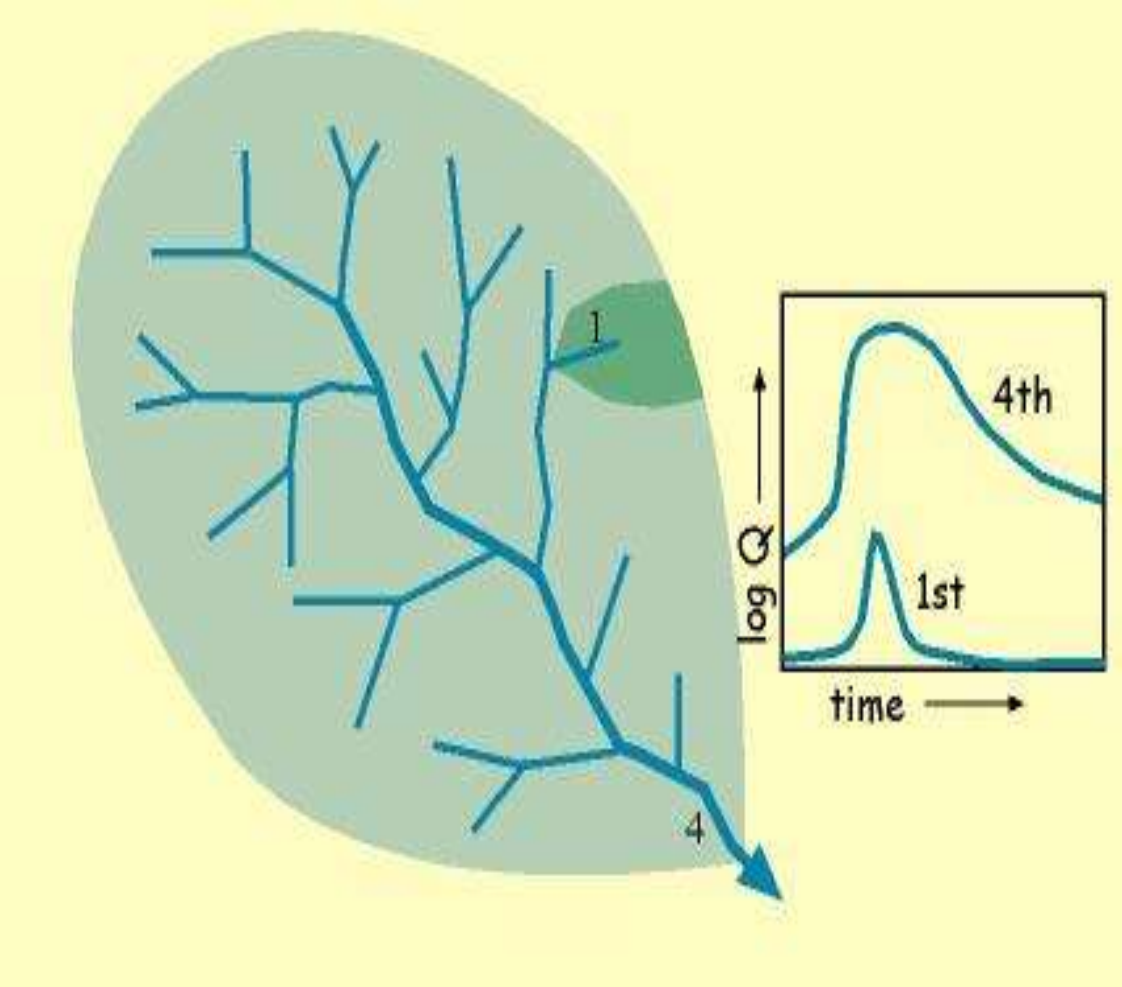
1. Rainfall Intensity:

If the rainfall intensity is greater than infiltration rate of soil then runoff starts immediately after rainfall. While in case of low rainfall intensity runoff starts later. Thus high intensities of rainfall yield higher runoff.

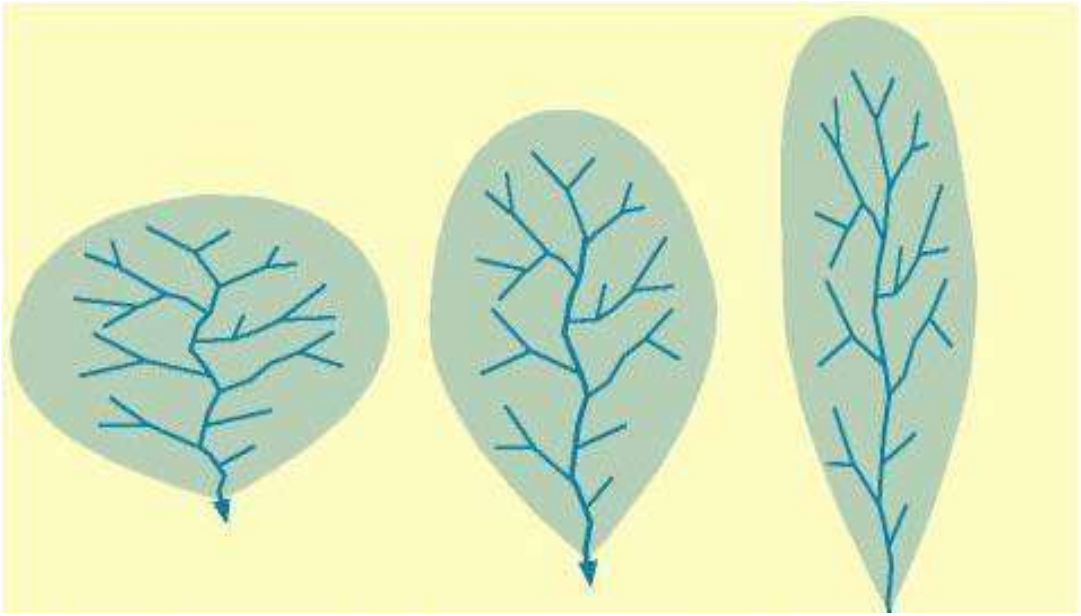
2. Duration of Rainfall:

It is directly related to the volume of runoff because infiltration rate of soil decreases with duration of rainfall. Therefore medium/low intensity rainfall may results in considerable amount of runoff if duration is longer.

