Unit - III

Runoff

Runoff means the drain water or flow water from any Precipitation from a Catchment area. It represents output from a Catchment in given unit of time when rainfall is input.

Rainfall - Evapotranspiration, Initial losses, Infiltration Detention - Storage = Runoff.

Based on time delay between Rainfall & Runoff, the runoff is Classified into two Categories:

1. Direct Runoff

a) Overland flow:

Travels all the time on the surface and reaches the Catchment outlet.

b) Interflow of Sub-surface flow:

Rainfall infiltrates and moves laterally through upper crusts of the soil & returns to surface at some location.

2. Base flow:

Infiltration and deep percolation and reach the ground water storage also called ground water runoff.

Factors affecting runoff

1. Climatic factors & 2. Physiographic factors.

1. Climatic factors

(i) Types of Precipitation

(ii) Rainfall Intensity

(iii) Forms of Precipitation

(iv) Duration of rainfall
(v) Rainfall distribution
(vi) Direction of prevailing wind
(vii) Other Climatic factors.

2. physiographic factors
   (i) Size of watershed.
   (ii) Shape of watershed
   (iii) Slope of watershed
   (iv) watershed orientation
   (v) land use
   (vi) Soil moisture
   (vii) Soil type &
   (viii) Topographic Characteristics

Estimation of peak runoff rate or Runoff Computation

The commonly used methods for peak runoff rate are
1. Rational method.
2. Curve Number method.
3. Cook's method.
4. Hydrograph method.
5. Infiltration indices and
6. Empirical formulae.

1. Rational method

$$Q_{peak} = \frac{CIA}{360}$$

Where, Q_{peak} = Peak runoff rate, m^3/s

C = Runoff co-efficient

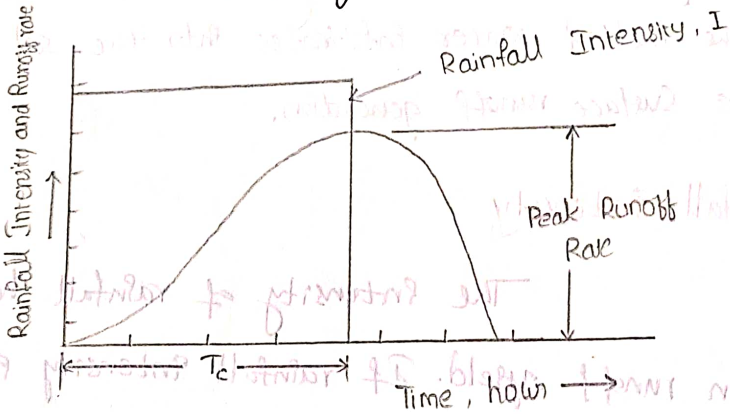
I = Rainfall intensity (mm/hr) for the duration equal to the time of concentration.

A = Area of watershed, ha.

[Ass]umptions of Rational method

1. Rainfall occurs with a uniform intensity for the duration, at least equal to the time of concentration of watershed area and

2. Rainfall occurs at a uniform intensity throughout the watershed area. If all these assumptions are satisfied to a given rainfall, then the relationship between rainfall and runoff for the watershed may be represented graphically, as shown in figure.



Runoff Co-efficient (C):

Runoff Coefficient, expresses the view about the fraction of rainfall resulting into surface runoff.

It may be defined as the ratio of the runoff and Rainfall. It is dimensionless factor. Its values are assigned on the basis of land use and soil types.

Rainfall Intensity (I):

It is defined as the rate of fall of rainfall, expressed as depth per unit time i.e. mm/hour. It is also expressed, as the ratio of total amount of rainfall to its duration. It is given by

$$I = \frac{P}{T}$$

Where I = Rainfall Intensity
P = Amount of Rainfall, mm
T = Time, hrs.

Factors affecting runoff

A) Climatic factors

(i) Type of Precipitation:

Types of Precipitation have a great effect the runoff. For example, a precipitation which occurs in form of rainfall, starts immediately in form of surface flow over the land surface, depending upon its intensity as well as magnitude, while a precipitation which takes place in form of snow or hails, the flow of water on ground surface will not takes place immediately, but after melting of the same. During the time interval of their melting, the melted water infiltrates into the soil and results a very little surface runoff generation.

(ii) Rainfall intensity

The intensity of rainfall has a dominating effect on runoff yield. If rainfall intensity is greater than infiltration rate of the soil, the surface runoff takes place very shortly, while in case of low intensity rainfall, there is found a reverse trend of the same. Thus, high intensities rainfalls yield higher runoff and vice-versa.

