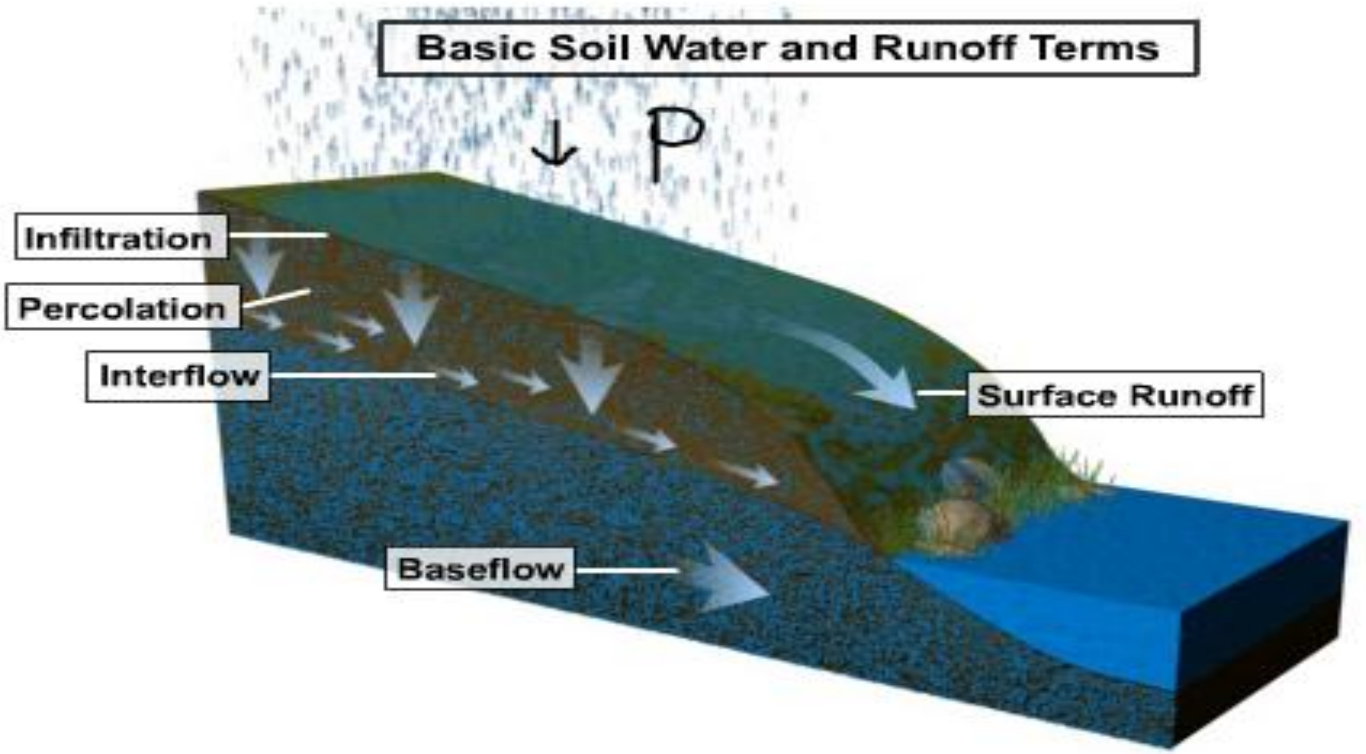
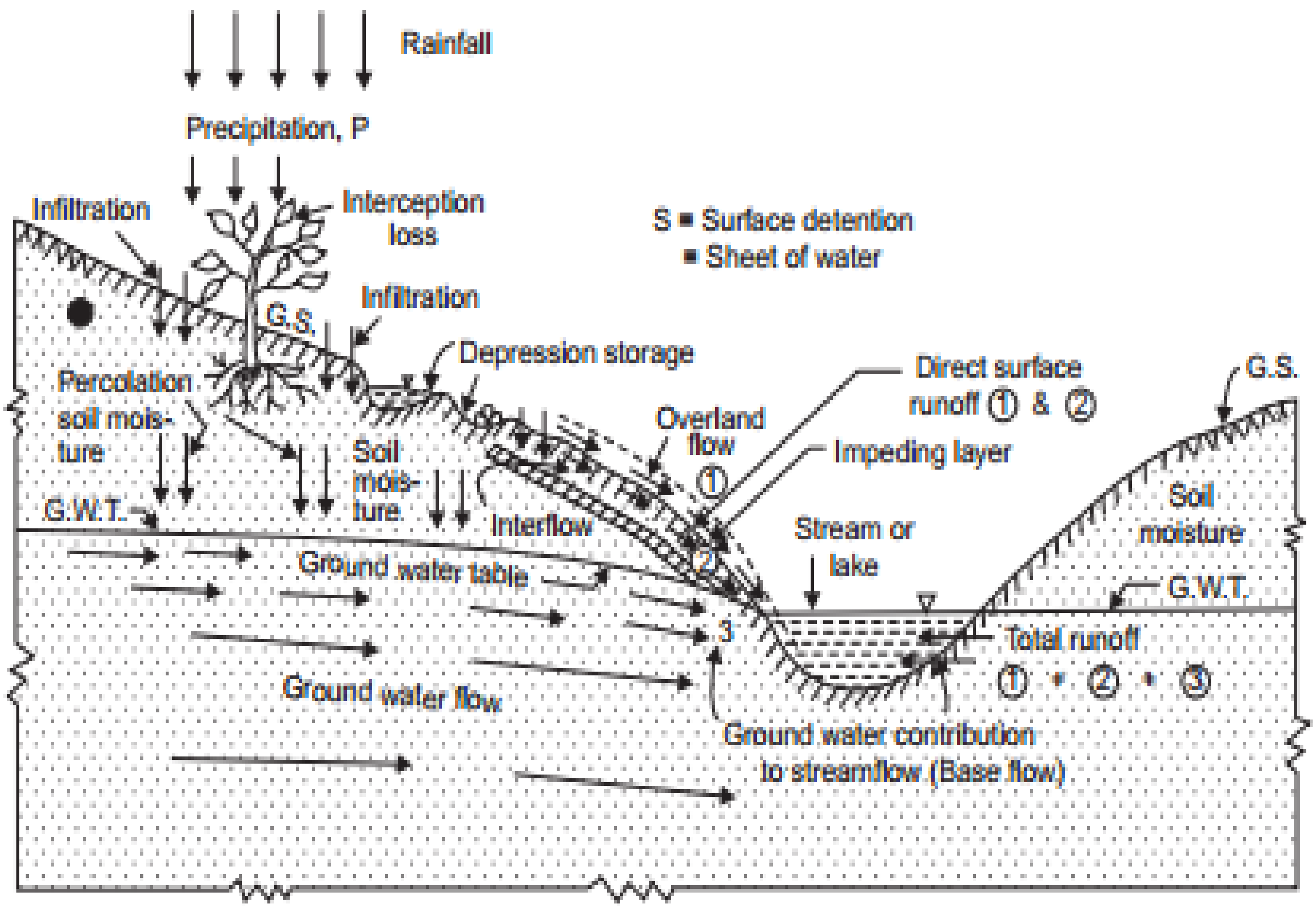
Runoff

❖ What is runoff ?

Runoff is often defined as the portion of rainfall, that runs over and under the soil surface toward the stream



COMPONENTS OF Runoff or STREAM FLOW



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- The types of runoff or flow or stream flow are

❖ Overland flow is a thin sheet of water that flows over the land surface

❖ Underflow (subsurface flow) or interflow is the movement of water in the subsoil laterally

❖ Base flow is the ground water flow to the stream

❖ Speed of flow: overland flow> interflow> base flow.