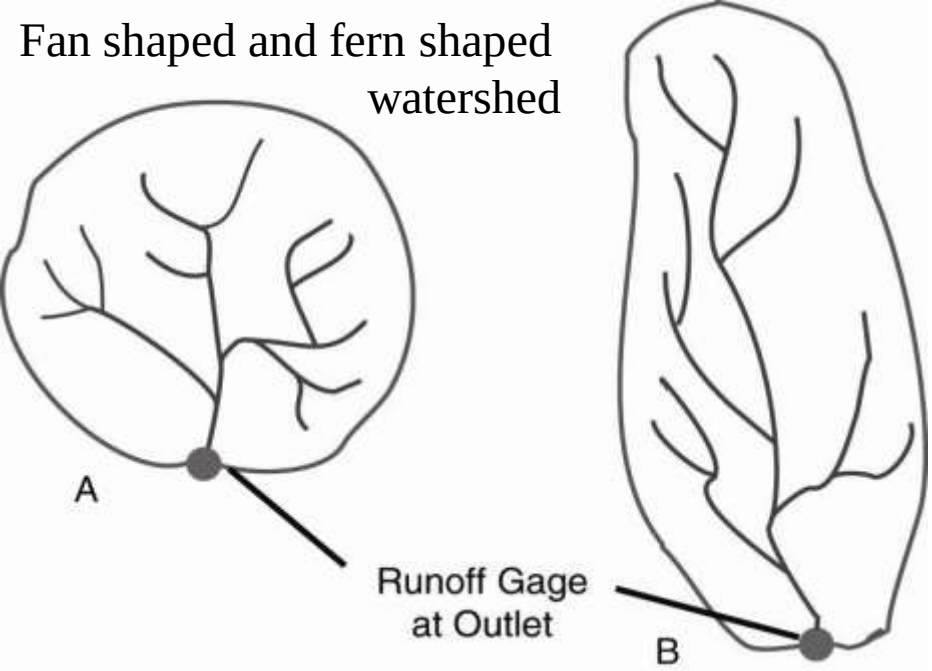
Stream order and flood response

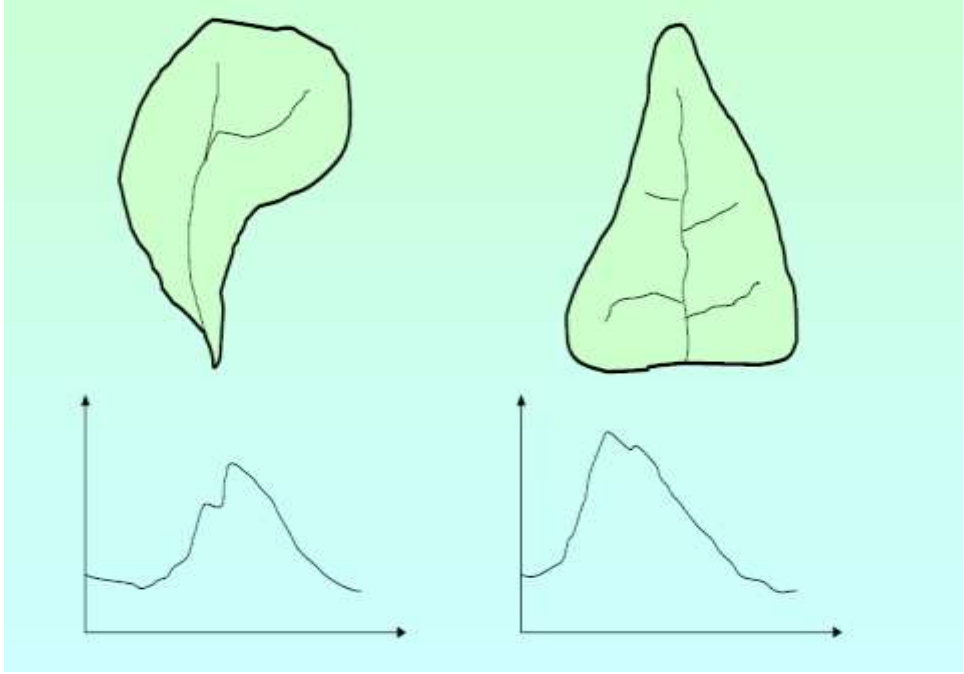


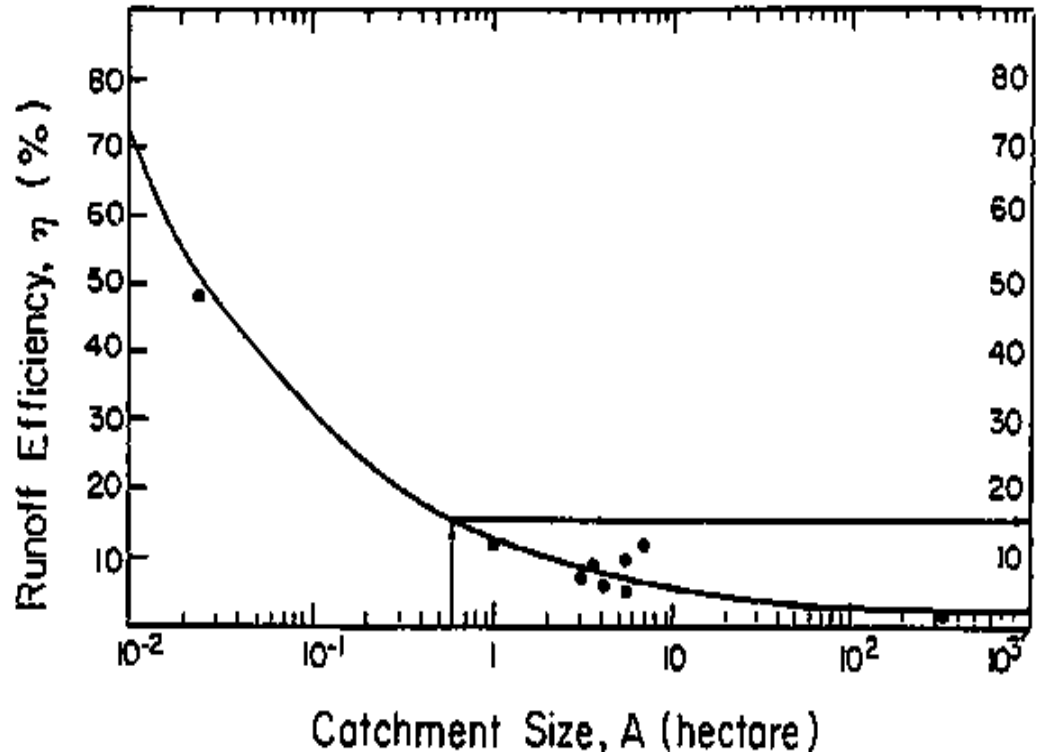
Basin geometry and flood response

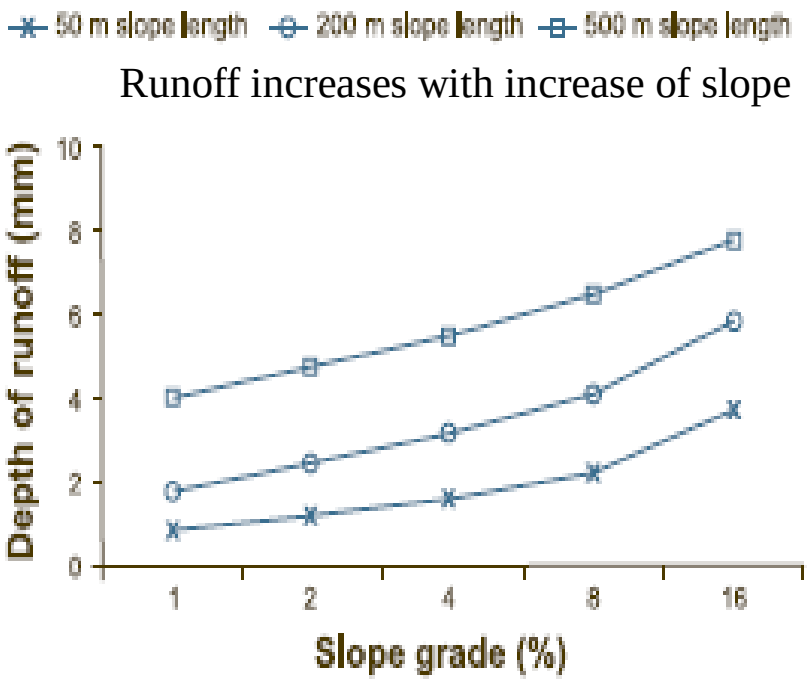


Fan shaped and fern shaped watershed









Runoff increases with increase of slope

Runoff

The volume of runoff from a site increases with increased grade and increased length of slope. An increase in the grade of the slope increases the gravitational force on water and, depending on soil factors (i.e., permeability, texture, etc.), may increase its tendency to flow along the surface rather than infiltrate into the soil.

The area contributing to runoff becomes greater with increased down slope distance, thus larger discharge may result at greater slope lengths.

Drainage density is defined as the ratio of the total channel length [L] in the watershed to total watershed area [A].

$$\text{Drainage density} = L / A$$

The effect of drainage density on runoff volume is associated with the time during which the runoff remains in the watershed. Low densities allow for long residence times; therefore, abstraction mechanisms have more time to remove water.

High densities usually allow fast runoff removal. Therefore, greater peaks and hydrographs with shorter durations are expected for watersheds with higher drainage densities.

Land use strongly affects the amount of runoff generated from a watershed.

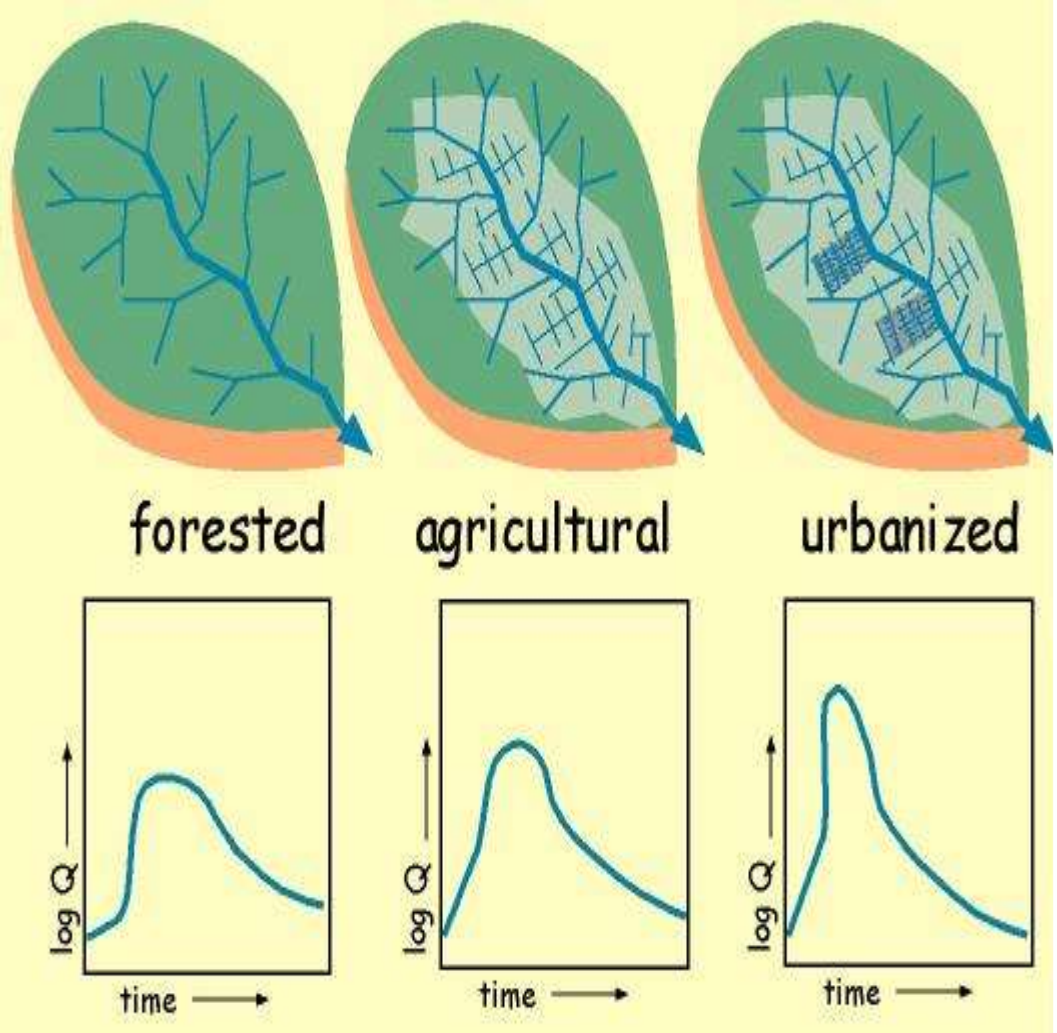
An urban watershed has a higher and quicker runoff peak and more runoff than a rural watershed.

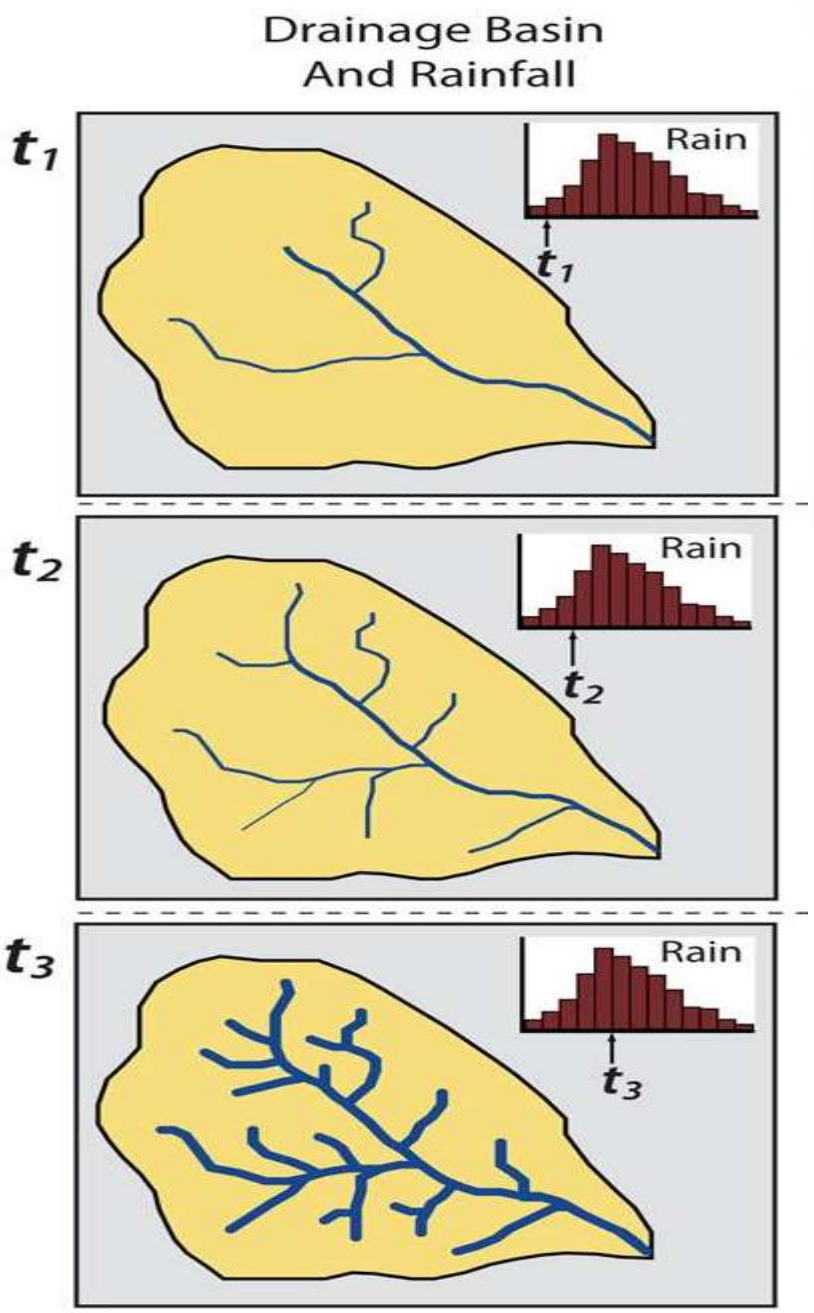
Antecedent moisture is the amount of water present in soil at the beginning of a storm.