(iii) Duration of rainfall

Rainfall duration is directly related to the volume of runoff, due to the fact, that infiltration rate of the soil goes on decreasing with the duration of rainfall, till it attains a constant rate. As a result of this, even a mild intensity rainfall lasting for longer duration may yield a considerable amount of runoff.

Rainfall distribution

Runoff from a watershed depends very much on the distribution of rainfall. The rainfall distribution for this purpose can be expressed by a term "distribution coefficient", which may be defined as the ratio of maximum rainfall at a point to the mean rainfall of the watershed. For a given total rainfall, if all other conditions are the same, the greater the value of distribution coefficient, greater will be the peak runoff and vice-versa.

(v) Direction of Prevailing wind:

The direction of prevailing wind, affects greatly the runoff flow. If the direction of prevailing wind is same, as the drainage system then it has a great influence on the resulting peak flow and also on the duration of surface flow, to reach at the outlet. A storm moving in the direction of stream slope, produces a higher peak in shorter period of time, than a storm moving in opposite direction.

(vi) Other Climatic factors:

The other climatic factors, such as temperature, wind velocity, relative humidity, annual rainfall etc. affect the water losses from the watershed area to a great extent & thus the runoff is also affected accordingly. If the losses are more, the runoff will be less and vice-versa.

B) Physiographic factors.

(i) Size of watershed

Regarding the size of watershed, if all other factors including depth and intensity of rainfall are being same, then two watersheds irrespective of their size, will produce about the same amount of runoff. However, a large watershed takes longer time for draining the runoff to the outlet, as a result the peak flow expressed as depth, is being smaller and vice-versa.

(ii) Shape of watershed

The shape of watershed has a great effect on runoff. The watershed shape is generally expressed by the terms "form factor" and "compactness coefficient."

The form factor may be defined as the ratio of average width to the axial length of the watershed expressed as:

$$\text{Form factor} = \frac{\text{Average width of the watershed}}{\text{Axial length of the watershed}} = \frac{B}{l}.$$

Regarding, axial length (l) of the watershed, it is the distance between outlet and remotest point of the area, whereas the average width (B) is concerned, it is obtained by ~~doing~~ dividing the area (A) to the axial length (l) of the watershed. Thus form factor, $\frac{B}{l} = \frac{A/l}{l}$ (or) A/l^2.

$$\text{Form factor} = \frac{A}{l^2}$$

ersh

Compactness Coefficient of watershed is the ratio of ...meter of watershed to the circumference of a circle, whose area is equal to the area of the watershed, is expressed as:

$$\text{Compactness Coefficient} = \frac{\text{Perimeter of the watershed}}{\text{Circumference of a circle, whose area is equal the watershed}}$$

$$\text{Compactness Coefficient} = \frac{P}{2\sqrt{\pi A}}$$

where, P = Perimeter of watershed

A = Area of the watershed

$\pi = 3.14$.

Regarding the watershed's shape, there are two types of watershed's shape, are commonly assumed, in which one is fan shape and other is fern shape. The fan shape watershed, tends to produce higher peak rate of runoff very early, than the fern shape, due to the fact that in former one, all parts of the watershed contribute the runoff to the outlet simultaneously, comparatively in little period of time, than the fern shaped watershed.

(iii) Slope of watershed:

The slope of watershed has an important role over runoff, land slope, soil conservation practices and vegetation cover have significant influence on the amount and rate of runoff. The time of concentration of rainfall in the drainage channel, which provide a cumulative effect on resulting peak runoff. forexample in case of a su... the time to reach the flow at outlet is less, becaus... greater runoff velocity, which results into formation of peak runoff very soon and vice-versa.

(iv) Orientation of watershed

This factor affects the evaporation & transpiration losses from the area by making influence on the amount of heat to be received from the sun. The north or south orientation of watershed, affects the time of melting of collected snow.

(v) Land use:

The land use pattern and land management practices, used have great effect on the runoff yield. for example, an area which is under forest covers, where a thick layer of mulch of leaves and grasses etc, has been accumulated, there formed a little surface runoff, due to the fact that more rain water is absorbed by the soil. while in a barren field, where not any type of covers is available, a reverse trend is obtained.

(vi) Soil moisture:

The magnitude of runoff yield depends upon the amount of moisture present in the soil at the time of rainfall. If rain occurs over the soil which has more moisture, the infiltration rate becomes very less, which results in more runoff yield. Similarly, if the rain occurs after a long dry spell this condition even intense rain may fall to produce appreciable runoff. But on the other hand, if the rain occurs in a close succession, as in the rainy season, runoff yield has reverse effect.