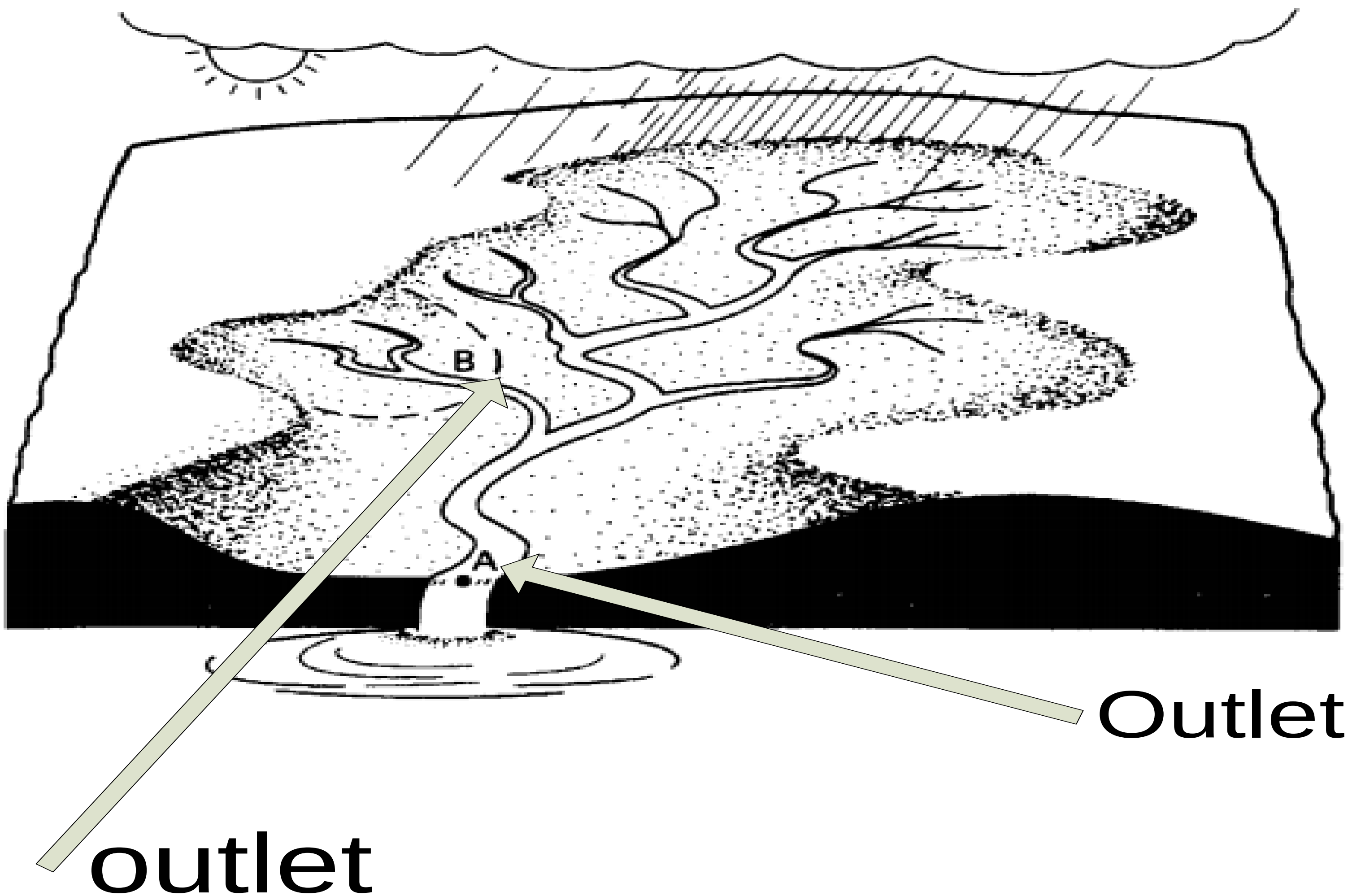
❖ Direct surface runoff = overland flow + interflow

❖ To total runoff = Overland flow + interflow + base flow

Catchment or drainage basin or Watershed Characteristics

- The concept of a watershed is basic to all hydrologic designs. Since large watersheds are made up of many smaller watersheds, it is necessary to define the watershed in terms of a point this point is usually the location at which the design is being made and is referred to as the watershed "outlet."
- With respect to the outlet, the watershed consists of all land area that sheds water to the outlet during a rainstorm.
- Using the concept that "water runs downhill," a watershed is defined by all points enclosed within an area from which rain falling at these points will contribute water to the outlet.

A watershed with outlets at point A and B

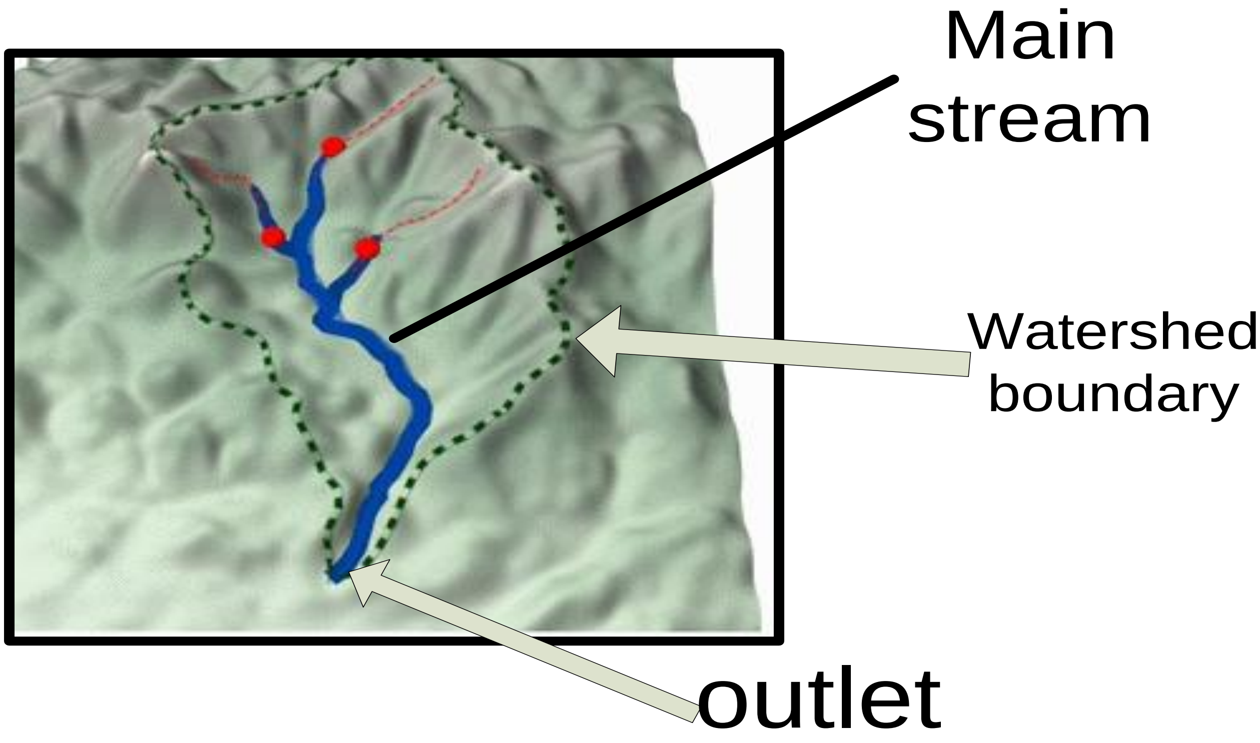


Factors that affect runoff

1. WATERSHED GEOMORPHOLOGY

- ❖ Drainage Area

- ➢ The drainage area (A) is probably the single most important watershed characteristic for hydrologic design. It reflects the volume of water that can be generated from rainfall.