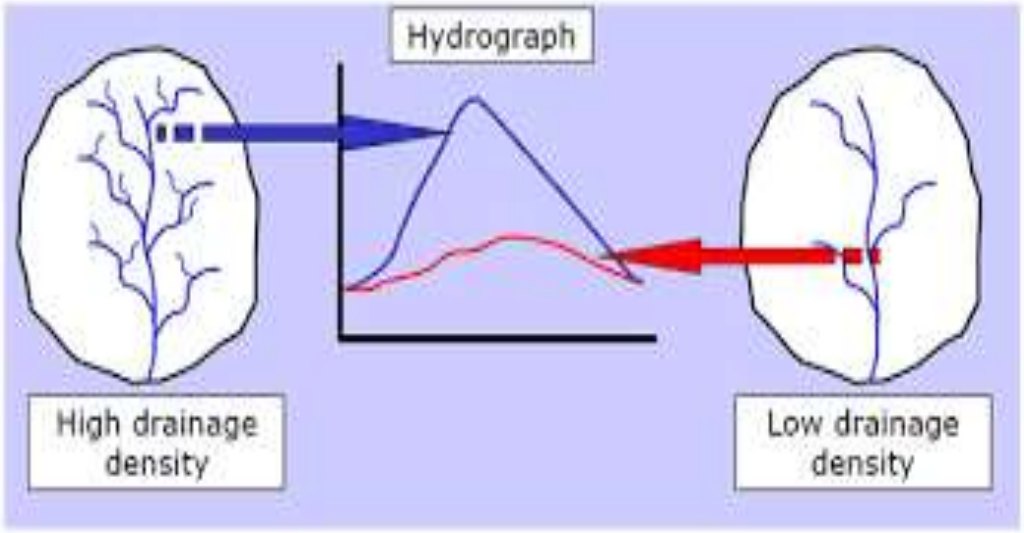
If the moisture content of the soil is high, more runoff will be produced because a smaller amount of water is required to saturate the soil.

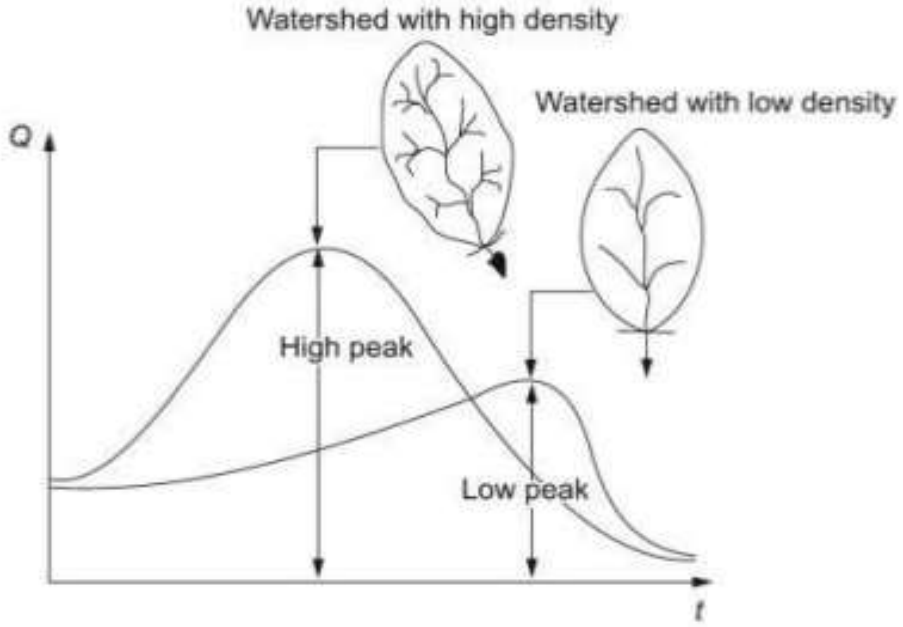
For equal-sized watersheds, runoff decreases as overland flow length increases (increased depression storage, resistance and infiltration).

Land use and flood response









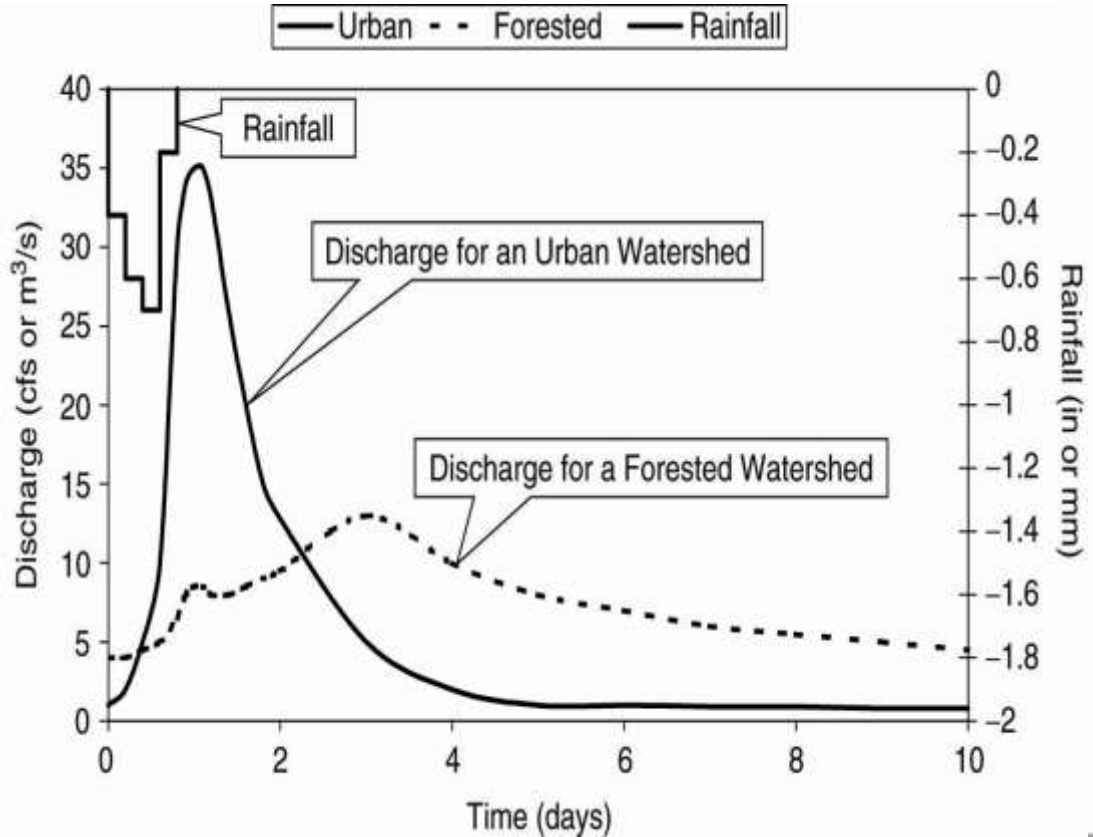
Effect of drainage density on peak flow.