(5)

Soil Type

In the watershed, Surface runoff is greatly influenced by the soil type, as loss of water from the soil, is very much dependent on infiltration rate, which varies with the types of soil.

(viii) Topographic Characteristics

Topographic characteristics include those topographical features of watershed, which create their effect on runoff; it is mainly undulating nature of the watershed. Undulate land has greater runoff than the flat land, because of the reason that runoff water gets additional power to flow due to slope of the surface and little time to infiltrate the water into soil.

Regarding channel characteristics, to describe their effect on runoff, the channel cross-section, roughness, storage and channel ~~destiny~~ density are mainly considered. These also have significant effect on runoff.

(ix) Drainage Density:

The drainage density is defined as the ratio of the total channel length in the watershed to the total watershed area. It is expressed as:

$$\text{Drainage density} = \frac{\text{Channel length (total)}}{\text{Watershed area}}$$

$$D.D = \frac{L}{A}$$

Time of Concentration (T_c)

The time required to reach the surface runoff from remotest point of the watershed to its outlet is known as time of concentration (T_c).

$$T_c = 0.0197\, L^{0.77} S^{-0.385}$$

Where, T_c = Time of concentration, minutes.

L = length of channel reach, metres (m)

S = Average channel slope, m/m.

Curve Number method

It is also called as SCS-CN method means Soil Conservation Service Curve Number method.

$$Q = \frac{(P - I_a)^2}{P - I_a + S}$$

$$I_a = 0.2S$$

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad \text{for } P > I_a$$

$$Q = 0 \quad \text{for } P \leq I_a$$

$$S = \frac{25400}{CN} - 254$$

$$CN = \frac{2540}{254 + S}$$

Where CN = Curve Number, ranges from 0 to 100.

S = maximum potential retention, mm.

P = Rainfall, mm

Antecedent Moisture Condition (AMC) - It is wetness

AMC-I: It refers to the lowest runoff generating potential of the watershed because of dryness of the soil.

AMC-II: Average moisture status regarding runoff generating potential.

AMC-III: It refers highest runoff generating potential of the watershed because of saturation of soil from antecedent rains.

Classification of AMC as per antecedent rainfall (SCS, 1986)

AMC - Group	5-day antecedent rainfall (mm)	
	Dormant Season	Growing Season
I	< 13 mm	< 36 mm
II	13 to 28 mm	36 to 53 mm
III	> 28 mm	> 53 mm.

Hydrologic Soil Group

Based on the hydrologic characteristics, the soils are classified into following four groups:

Soil Group A: Low Runoff potential
High Infiltration rate.

Group B: Moderately low runoff potential
Moderately high infiltration rate

Group C: Moderately high runoff potential
Moderately low infiltration rate.

Group D: High Runoff Potential
Low infiltration rate.

Method

This method consists of evaluating the four watershed characteristics i.e. relief, infiltration rate, vegetal cover and surface storage. For these characteristics, numerical values are assigned for computing the runoff. The values are mainly given on the basis of observation and comparison of above features with similar conditions of the watershed.

Numerical values (W) Based on watershed characteristics for Cook's method.

S.No.	Range	Numerical values assigned for runoff Producing watershed's characteristics.			
		Relief	Soil infiltration	vegetal cover	Surface Storage
1.	Low	(10 to 0) Land is relatively flat, avg. slope ranges from 0 to 5%.	(5) Infiltration rate is more than 2cm/hr, soil contains high sand & loamy sand	(5) About 9% of total area is covered under good vegetation either by forest or equivalent	(5) land consists of high surface depressions; drainage system is not very well.
2.	Normal	(20 to 10) The land is rolling in shape & slope ranges from 5% to 10%	(10) Infiltration rate varies from 0.75 to 2cm/hr, the soil is in normal & deep permeable nature	(10) About 50% of total area is under good grass land or any other equivalent cover.	(10) Considerable depression storage, lakes, Ponds & marshes are less than 2% of entire drainage system.
3.	High	(30 to 20) Lands are hilly in nature, average slope ranges from 10 to 30%.	(15) Infiltration rate ranges from 0.25–0.75 cm/hr, the soil is relatively hard such as clay soil.	(15) Vegetal cover varies from poor to fair, less than 10% of total area is under grass cover.	(15) Surface depression is very low & area is well drained.
4.	Extreme	(40 to 30) Lands are steep and are steep terrain, slope ranges upto 30%.	(20) Infiltration rate is less.	(20) land is bare, no effective grass cover.	(10) Surface depressions are negligible, drainage of land is very well, & no ponds or tanks are available.