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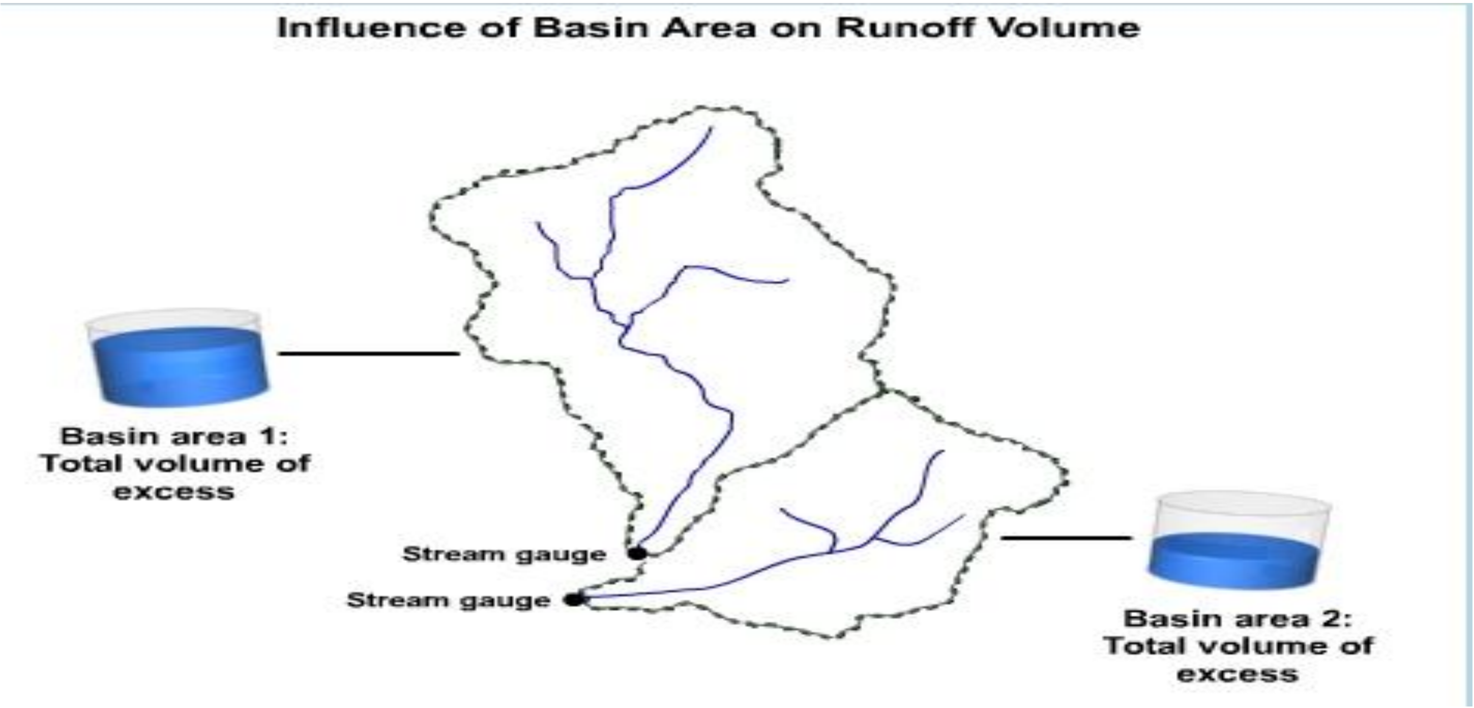
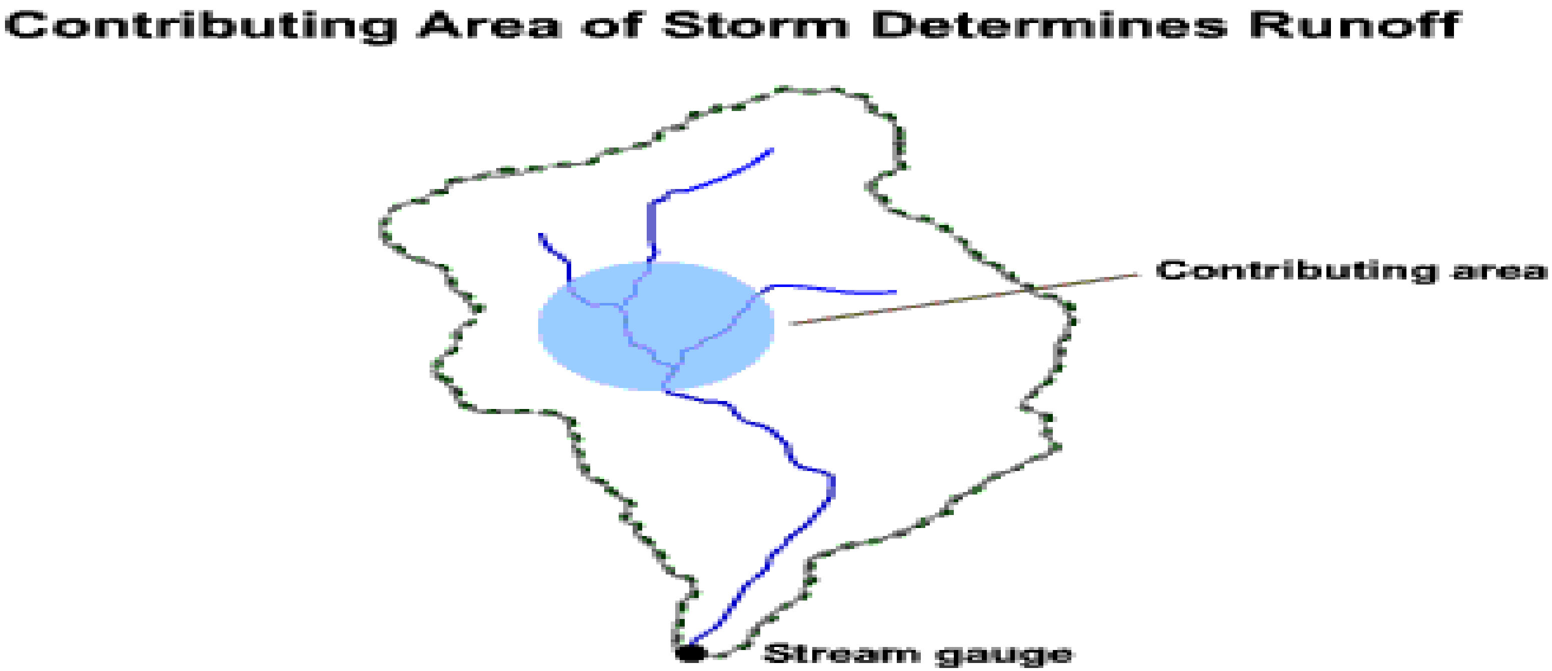


- It probably comes as no surprise that when rain falls in a uniform manner over a larger basin and a smaller basin, the larger basin produces more runoff volume

Cont….



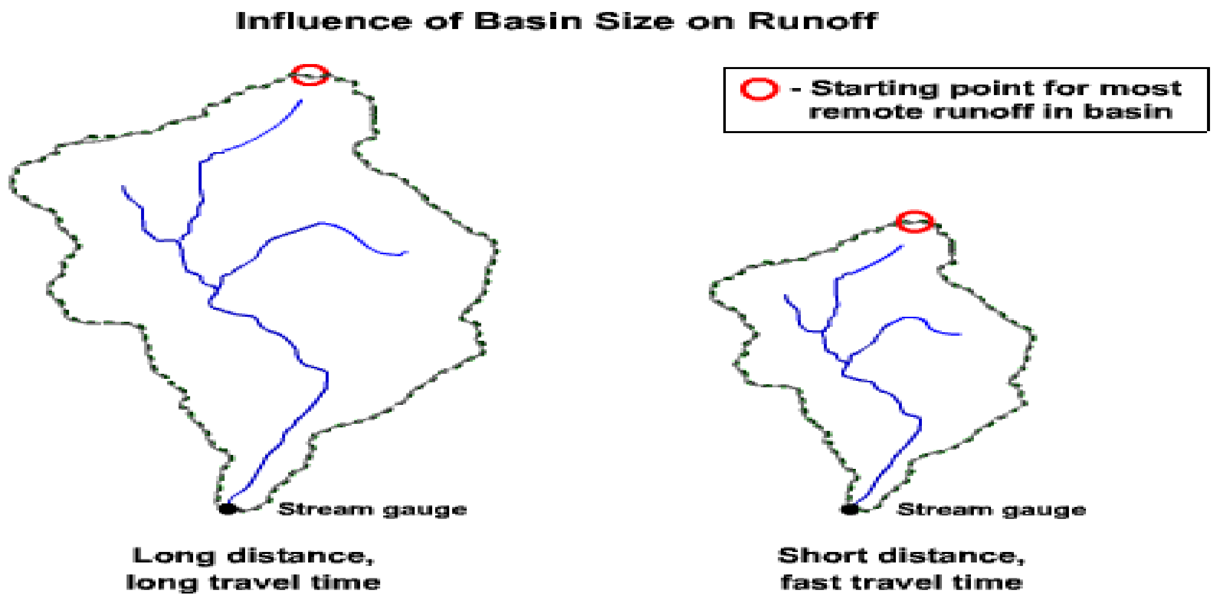
- Of course many storms will cover only part of a basin. So for most situations, the runoff volume will be determined by the contributing area—that part of the basin covered by a storm—not the total size of a basin.