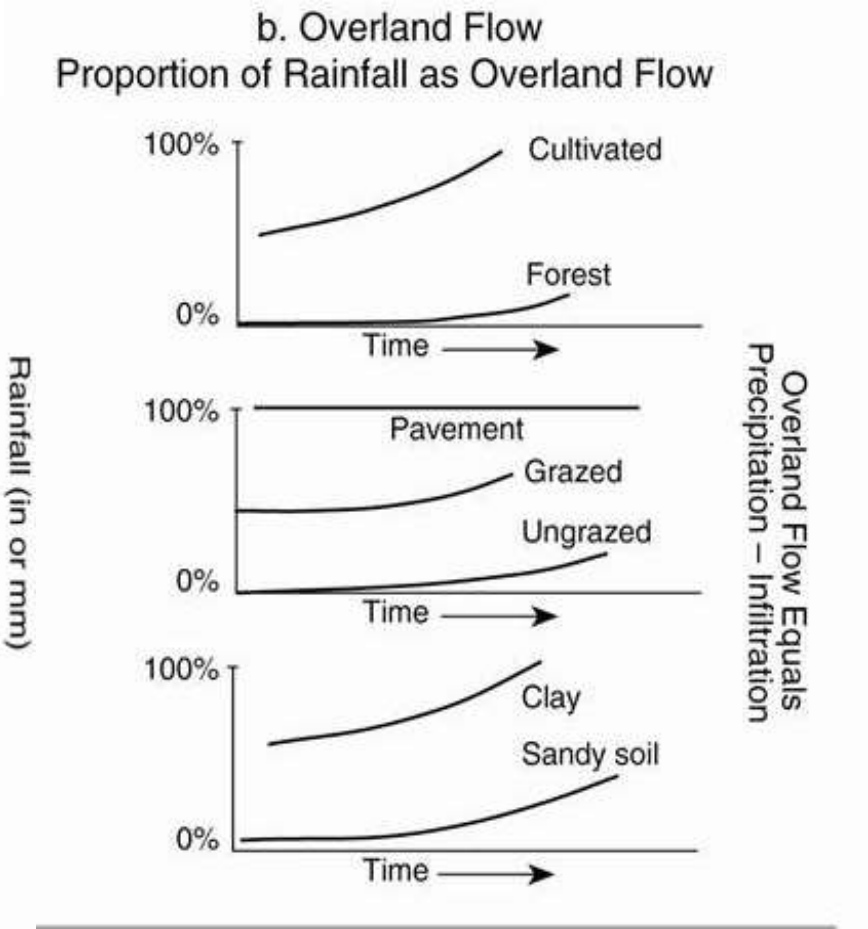
Delayed and lower peak flow



Watersheds with different drainage densities

Effect of land use on runoff





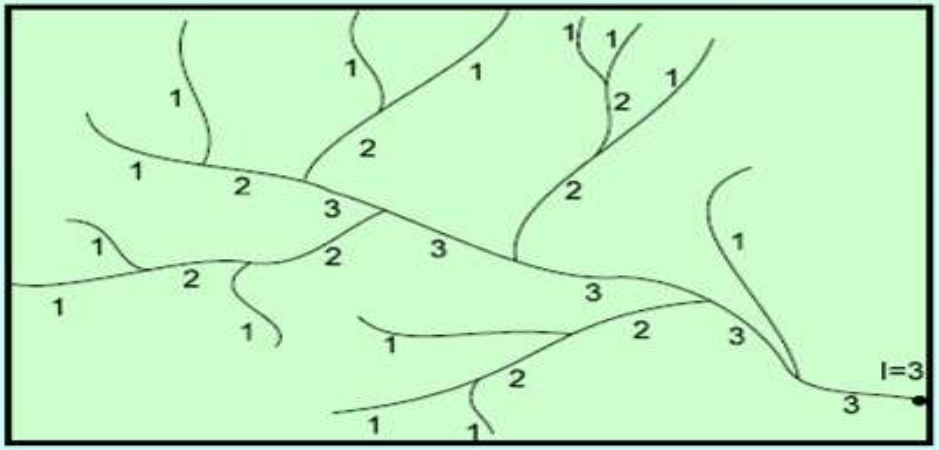
Runoff

Drainage Patterns

- watersheds are typically characterized by one main drainage channel and a series of tributaries that ultimately drain into the main channel
- the concept of **stream order** was developed in order to quantify the drainage network
- the smallest tributaries of the watershed are classified as Order 1
- the segment where 2 first-order streams meet is classified as Order 2
- order 3 stream segments exist where two Order 2 streams meet
- this classifying continues until the main channel at the watershed outlet has been classified

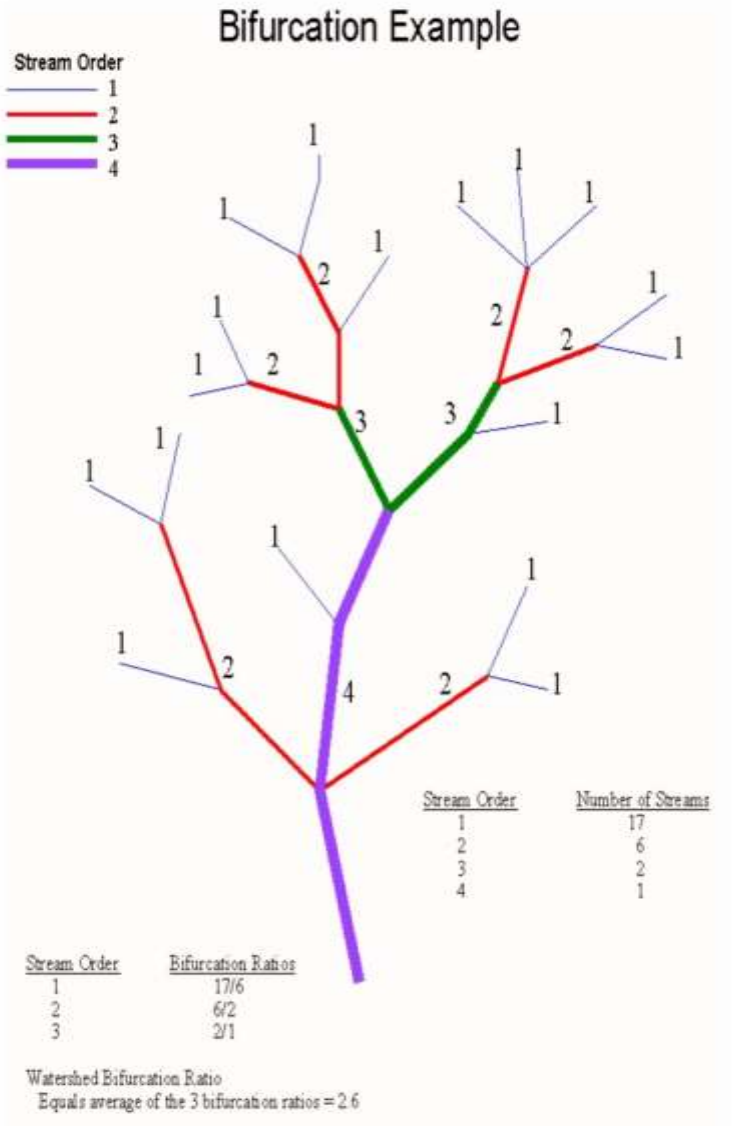
When a channel of lower order joins a channel of higher order, the channel downstream retains the higher of the two orders.

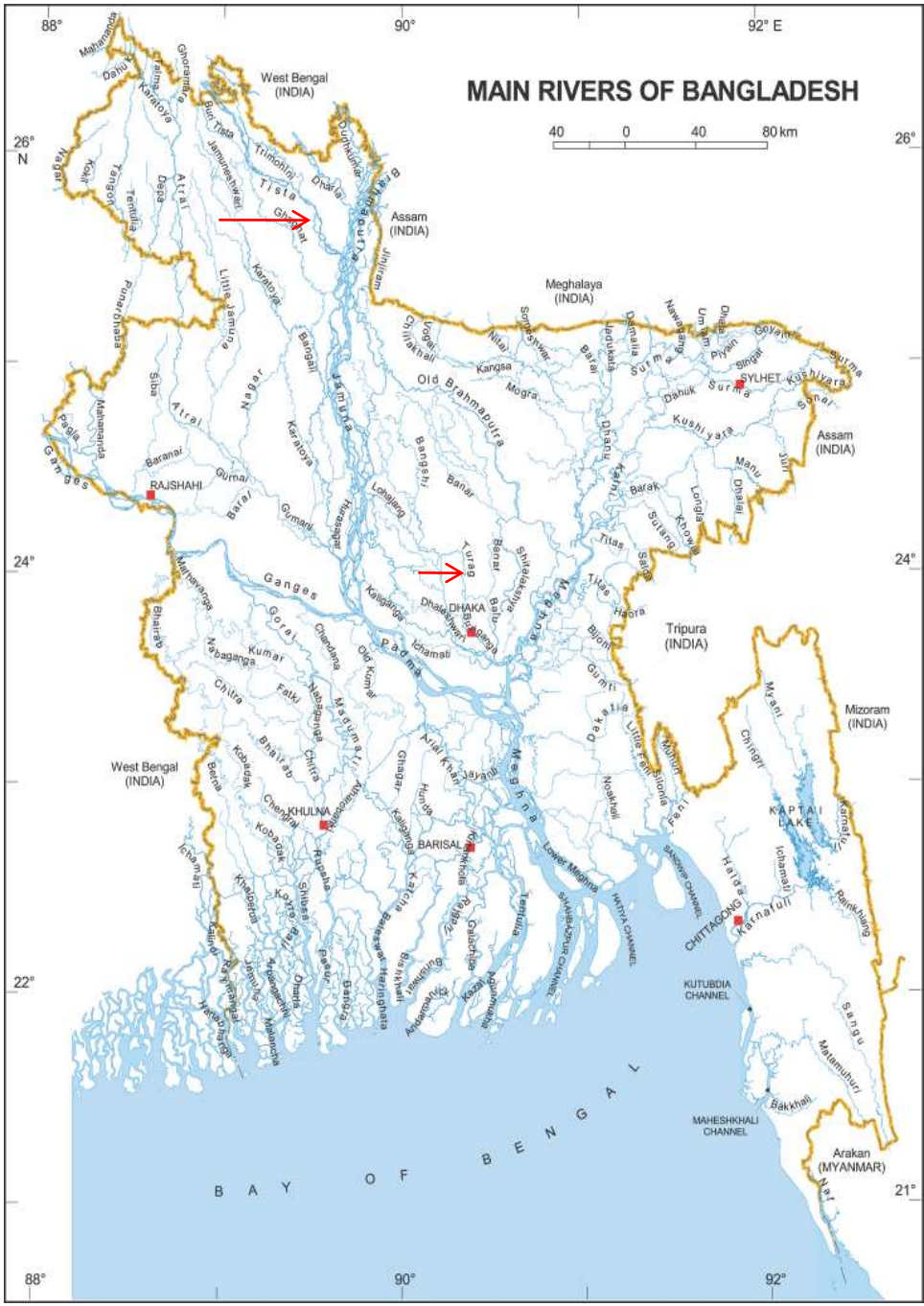
The Mississippi River is Order 12 at its mouth



Tributary: a stream that flows to a larger stream or other body of water.
Distributary: an outflowing branch of a stream or river, typically found in a delta (as opposed to tributary).

Teesta is a tributary of the Brahmaputra/Jamuna and Turag is a distributary of the Brahmaputra/Jamuna.





Runoff

Elements of Hydrograph

The three elements of a hydrograph are: rising limb, falling limb (recession curve) and crest (peak discharge).

The rising limb represents the increasing discharge (stage) with time as the runoff starts reaching the gauge.

The crest or peak discharge is the highest discharge (stage) within the hydrograph and is primarily needed for the hydrologic design.

The portion of the hydrograph after the peak is the falling limb.

The recession limb starts from the point of inflection of the falling limb and represents the starting point of withdrawal of water from basin storage (interflow and groundwater flow).

Recession Curve

The recession limb (recession curve) for a watershed can be expressed as:

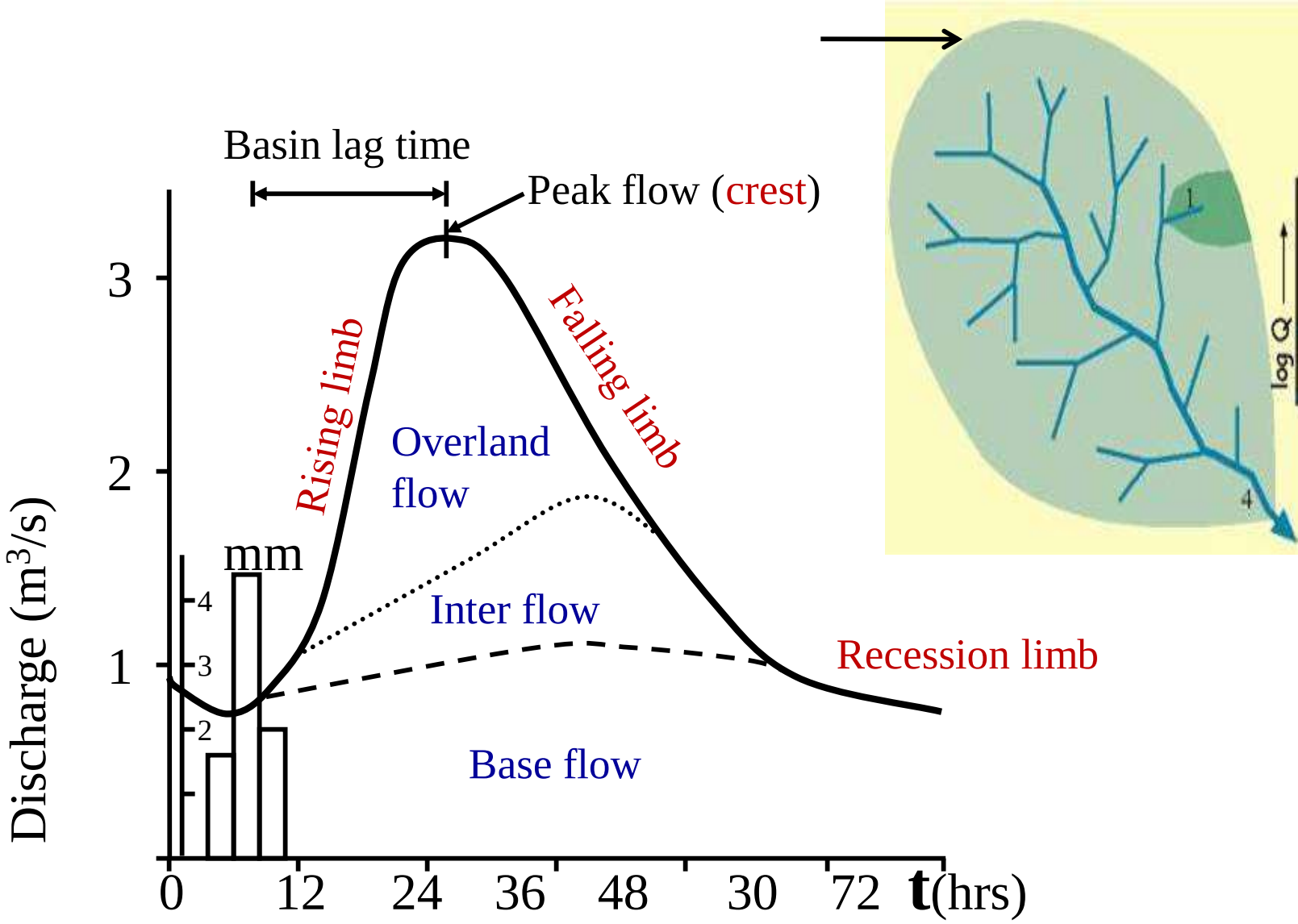
$$Q_t = Q_0 K_r^t$$

Where, Q_0 and Q_t are the initial discharge (at the start of recession) and discharge at time t from recession and K_r is the recession constant. The value of K_r is < 1.

Taking log both sides of the above equation:

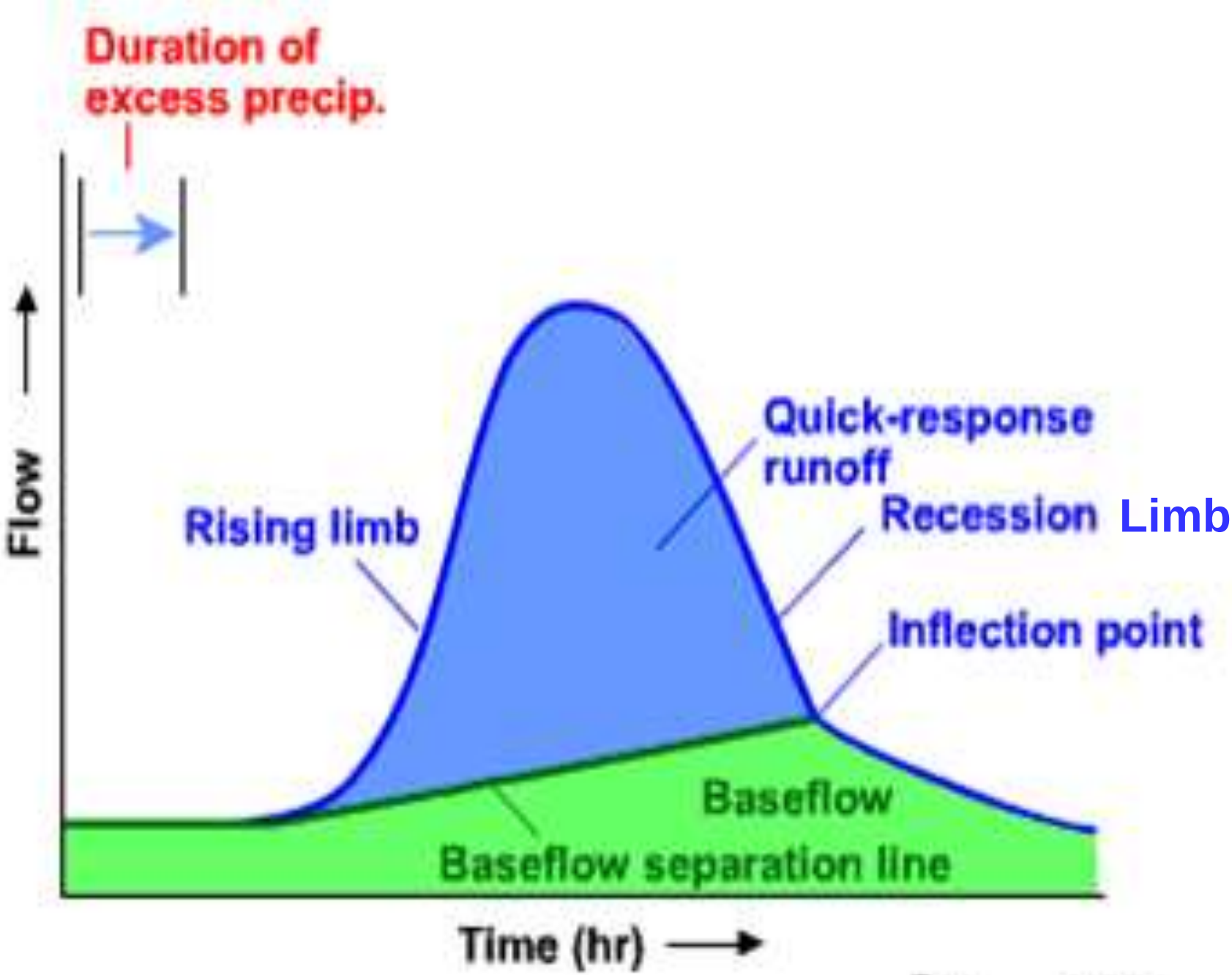
$$\log Q_t = \log Q_0 + t \log K_r$$

As Q_0 and K_r of the above equation are constants, a plot of t in the normal scale and Q_t in the log scale will be a straight line in the semi-log paper with $\log K_r$ as the slope.



___ Components of hydrograph

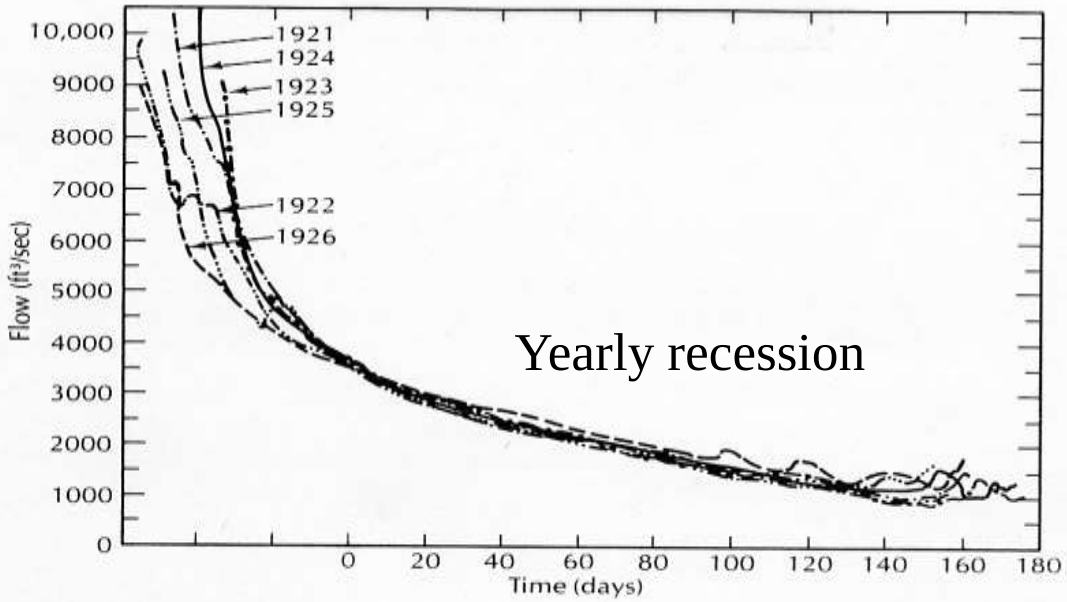
___ Elements of Hydrograph


Duration of
excess precip.
Flow
Rising limb
Quick-response
runoff
Recession Limb
Inflection point
Baseflow
Baseflow separation line
Time (hr)