Cont….

❖ Watershed Length

- The length (L) of a watershed is the second watershed characteristic of interest. While the length increases as the drainage area increases, the length of a watershed is important in hydrologic computations; for example, it is used in time-of-concentration calculations
- Watershed length is usually defined as the distance measured along the main channel from the watershed outlet to the basin divide
- The length is measured along flow path

Cont…



- consider two similarly shaped basins, with one larger than the other. Runoff traveling from most upstream point of the larger basin will travel a longer path, and therefore take longer to reach the basin outlet than runoff traveling from the farthest point in the smaller basin. In addition, a single thunderstorm will likely only impact a portion of the large basin at any given time, but it may envelope the entire small basin.

Cont…

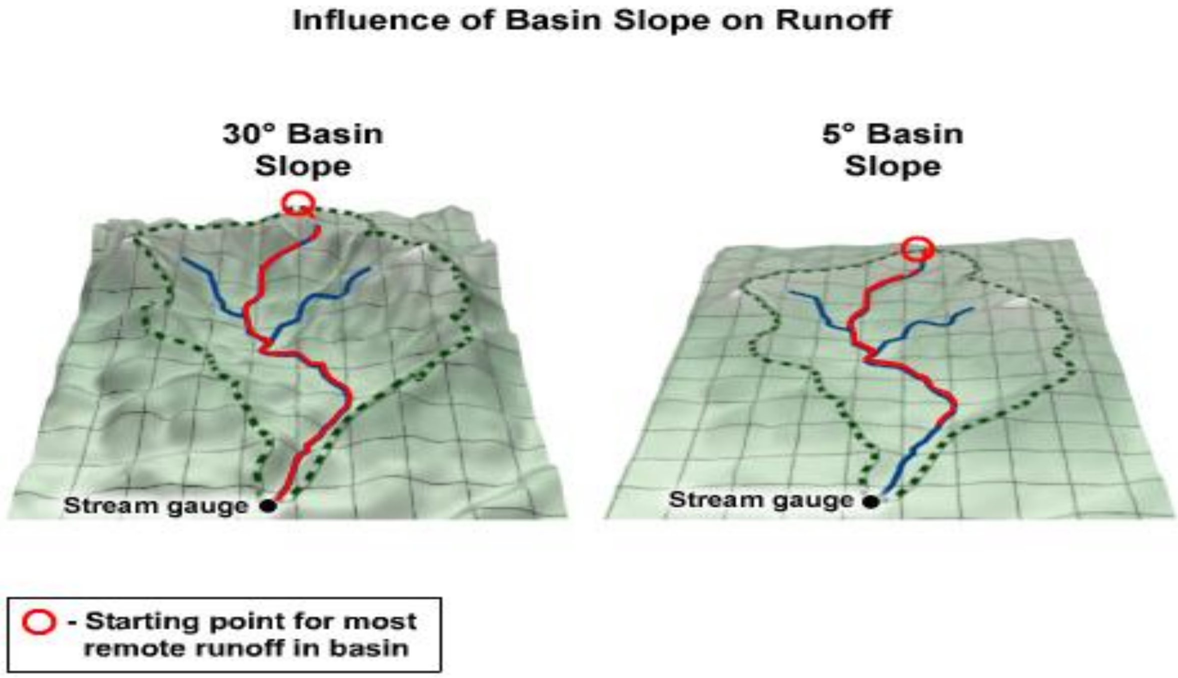
- ❖ Watershed Slope

- ➢ Watershed slope reflects the rate of change of elevation with respect to distance along the principal flow path.

- ➢ Typically, the principal flow path is delineated, and the watershed slope (S) is computed as the difference in elevation (E)between the end points of the principal flow path divided by the hydrologic length of the flow path (L):

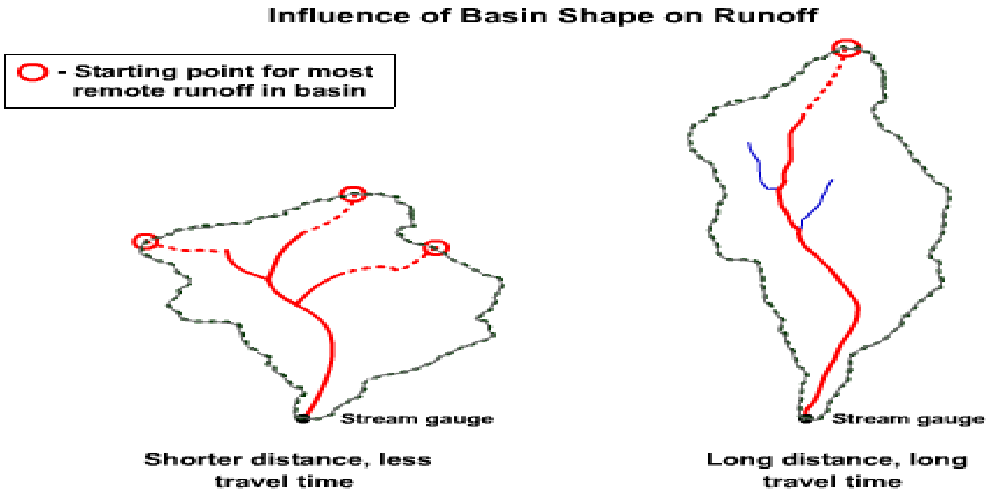
- ❖ Watershed Shape : watershed have a lot of different shapes though the shapes are not directly used in hydrological design

Cont…



- As the slope of the land increases several factors come into play. The first is that water contact to the surface is no longer perpendicular. With the land sloping, gravity no longer pulls the water directly into the ground, so more water is likely to become surface runoff.
- Another factor is the movement of water across the land surface. As the ground becomes increasingly steep, water will move faster and will have less time in contact with the ground surface, reducing the time during which it could infiltrate

Cont….



- Basin shape also has an influence on magnitude and timing of the peak flow at the basin outlet.
- Consider two basins of equal area where one is long and narrow, and the other is more round. Then consider runoff traveling from the farthest point in each basin to their respective outlets. The runoff in the more round basin will arrive more quickly at the basin outlet.