Recession Limb

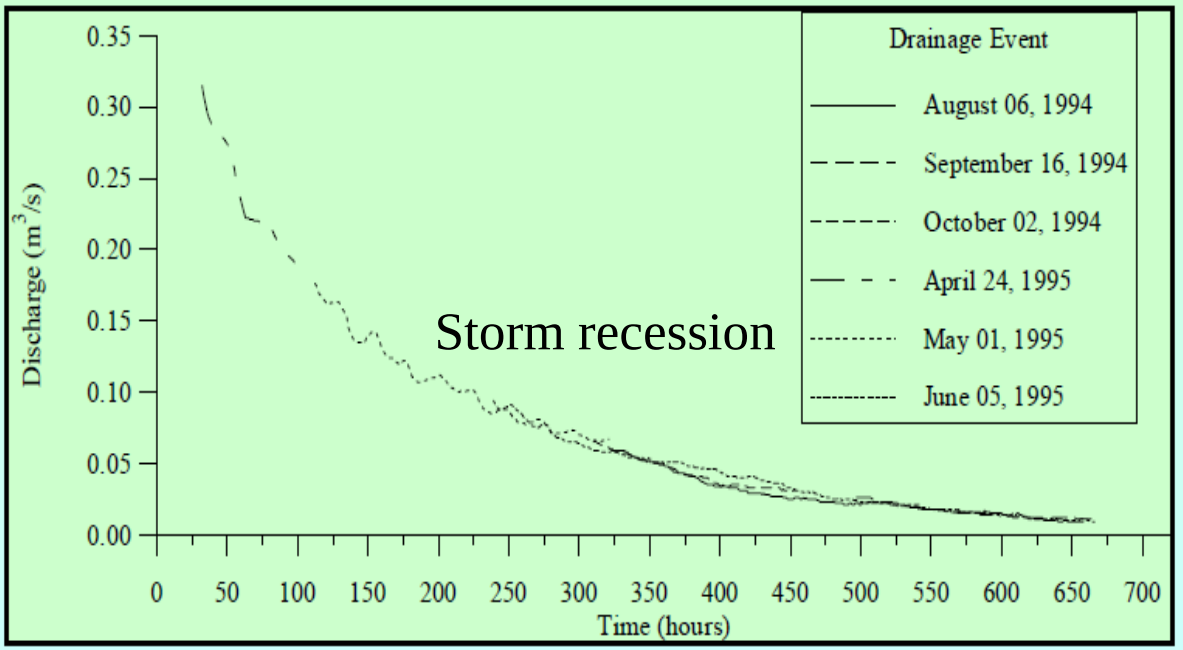
- It extends from the point of inflection at the end of the crest segment to the start of the natural groundwater flow
- It represents the withdrawal of water from the storage built up in the basin during the earlier phases of the hydrograph.
- The starting point of the recession limb (the point of inflection)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

Recession Curve



Yearly recession

FIGURE 3.7 Annual baseflow recessions for six consecutive years for the Lualaba River, Central Africa. Source: C. O. Wisler & E. F. Brater, eds., *Hydrology*, 2nd ed. (New York: John Wiley, 1959). Used with permission.



Storm recession

Runoff

Recession Constant

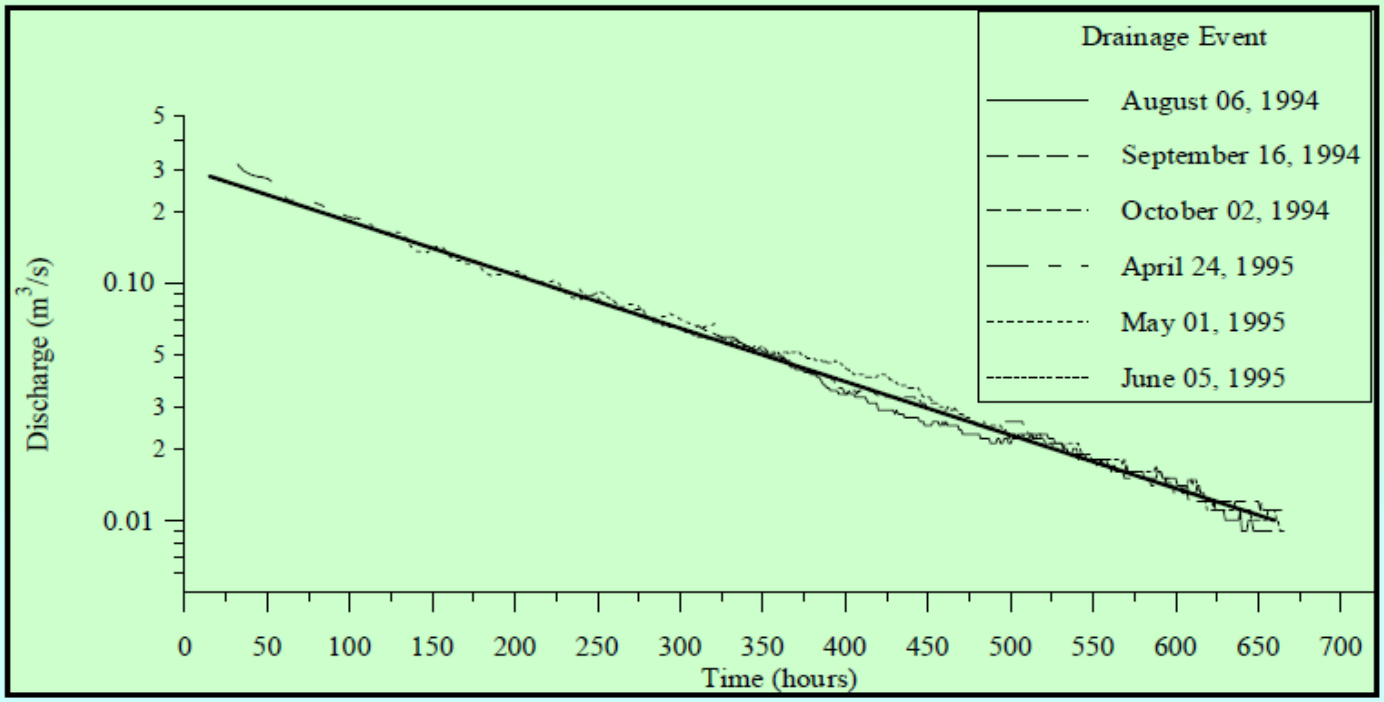
The recession equation can also be written as:

$$Q_t = Q_0 K_r^t$$

Taking log both sides: $\log Q_t = \log Q_0 + t \log K_r$

As Q_0 is a constant, a plot of t in the normal scale and Q_t in the log scale will be a straight line in the semi-log paper from which the value of the slope will give the value of K_r. A plot of log or ln of Q_t and t in normal paper would also give K_r.

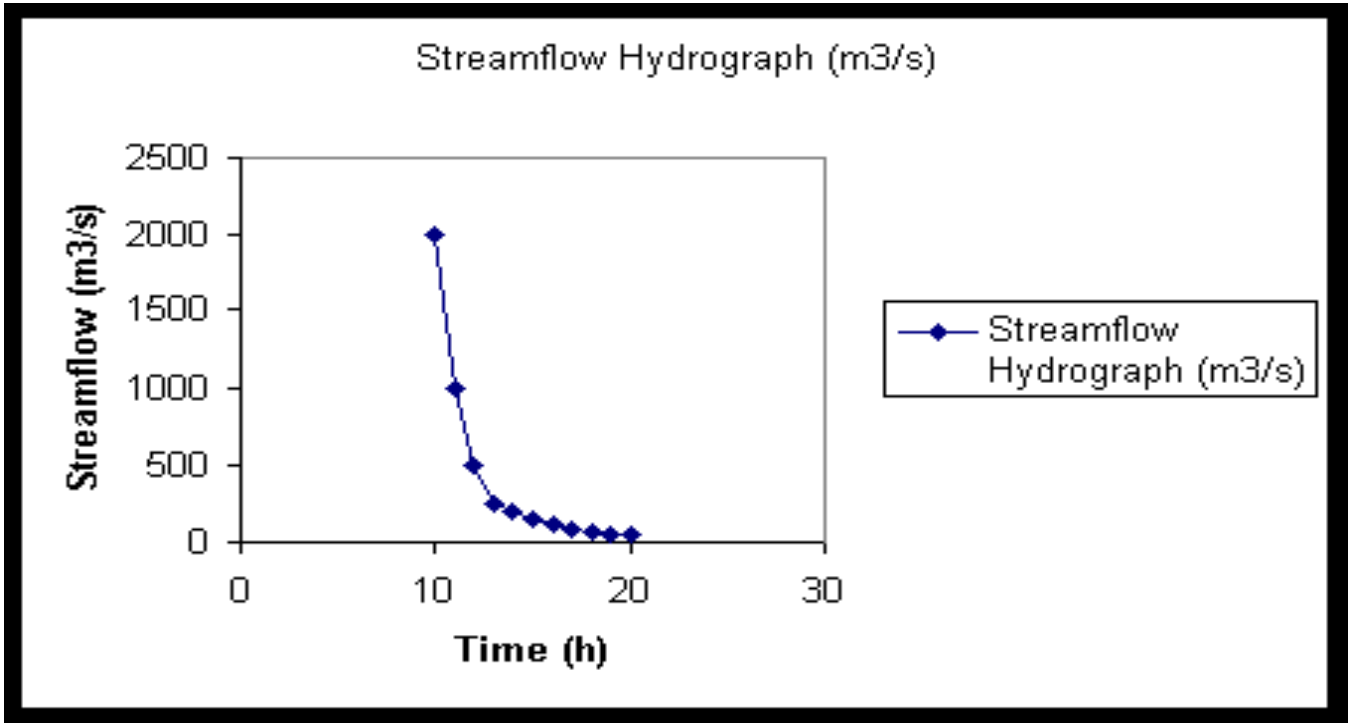
Note: the value of K_r must be < 1.

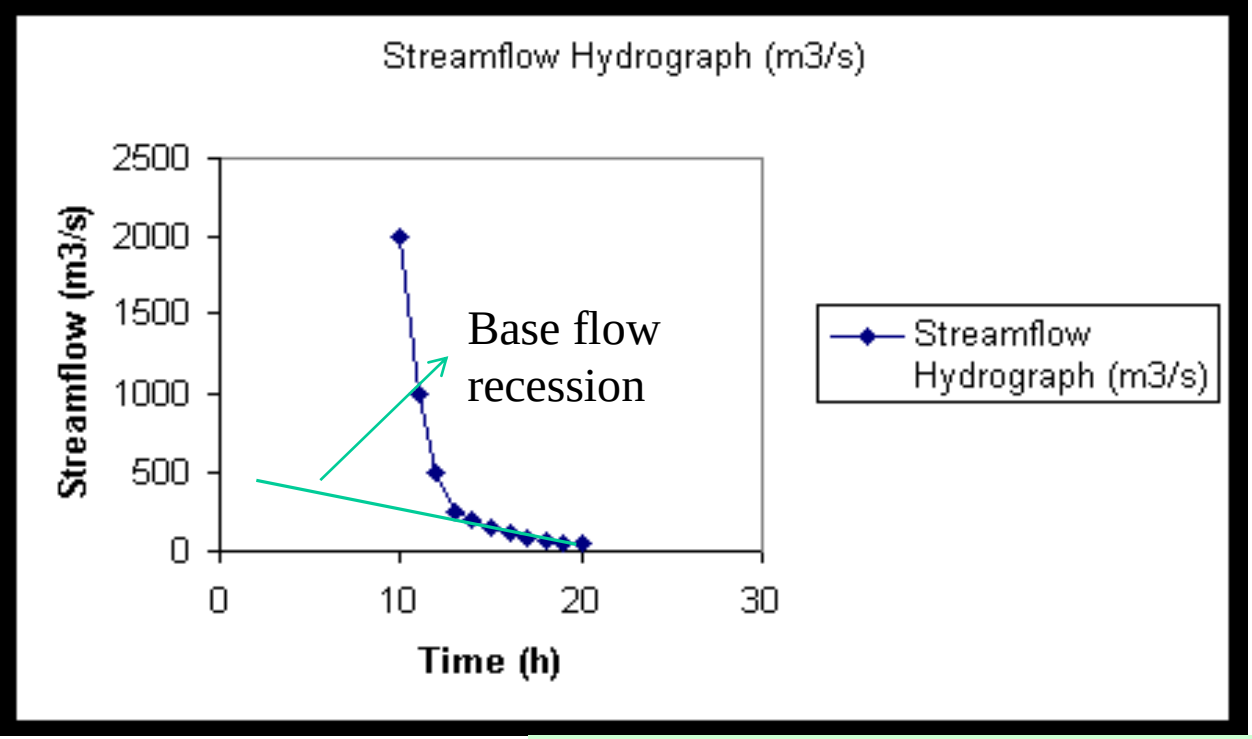


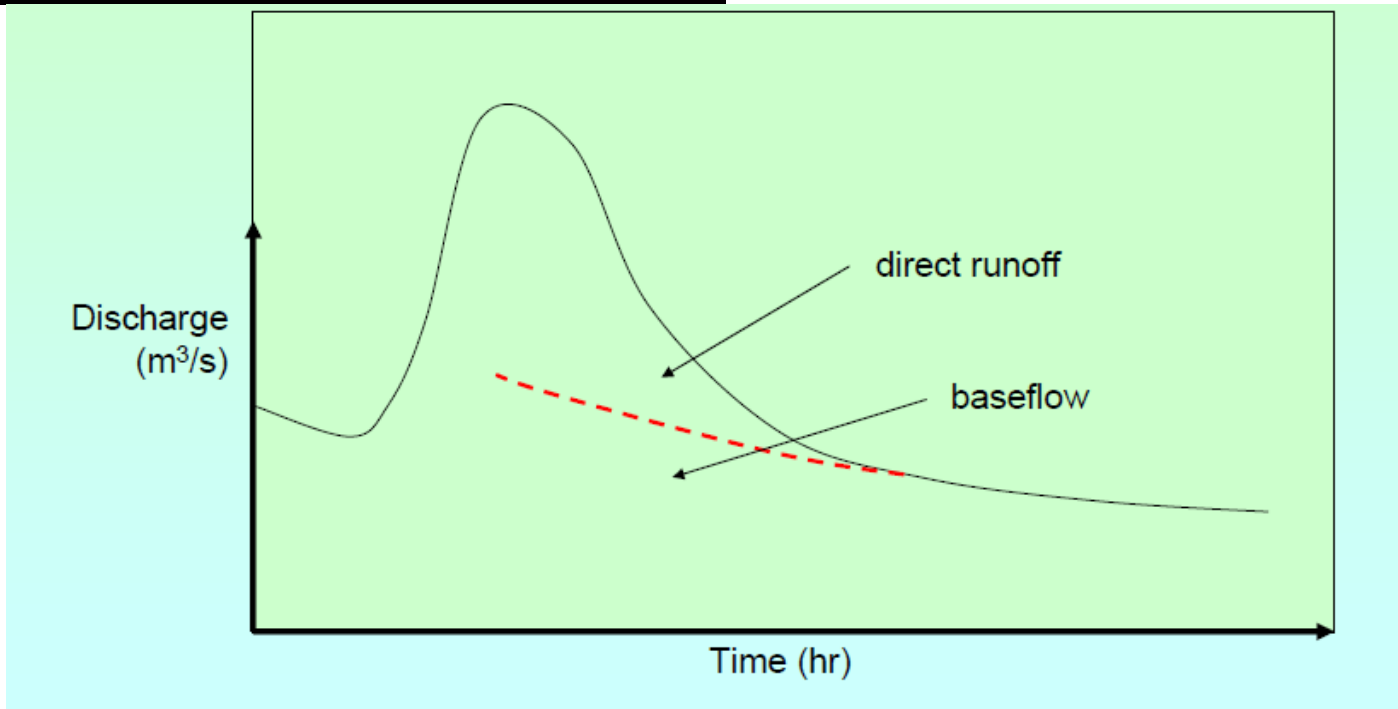
Example

Obtain the recession constant and the recession equation using the following data. The table below presents the recession limb of a total streamflow hydrograph.

Time (h)	Streamflow Hydrograph (m^3/s)
10	2000
11	993
12	493
13	245
14	191
15	149
16	116
17	90
18	70
19	55
20	43



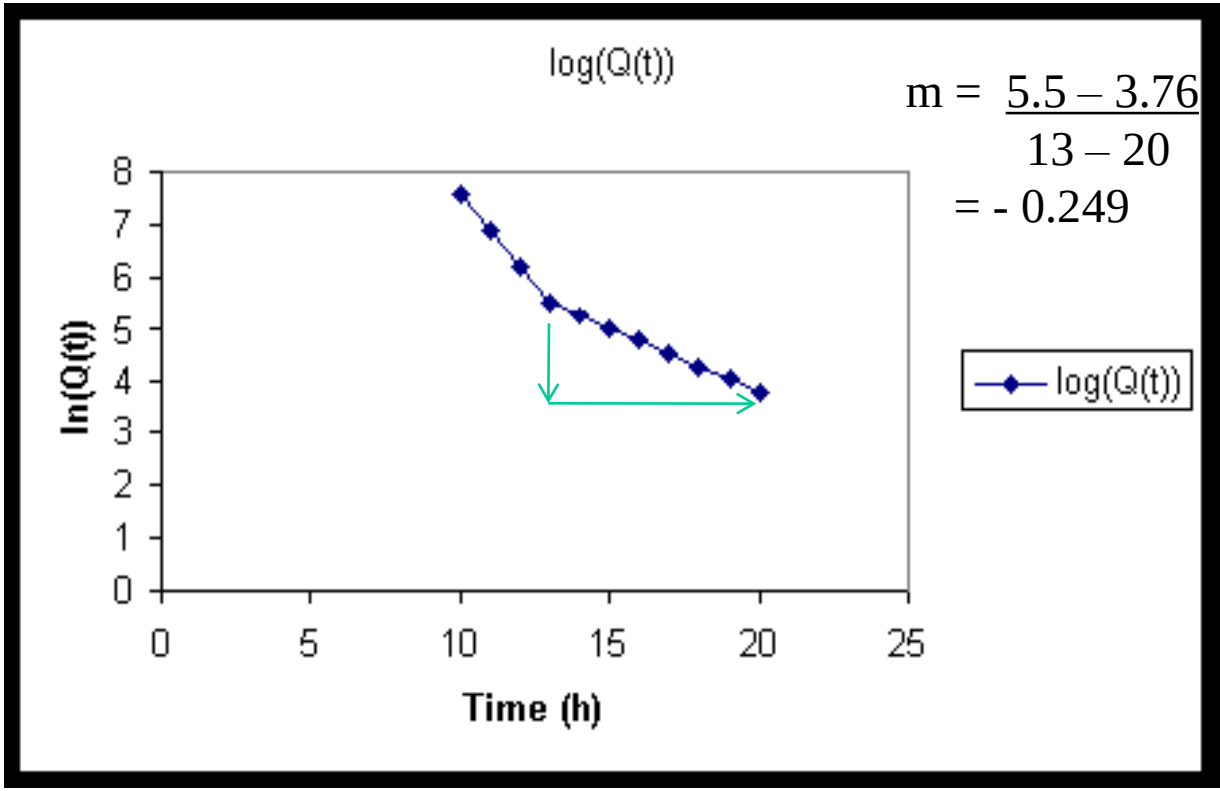

Streamflow Hydrograph (m3/s)
Streamflow (m3/s)
2500
2000
1500
1000
500
0
0
10
20
30
Time (h)
Base flow recession
Streamflow Hydrograph (m3/s)


Discharge (m^3/s)
direct runoff
baseflow
Time (hr)

Because there exist several distinct storages in a basin, the recession limb of hydrographs includes contributions from all of those storages. Thus, the procedure outlined below can be used sequentially to obtain the corresponding recession constants for each one of the storages (surface, interflow and subsurface). The existence of the different storages is easily observable in the semi-log domain as shown in the graph.

In the graph the recession starts at time t = 13 h ($t = t_0$ and $Q = Q_0$). Thus, for t > 13 h the recession constant is obtained as the slope of the line as log K = - 0.249.

Time (h)	Streamflow Hydrograph (m3/s)	ln(Q(t))
10	2000	7.600902
11	993	6.900731
12	493	6.200509
13	245	5.501258
14	191	5.252273
15	149	5.003946
16	116	4.75359
17	90	4.49981
18	70	4.248495
19	55	4.007333
20	43	3.7612