Cont…

2. Land Cover and Use

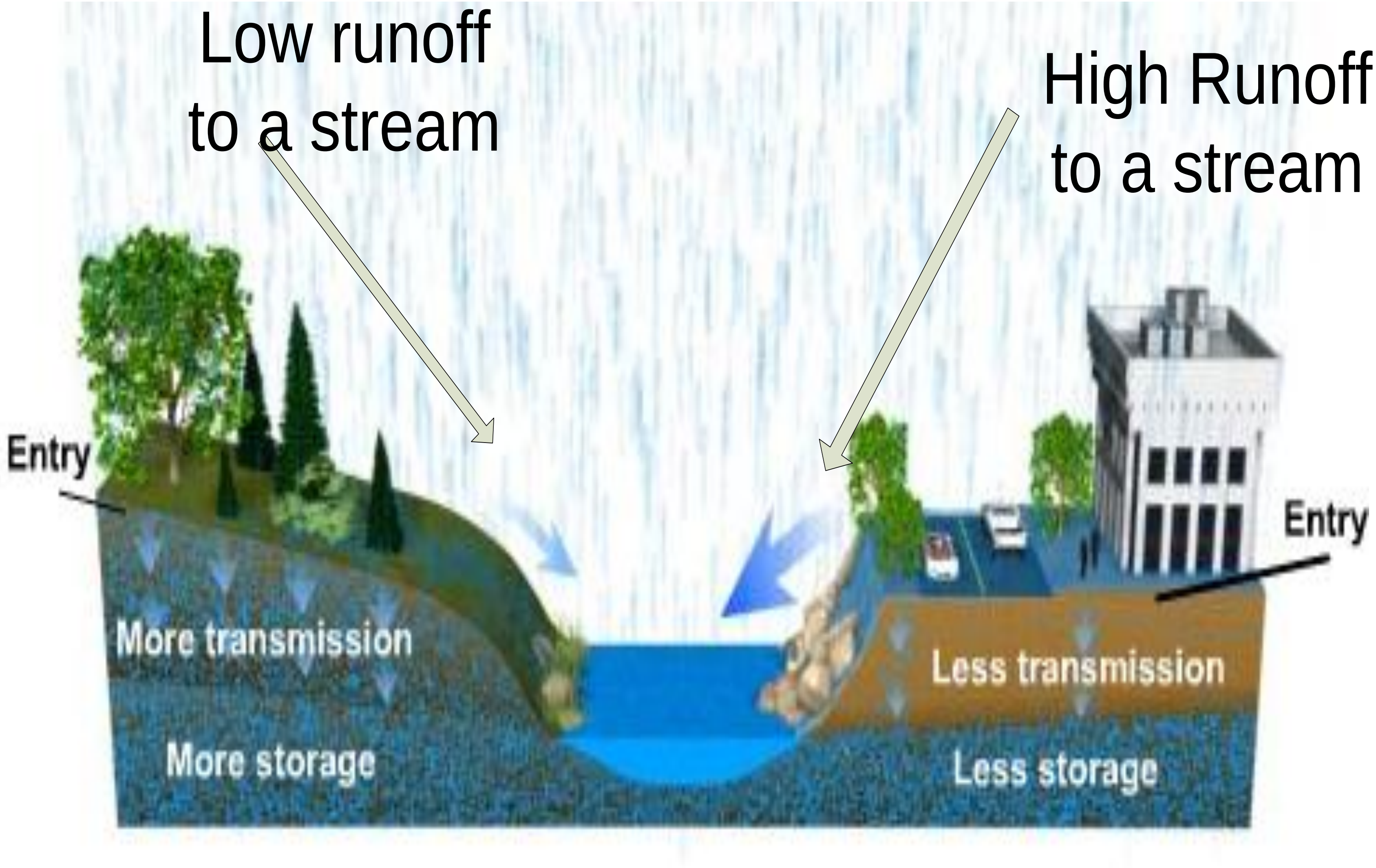
- Different land covers and use have different runoff coefficients and affect the rate of runoff

3. Soil type

- As soil types varies spatially, the property of runoff also varies

4. Climatic factors

How land use and cover affect runoff



ESTIMATION OF RUNOFF

- ❖ The run off from a catchment can be computed daily, monthly or yearly. The following are some of the methods for estimating the runoff :
- ➢ By linear or exponential regression
- ➢ Empirical formulae, curves and tables
- ➢ Rational method
- ➢ Infiltration method
- ➢ Unit hydrograph method
- ➢ Lumped Modeling
- ➢ Semi- distributed Modeling
- ➢ Distributed modeling

By linear regression method

- By Regression analysis

- Regression analysis is a procedure for fitting an equation to a set of data. Specifically, given a set of measurements on two random variables, y and x, regression provides a means for finding the values of the coefficients, b_0 and b, for the straight line ($y = b_0 + bx$) that best fits the data
- The mathematical model relates a random variable, called the criterion or dependent variable, to the unknowns and the predictor variable x, which is sometimes called the independent variable. The predictor variable usually has a causal relationship with the criterion variable.

Cont….

- The most frequently used linear model relates a criterion variable y to a single predictor variable x by the equation

$$\hat{y} = b_0 + b_1 x$$

Where

b_0, is the intercept coefficient and b_1 is the slope. The coefficients are often called regression coefficients because they are obtained from a regression analysis. As an example, one may attempt to relate runoff (R), the dependent variable to the predictor precipitation (P) using the linear model

$$R = b_0 + b_1 * P$$

Cont….

- The linear multivariate model relates a criterion variable to two or more predictor variables:

$$\hat{y} = b_0 + b_1x_1 + b_2x_2 + ... + b_px_p$$

Where

The predictors variables can be precipitation, area, slope etc

The coefficients are found by least square method as we have seen in chapter two

- Some times a non linear relationship between precipitation (P) and runoff (R) can be developed

$$R= cP^D$$

Where C and D are coefficients

Example

In the table below data for precipitation and runoff both in depths of cm are given for June during ten years from 1960 to 1969. Develop a linear equation relating precipitation and runoff

Year	P	R
1960	1.95	0.46
1961	10.82	2.85
1962	3.22	0.99
1963	4.51	1.40
1964	6.71	1.98
1965	1.18	0.45
1966	4.82	1.31
1967	6.38	2.22
1968	5.97	1.36
1969	4.64	1.21

solution

- The data were analyzed using regression analysis. Based on the summations given in Table below the slope and intercept coefficients are

$$\hat{y} = b_0 + b_1 x$$

$$nb_0 + b_1 \Sigma x = \Sigma y$$

$$b_0 \Sigma x + b_1 \Sigma x^2 = \Sigma xy$$

Year	P	R	P^2	R^2	PR
1960	1.95	0.46	3.80	0.21	0.90
1961	10.82	2.85	117.07	8.12	30.84
1962	3.22	0.99	10.37	0.98	3.19
1963	4.51	1.40	20.34	1.96	6.31
1964	6.71	1.98	45.02	3.92	13.29
1965	1.18	0.45	1.39	0.20	0.53
1966	4.82	1.31	23.23	1.72	6.31
1967	6.38	2.22	40.70	4.93	14.16
1968	5.97	1.36	35.64	1.85	8.12
1969	4.64	1.21	21.53	1.46	5.61
	50.20	14.23	319.11	25.36	89.26

Cont….

$$b_1 = \frac{\Sigma PR - \Sigma P \Sigma R/n}{\Sigma P^2 - (\Sigma P)^2/n} = \frac{89.26 - 50.20(14.23)/10}{319.11 - (50.20)^2/10} = 0.2657$$

$$b_0 = \bar{R} - b_1\bar{P} = \frac{14.23}{10} - 0.2657\,\frac{50.20}{10} = 0.08918$$

There fore, the linear equation is R = 0.0892+ 0.2657P or

Runoff = 0.0892 + 0.2657*precipitation

The Rational Method

- Amongst various types of empirical relations, rational formula is the most rational method of calculating peak discharge for small catchments.

$$Qp = CiA$$

Where

Qp= peak runoff (m3/s)

C= runoff coefficient

i= Average rainfall intensity

A= Average drainage area

- Note:

if the units for intensity and area are given in other

metric measurements, the units should be changed to m/s and m2 respectively in order to get a metric measure for Q in m3/s

Run coefficient C

- Runoff coefficient is a highly critical element that serves the purpose of converting the average rainfall rate of a particular recurrence interval to the peak runoff intensity of the same frequency
- Its magnitude depends upon the following factors

I. Antecedent moisture condition
II. Ground slope
III. Ground cover
IV. Depression storage
V. Soil moisture
VI. Intensity of rainfall
VII. Geology of the catchment

- In spite of all the above factors that affect the runoff coefficient, its value is generally considered fixed for any drainage area, depending **only on the surface type**
- The following tables suggests ranges of C values for various categories of ground cover for urban and rural areas

Runoff Coefficients for Urban Watersheds

Runoff Coefficients for Urban Watersheds

Type of Drainage Area	Runoff Coefficient
Business:	
♦ downtown areas	0.70-0.95
♦ neighborhood areas	0.30-0.70
Residential:	
♦ single-family areas	0.30-0.50
♦ multi-units, detached	0.40-0.60
♦ multi-units, attached	0.60-0.75
♦ suburban	0.35-0.40
♦ apartment dwelling areas	0.30-0.70
Industrial:	
♦ light areas	0.30-0.80
♦ heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.30-0.40
Railroad yards	0.30-0.40

Cont… runoff coefficients for urban water sheds

Unimproved areas:	
♦ sand or sandy loam soil, 0-3%	0.15-0.20
♦ sand or sandy loam soil, 3-5%	0.20-0.25
♦ black or loessial soil, 0-3%	0.18-0.25
♦ black or loessial soil, 3-5%	0.25-0.30
♦ black or loessial soil, >5%	0.70-0.80
♦ deep sand area	0.05-0.15
♦ steep grassed slopes	0.70
Lawns:	
♦ sandy soil, flat 2%	0.05-0.10
♦ sandy soil, average 2-7%	0.10-0.15
♦ sandy soil, steep 7%	0.15-0.20
♦ heavy soil, flat 2%	0.13-0.17
♦ heavy soil, average 2-7%	0.18-0.22
♦ heavy soil, steep 7%	0.25-0.35
Streets:	
♦ asphaltic	0.85-0.95
♦ concrete	0.90-0.95
♦ brick	0.70-0.85
Drives and walks	0.75-0.95
Roofs	0.75-0.95

Runoff Coefficient for Rural Watersheds

Runoff Coefficient for Rural Watersheds

	Extreme	**High**	**Normal**	**Low**
Relief (C_r)	*0.28-0.35* steep, rugged terrain with average slopes above 30%	*0.20-0.28* hilly, with average slopes of 10-30%	*0.14-0.20* rolling, with average slopes of 5-10%	*0.08-0.14* relatively flat land, with average slopes of 0-5%
Soil Infiltration (C_i)	*0.12-0.16* no effective soil cover either rock or thin soil mantle of negligible infiltration capacity	*0.08-0.12* slow to take up water, clay or shallow loam soils of low infiltration capacity or poorly drained	*0.06-0.08* normal; well drained light or medium textured soils, sandy loams	*0.04-0.06* deep sand or other soil that takes up water readily, very light well drained soils
Vegetal Cover (C_v)	*0.12-0.16* no effective plant cover, bare or very sparse cover	*0.08-0.12* poor to fair; clean cultivation, crops or poor natural cover, less than 20% of drainage area over good cover	*0.06-0.08* fair to good; about 50% of area in good grassland or woodland, not more than 50% of area in cultivated crops	*0.04-0.06* good to excellent; about 90% of drainage area in good grassland, woodland, or equivalent cover
Surface (C_s)	*0.10-0.12* negligible; surface depression few and shallow, drainageways steep and small, no marshes	*0.08-0.10* well defined system of small drainageways, no ponds or marshes	*0.06-0.08* normal; considerable surface depression storage lakes and ponds and marshes	*0.04-0.06* much surface storage, drainage system not sharply defined; large floodplain storage or large numbers of ponds or marshes

- Runoff coefficients, listed in for urban and rural watersheds and others apply to storms of two-year, five-year, and 10-year frequencies. Higher frequency storms require modifying the runoff coefficient because infiltration and other abstractions have a proportionally smaller effect on runoff. Adjust the runoff coefficient by the factor Cf as indicated in the table below. Runoff Coefficient Adjustment Factors for Rational Method. The product of C and Cf should not exceed 1.0.

Runoff Coefficient Adjustment Factors for Rational Method	
Recurrence Intervals (years)	C_f
25	1.1
50	1.2
100	1.25

Rainfall Intensity(i)

- The rainfall intensity (i) is the average rainfall rate for a specific rainfall duration and a selected frequency. The duration is assumed to be equal to the time of concentration. you may compute the rainfall intensity using intensity-duration-frequency (IDF) curve.

Rational Method Procedure

❖ The following procedure outlines the Rational method for estimating peak discharge:

1. Determine the watershed area
2. Determine the time of concentration, with consideration for future characteristics of the watershed.
3. Determine the rainfall intensity or
4. Use IDF curve in your study are to determine rainfall intensity
5. Assure consistency with the assumptions and limitations for application of the Rational Method.
6. Select or develop appropriate runoff coefficients for the watershed. Where the watershed comprises more than one characteristic, you must estimate C values for each area segment individually. You may then estimate a weighted Cw

- The weighted runoff coefficient is calculated as follows

$$C_w = \frac{\sum_{j=1}^{n} C_j A_j}{\sum_{j=i}^{n} A_j}$$

7. Calculate the peak discharge for the watershed for the desired frequency using the rational method equation

Limitations of Rational formula

I. The formula gives good results only for small catchments, having area up to 50km2
II. It is applicable only if the duration of rainfall is equal to or more than the time of concentration (tc)
III. Rainfall intensity (i) should be constant over the entire catchment, during the time of concentration
IV. It assumes constant value of C for a given area, for all storms, which is not reasonable
V. If a plot is made between peak flow and intensity , a straight line is obtained with zero intercept. Nature does not follow such a linear relationships
VI. Due to the above limitations, the rational formula is generally used in the design of urban drainage system, small culverts, and bridges etc.

Some of the uses of the rational method are

- For the design of culverts

Cont..

- For the design of urban drainage, storm sewers ets

Cont…

- For the design of bridges

Example 1 on Rational Formula Method

- A small watershed consists of 3.2 km2 of cultivated area with C= 0.22, 4.8m2 under forest with C= 0.12 and 1.8 km2 under grass cover with C= 0.32. The water course, 2.4 km in length has a fall of 30m. The IDF relation for the area is expressed by the following relation
- i= $\frac{78T^{0.22}}{(t+12)^{0.45}}$ where i is in cm/h, T (return period) is in yours , t is in minutes and time of concentration (tc) is given by the following equation
- tc= $0.000323L^{0.77}S^{-0.385}$ where tc is in hours ,Length (L) is in meters and S is slope

Estimate the peak runoff for 30 years return period using the rational method formula.

solution

- Slope of water course , S= $\frac{\Delta H}{L}$= $\frac{30}{2400}$=$\frac{1}{80}$
- Time of concentration t=tc= $0.0003232400^{0.77}(\frac{1}{80})^{-0.385}$

  = 0.6993 hours = 42 minutes

- Intensity, i= $\frac{78(30)^{0.22}}{(42+12)^{0.45}}$ =27.38 cm/h
- Weighted runoff coefficient, = $C_w = \frac{\sum_{j=1}^{n} C_j A_j}{\sum_{j=i}^{n} A_j}$ $=\frac{A1*C1+A2*C2+A3*C3}{A1+A2+A3}$

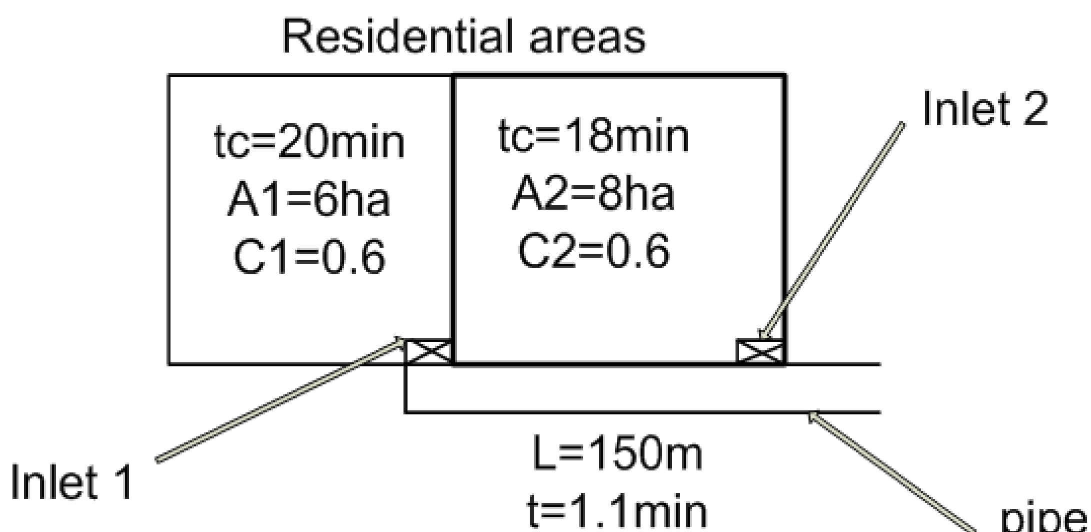
  $= \frac{3.2*0.22+4.8*0.12+1.8*0.32}{3.2+4.8+1.8}$ = 0.189

- Q_{peak} = $C_w iA$= 0.189* 27.38cm/h* 9.8km^2 = 141.2 m3/s which is a design flow

Assignment on Rational Formula Method (5%)

A storm drain, 150 m long, drains a residential area. The drainage area to the upstream end is 6 hectares and there is an additional 8 hectares before the downstream end. The ground is sloped at 1.0%. For 10 year return period the rainfall intensity (mm/hr) is given by

$i = 77e^{-0.0277tc}$,tc is time of concentration in minutes, the runoff coefficients ,time of concentrations and travel time in the pipe between inlet 1 and inlet 2 are given in the figure below.



cont… on assignment

1. Determine the design flow(peak runoff) at outlet 1
2. Assuming a pipe roughness, n= 0.013, find the diameter of the pipe at outlet 1
3. What is the design flow (peak runoff) at the downstream of outlet 2
4. Assuming a pipe roughness, n= 0.013, find the diameter of the pipe at the down stream of outlet 2

8. Hydrology of midsize watersheds

The following characteristics describe a midsize watershed: (1) rainfall intensity varies within the storm duration, (2) rainfall can be assumed to be uniformly distributed in space, (3) runoff is by overland flow and stream channel flow, and (4) channel storage processes is negligible.