$$m = \frac{5.5 - 3.76}{13 - 20} = -0.249$$

The recession equation is : $\log Q_t = \log Q_0 + t \log K_r$

Since, $\ln K_r = -0.249$ $K_r = e^{-0.249}$ or $K_r = 0.78$

From the graph: $Q_0 = 245$

So, the recession equation is: $Q_t = 245\ (0.78)^t$

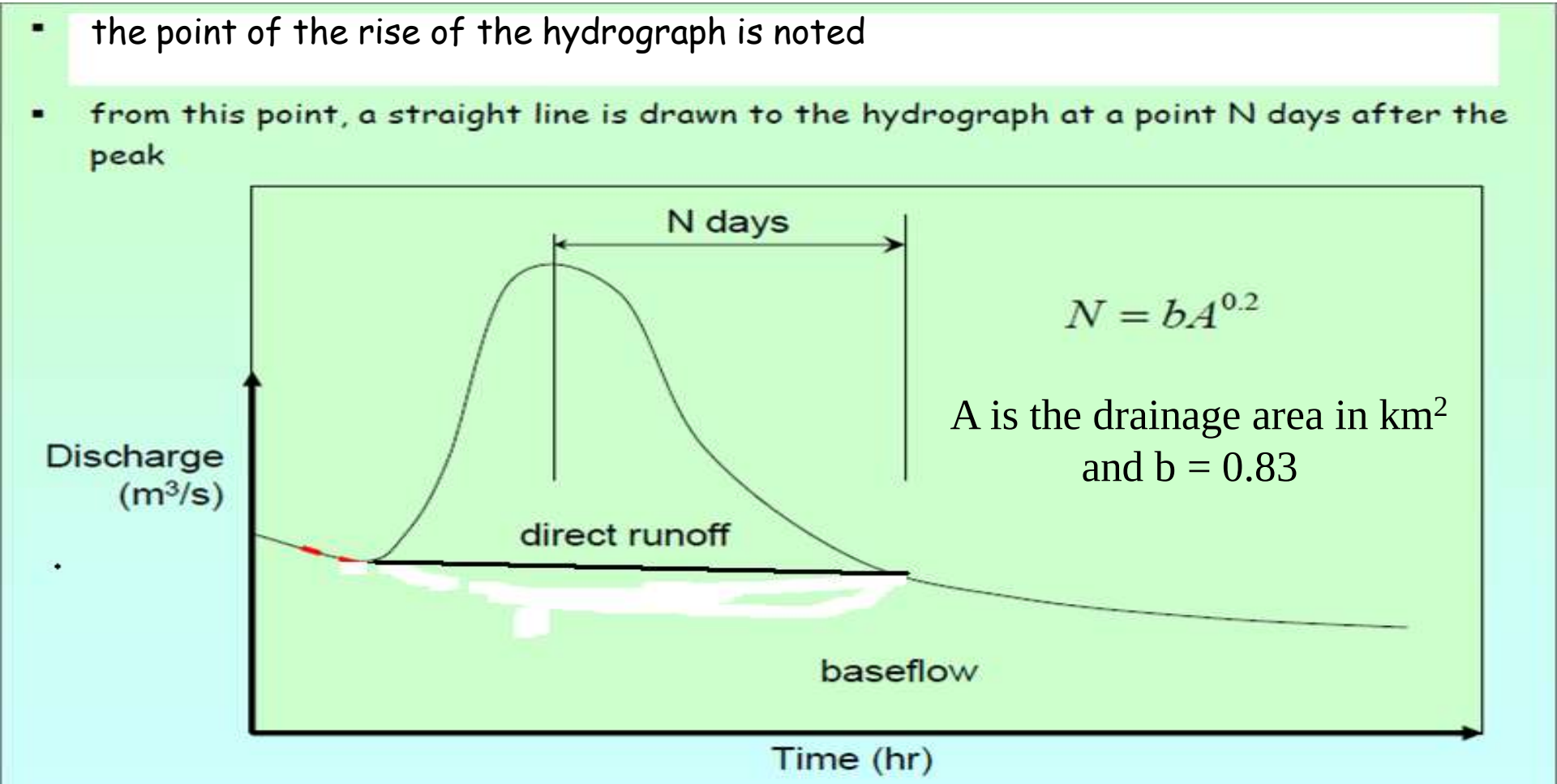
Runoff

Hydrograph Separation

The separation of direct runoff and base flow of a hydrograph is known as hydrograph separation or base flow separation. There are three methods of separating the base flow from the hydrograph. The methods are described below.

Method I

- the point of the rise of the hydrograph is noted
- from this point, a straight line is drawn to the hydrograph at a point N days after the peak

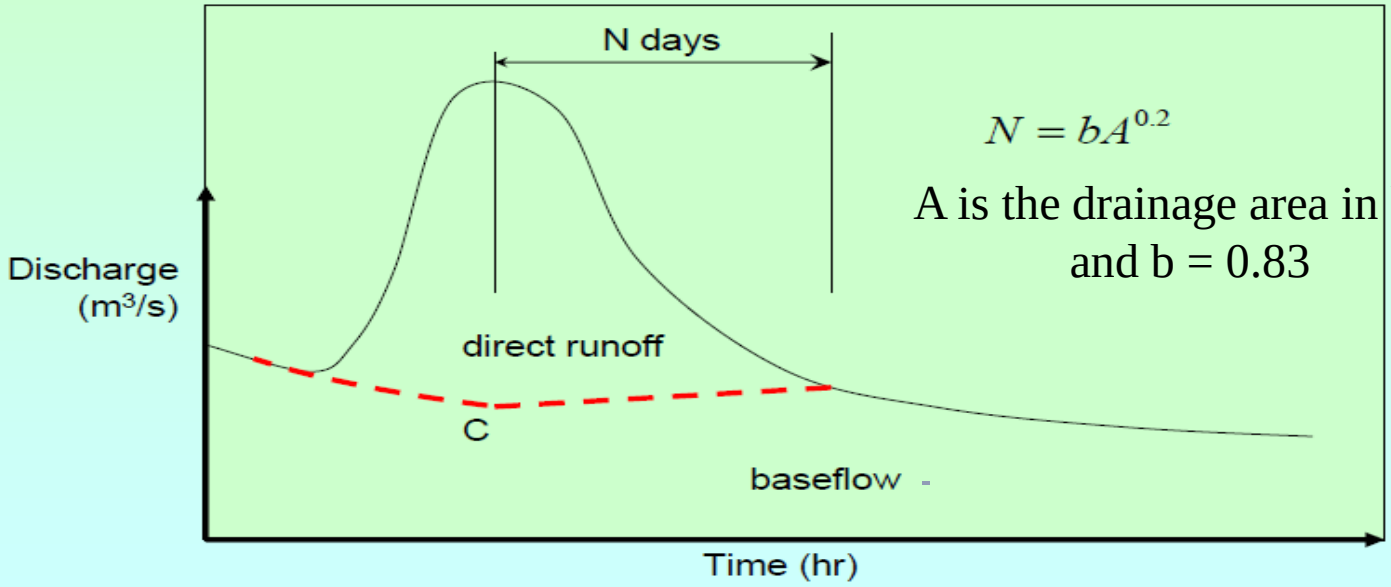


$$N = bA^{0.2}$$

A is the drainage area in km^2 and b = 0.83

Method II

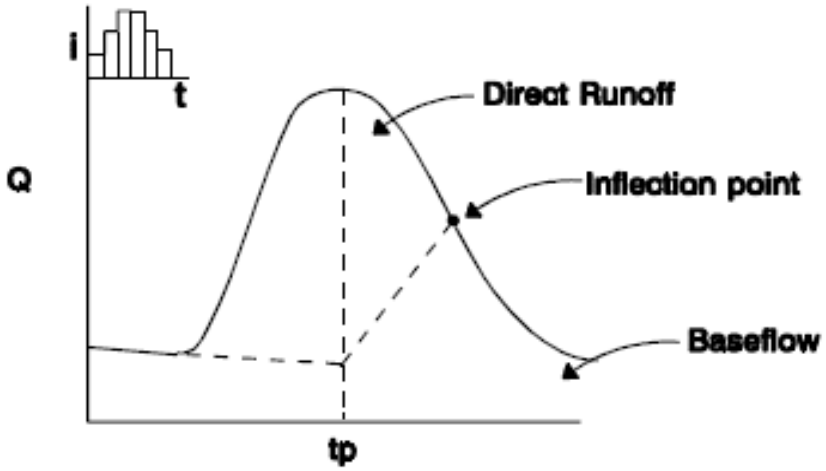
- an alternative approach is to project the initial recession curve downward to a point directly beneath the hydrograph peak (Point *C*)
- from this point, a straight line is drawn to the hydrograph at a point N days after the peak



$$N = bA^{0.2}$$

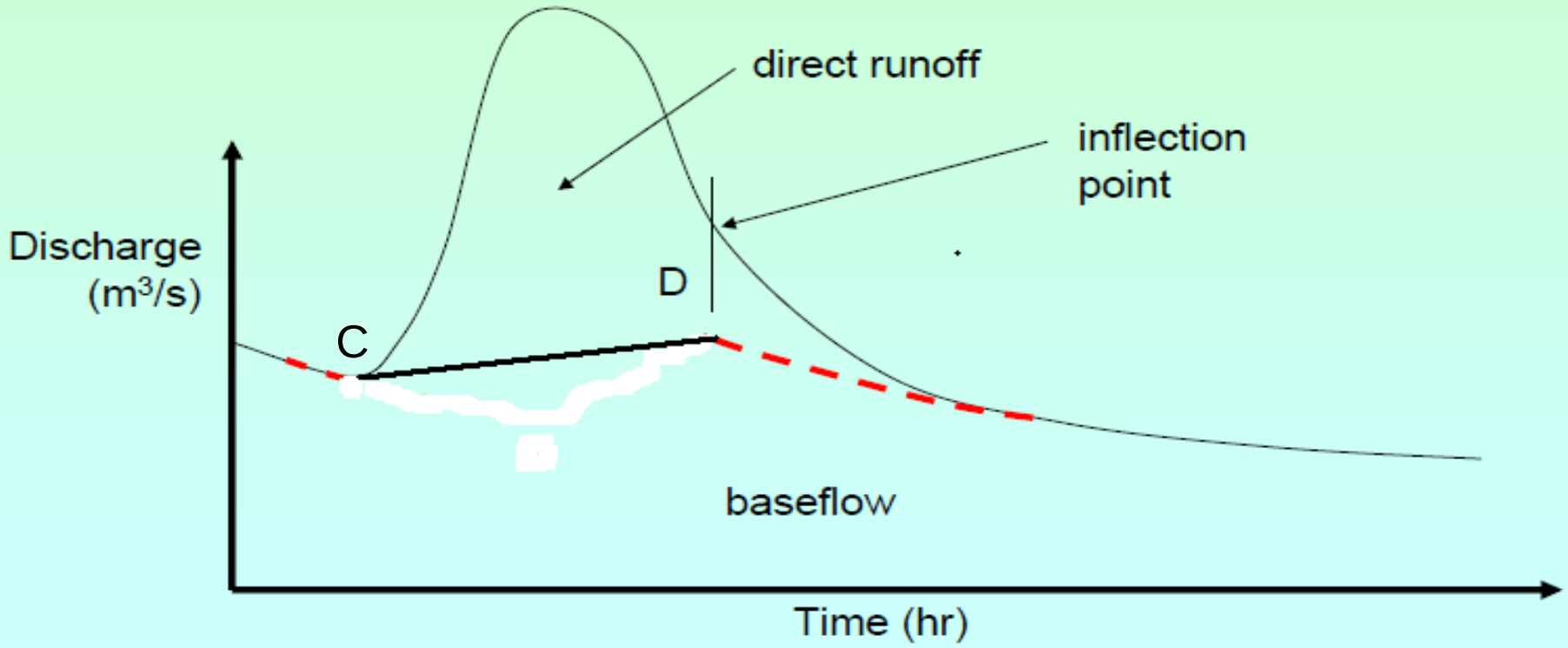
A is the drainage area in km^2 and b = 0.83

When N is too large, a modification is applied by connecting C with the point of inflection of the falling limb.



Method III

- the previous approach can be extended by making use of the baseflow recession curve
- we can project the recession curve backwards under the hydrograph to some point D, chosen somewhat arbitrarily below the inflection point of the hydrograph
- connecting points C and D allow us to separate the baseflow component



A modification of this method is to extend the recession curve up to the peak level and then connect the point with C.