For midsize watersheds, runoff response is primarily a function of the characteristics of the storm hyetograph, with concentration time playing a secondary role. Watershed values ranging from few 100 km^2 to 5000 km^2 may be considered as midsize watersheds. The lower limit however could go up to 50 ha depending on the design guideline followed for a specific purpose.

Commonly used hydrological techniques for estimating flood hydrograph from midsize watershed are the Soil Conservation Service (SCS) and the unit hydrograph methods.

8.1 The SCS method

The SCS method is widely used for estimating floods on small to medium-sized ungaged drainage basins around the world (Graphical presentation is given in Figure 8.1) . The method was developed based on 24-hr rainfall runoff data in USA. In its derivation it is assumed that no runoff occurs until rainfall equals an initial abstraction (that is losses before runoff begins) I_a, and also satisfies cumulative infiltration F (the actual retention before runoff begins) or water retained in the drainage basin, excluding I_a. The potential retention (the potential retention before runoff begins) S is the value that $(F + I_a)$ would reach in a very long storm.

If P_e is the effective storm rainfall equal to $(P - I_a)$, and r_d = depth of runoff
the basic assumption in the method is

$$\frac{F}{S} = \frac{r_d}{P_e} \qquad (8.1)$$

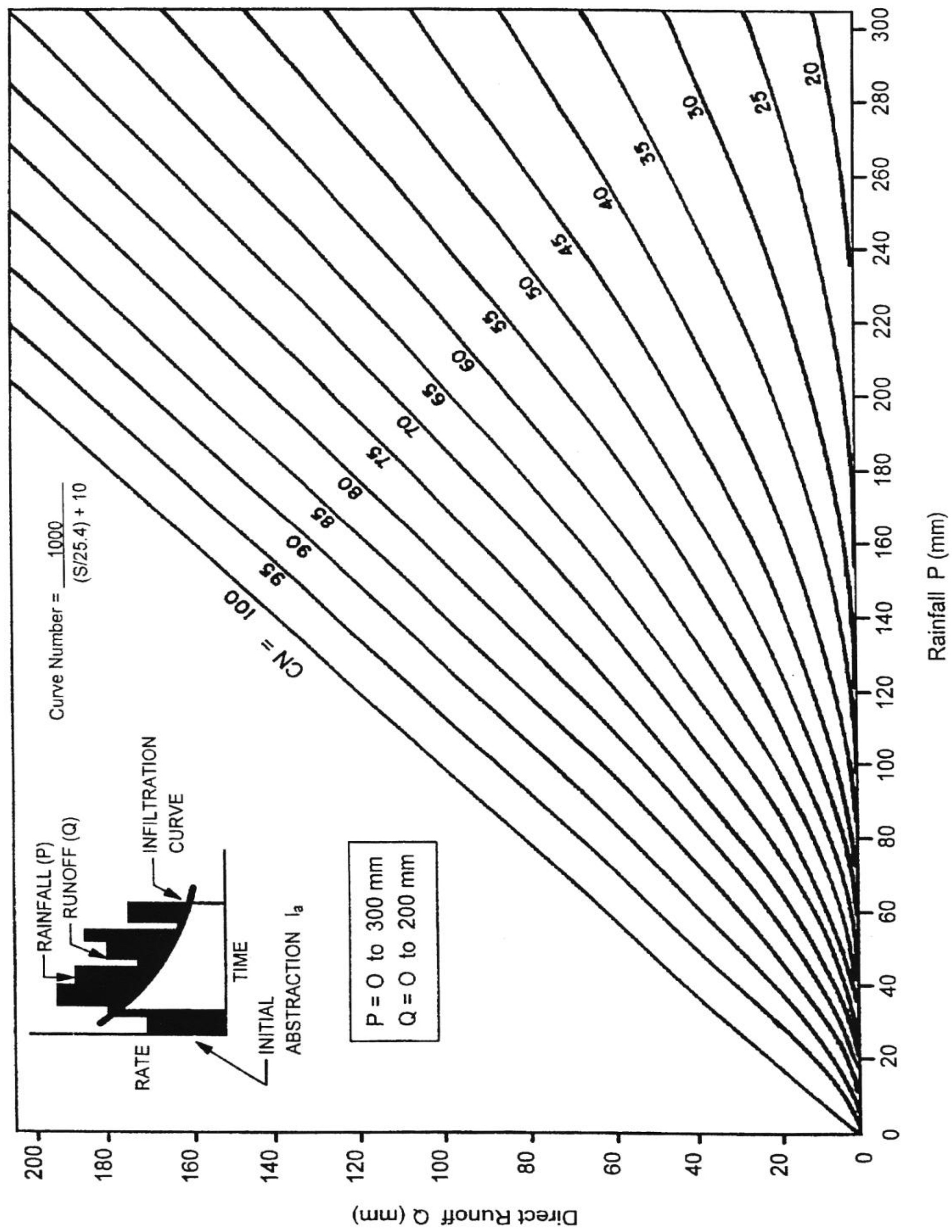


Figure 8-1: SCS Relation between Direct Runoff, Curve Number and Precipitation

Eq. (8.1) states that the ratio of actual retention to potential retention is equal to the ratio of actual runoff to potential runoff. The empirical relation Ia = 0.2S was adopted as the best approximation from observed data, and so P_e = (P - 0.2S). For convenience and to standardize application of SCS method, the potential retention is expressed in the form of a dimensionless runoff curve number CN.

8.1.1 SCS Peak discharge and flood hydrograph determination

The peak discharge in the SCS method is derived from the triangular approximation to the hydrograph shown in Figure 8.2 resulting from rainfall excess of duration D.

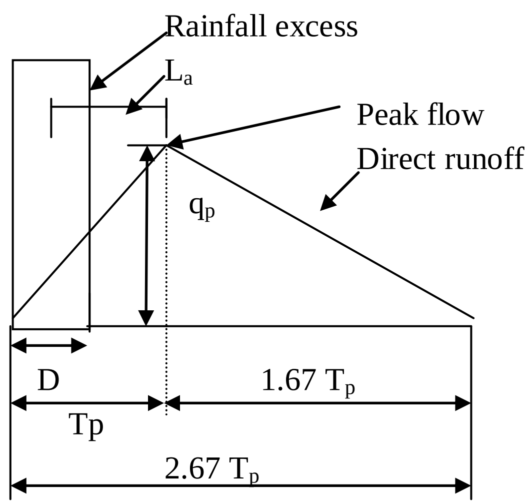


Figure 8.2: SCS triangular hydrograph

The lag L_a of the peak flow, time from the centroid of rainfall excess to the peak of the hydrograph, is assumed to be $0.6t_c$. Then the time of rise T_p to the peak of the hydrograph is

$$T_p = 0.5D + 0.6t_c \tag{8.2}$$

The base length of the hydrograph is assumed to be 2.67Tp. Then from a triangular hydrograph assumption (excess rainfall depth = runoff depth) the peak discharge can then be estimated from

$$q_p = \frac{0.208 A r_d}{0.5D + 0.6t_c} \tag{8.3}$$

Where:

q_p = peak discharge (m^3/s)

r_d = the excess rainfall depth (mm) determined from Eq. (8.4)

A = watershed area (km^2)

t_c = time of concentration (hr)

D = duration of excess rainfall (hr)

The depth of runoff resulting from a required return period rainfall depth of duration corresponding to the time of concentration t_c is estimated by

$$r_d = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{8.4}$$

where:

r_d = depth of runoff equal to depth of excess rainfall (mm)

S = the potential retention (mm)

P = design rainfall amount of duration t_c corresponding to T years return period (mm)

and S (mm) is estimated using

$$S = 254\left(\frac{100}{CN} - 1\right) \tag{8.5}$$

To estimate the time of concentration t_c the Kirpich formula (Chapter 7) may be used, that is

$$t_c = 3.97\, L^{0.77} G^{-0.385}$$

where:

L = the length of the river from the divide to the outlet (km)

G = the average river slope (m/m)

t_c = time of concentration (min)

The explicit consideration of the various factors that are thought to affect flood runoff makes the method attractive. Designers however may have uncertainties in choosing the CN and in determining the method for t_c. It is found that assumed antecedent moisture condition had major effect and that results were better for bare soil or sparse vegetation than for dense vegetation. Therefore care is required in its application, and there is a need for checking of the method against observed flood data for the region of interest or with other methods. Table 8.1 & Table 8.2 provide experimental values of CN for different land use or crop, treatment practice, hydrological soil group and antecedent moisture conditions. The use of SCS method is illustrated by Example 8.1.

Example 8.1 A certain watershed experienced 12.7 cm heavy storm in a single day. The watershed is covered by pasture with medium grazing, and 32 % of B soils and 68 % of C soils. This event has been preceded by 6.35 cm of rainfall in the last 5 days. Following the SCS methodology, determine the direct runoff for the 12.7 cm rainfall event.

Solution. From Table 8.1, for pasture range fair hydrologic condition for B soil the CN = 68 and for C soil the CN = 79. The weighted curve number for the AMC II is

$$CN = 0.32*68 + 0.68*79 = 76$$

AMC III is taken because for the last 5 days there was substantial rainfall. The CN for the AMC III is

$$CN_{III} = \frac{CN_{II}}{0.43 + 0.0057 CN_{II}}$$

$$CN_{III} = \frac{76}{0.43 + 0.0057 * 76} = 88$$

Then S is calculated using

$$S = 254\left(\frac{100}{CN} - 1\right)$$

$$= 254(100/88 - 1) = 35 \text{ mm}$$

The direct runoff depth is

$$r_d = \frac{(P - 0.2S)^2}{P + 0.8S}$$

$$= \frac{(127 - 0.2 * 35)^2}{127 + 0.8 * 35} = 93 \ mm$$

The direct runoff produced by the 127 mm heavy storm is thus 93 mm. It is 73 % of the total rainfall. If this rainfall would have occurred on the AMC I - dry condition then

$$CN_I = \frac{76}{2.3 - 0.013 * 76} = 58$$

$$S = 254(\frac{100}{CN} - 1)$$

= 254(100/58 - 1) = 183 mm

$$r_d = \frac{(P - 0.2S)^2}{P + 0.8S} = \frac{(127 - 0.2*183)^2}{127 + 0.8*183} = 29mm$$

which is 29/127=23 % of the total rainfall. The AMC III and AMC I gave results of dramatic difference.

Table 8.1: Runoff curve numbers for hydrological soil-cover complexes for antecedent rainfall condition II and $I_a = 0.2S$. For Conditions I and III see Table 8.2 (Maidment, 1993)

Land use or Crop	Treatment or practice	Hydrologic condition	Hydrologic soil group			
			A	B	C	D
Fallow	Straight row	-	77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	97	84	88
	Contoured	Good	65	75	82	86
	Terraced	Poor	66	74	80	82
	Terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Terraced	Poor	61	72	79	82
	Terraced	Good	59	70	78	81
Close-seeded	Straight row	Poor	66	77	85	89
legumes or rotation meadow	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Terraced	Poor	63	73	80	83
	Terraced	Good	51	67	76	80
Pasture range		Poor	68	79	86	89
		Fair	49	68	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow (permanent)		Good	30	58	71	78
Wood (farm woodlots)		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		---	59	74	82	86
			74	84	90	92

Soil Group	Description	Final infiltration rate (mm/hr)
A	Lowest runoff potential. Include deep sands with very little silt and clay, also deep loess and aggregated silt.	8-12
B	Moderately low runoff potential: mostly sandy soils less deep than A and loess less deep and aggregated than A, but the group as a whole has above-average infiltration after thorough wetting.	4-8
C	Moderately high runoff potential: comprises shallow soils and soils containing considerable clay and colloids, though less than those of group D. Clay loams, Shallow sandy loam, The group has below average infiltration after pre-saturation	1-4
D	Highest runoff potential. Includes mostly clays of high swelling soil, heavy plastic clays, but the group also includes some shallow soils with nearly impermeable sub-horizons near the surface	0-1

Table 8.2 Antecedent rainfall conditions and curve numbers (for $I_a = 0.2S$)

Curve number for Condition II	Factor to convert curve number for condition II to	
	Condition I	Condition III
10	0.40	2.22
20	0.45	1.85
30	0.50	1.67
40	0.55	1.50
50	0.62	1.40
60	0.67	1.30
70	0.73	1.21
80	0.79	1.14
90	0.87	1.07
100	1.00	1.00

		5-day antecedent rainfall (mm)	
Condition	General description	Dormant Season	Growing Season
I	Optimum soil condition from about lower plastic limit to wilting point	< 13	< 36
II	Average value for annual floods	13 – 28	36 – 53
III	Heavy rainfall or light rainfall and low temperatures within 5 days prior to the given storm	> 28	> 53

Note that the dry and wet antecedent moisture conditions, AMC I and AMC III may be calculated from

$$CN_I = \frac{CN_{II}}{2.3 - 0.013 CN_{II}}, \quad CN_{III} = \frac{CN_{II}}{0.43 + 0.0057 CN_{II}} \tag{8.7}$$

or estimated using the coefficients given in Table 8.1

Example 8.2 Determine (a) the design peak runoff rate, for a 50-year return period storm from a 120 km^2 watershed having IDF curve (I in mm/hr, T in years and t_c in minutes) given by

$$I = \frac{500 T^{0.18}}{(t_c + 20)^{0.78}}$$

and with the following characteristics:

Subarea (km^2)	Topography Slope (%)	Soil group	Land use, treatment, and hydrological condition
75	10-35	C	Row crop, contoured, good
45	20-45	B	Woodland, good

The maximum length of flow is 15 km and the difference in elevation along this path is 450 m.

Solution.

First we estimate the time of concentration:

$$t_c = 3.97\, L^{0.77} S^{-0.385}$$

$$t_c = 3.97\, 15^{0.77} (450/15000)^{-0.385}$$

= 123 min.

for the return period of 50 years and t_c = 123 min, the design intensity of rainfall is estimated by

$$I = \frac{500T^{0.18}}{(t_c + 20)^{0.78}}$$

$$I = \frac{500 * 50^{0.18}}{(123 + 20)^{0.78}}$$

= 22 mm/hr

The average curve number CN for the watershed is

$$CN = \frac{75}{120} CN1 + \frac{45}{120} CN2$$

From Table 8.1 and 8.2 CN_I for the soil group C and Row crop, contoured, good condition is 82, CN_{II} for the soil group B and wood land and good condition is 55, and CN = 72. Estimating s with

$$S = 254\left(\frac{100}{CN} - 1\right)$$

$$S = 254\left(\frac{100}{72} - 1\right)$$

= 98.7 mm

The net rainfall estimated from

$$r_d = \frac{(P - 0.2S)^2}{P + 0.8S}$$

$$r_d = \frac{(22 * 2 - 0.2 * 98.7)^2}{44 + 0.8 * 98.7}$$

= 4.8 mm

The peak discharge then is

$$q_p = \frac{0.208 A r_d}{0.5D + 0.6t_c}$$

$$q_p = \frac{0.208 * 120 * 4.8}{0.5 * 2 + 0.6 * 2}$$

= 54 m^3/s