For Computation of runoff, the next-step

Obtain the sum of all numerical values (ΣW) and then uncorrelated runoff is determined, using the runoff curve, against the sum of the numerical value. The runoff determined so is valid for a 10 years recurrence interval. Again this value of runoff is modified for geographic location of the given watershed and for the desired recurrence interval. This is done by the following formula:

$$Q = PRFS$$

where, Q = Peak runoff rate for a specified geographic location & desired recurrence interval.

P = Uncorrelated value of runoff i.e. obtained from runoff-curve.

R = Geographic rainfall factor.

F = Recurrence interval factor

S = Shape factor of the watershed.

Land Use Capability Classification and Land Use planning

Land Capability is the suitability of land for use without damage. Farm land is used for the production of crops requiring tillage, or for some form of permanent vegetation (usually grass, other forage plants, or timber) requiring little or no tillage. The land use capability classification is a systematic grouping of different kinds of land for sustained productivity.

It is also provide suitability of different classes of land for specific uses. Class I, II and III include lands suited for regular cultivation, whereas class IV can be cultivated only under great care. Class V, VI and VII lands are suited to pasture, orchards and forestry, class VIII land can be used for forestry and recreation.

Land Use Capability Classification

(i) Land Suited for agriculture

Class-I: Slope 0-1%

Good lands from all points of view, which can be cultivated by following scientific farming practices. It is normally level land which does not easily erode by water or wind. Soil is moderately deep to deep and easy to work with. It has good water holding capacity and is capable of supplying fair amount of nutrients. It is well drained and can be cropped intensively with adequate supply of fertilizers and organic manures coupled with proper crop rotations.

Class-II : Slope 1-3%.

It is good soil from many points but not as good as class I in view of certain physical conditions such as susceptibility to slight erosion due to gentle slope moderate depth (22.5-45 cm), moderate wetness, and slow drainage. Good water holding capacity. Doesnot eroded by water or wind. Contour-cultivation, strip cropping and use of cover crops in crop rotation, these lands can be made quite productive.

Class-III : Slope 3-5%.

It is moderately good for cultivation, with limitations of moderately steep slopes, high susceptibility to erosion, shallow depth (7.5-22.5 cm) to clay or hard pan or bed rock, low water holding capacity, slow or very slow permeability and susceptible to water logging; reamires intensive soil conservation measures. Adequate supply of fertilizers and organic manure should from the major farming practice.

Class-IV : Slope 5-8%.

Serious limitations restricting the choice of cropping which need careful and efficient management. It can be cultivated only periodically as crop planning is limited by severe susceptibility to erosion, steep slopes, shallow soils with low water holding capacity. Excess wetness and water logging con[...] may be frequent. Salt accumulation can also be a limit[...]

Land Suited for Permanent vegetation

Class-V: Slope 8-12%.

Cultivation is not feasible due to stoniness, wetness and other limitations. Soils may be moderately deep with gentle slope[...]

susceptible to water or wind erosion. Suitable for pasture & forestry, Susceptible to only slight erosion by water. (9)

Class - VI : Slope 12-18%.

These soils are subject to moderate permanent limitations, having shallow depth and steep slopes. Can be used for grazing and forestry and respond well if properly managed.

Class - VII : Slope 18-25%

These soils are steep, rough, eroded, shallow, droughty or swampy. These factors limit their use for grazzing or forestry and have to be used carefully, Particularly when used for grazing if rainfall is sufficient, forestry would be an ideal choice.

Class - VIII : Slope greater than 25%

These lands are unfit even for grazing or intensive forestry. They could be used for natural vegetative cover, wildlife, and recreation. These lands include marshes, deserts, deep gullies, high mountains, and stony barren areas.

Erosion Control Measures

Sloping lands when put under cultivation are subjected to accelerated soil erosion. The top fertile soil is washed away with every rain depleting the soil fertility. In addition, the rainwater does not get sufficient time to be absorbed by the soil and is wasted as surface runoff.

Crops in such areas suffer both from loss of so... and loss of water. Conservation measures are therefore necessary to control soil erosion and retain as much water as possible in the soil.

Soil and water conservation measures for agricultural lands depend upon the soil, land slope and rainfall characteristics of the area. The measures adopted are broadly classified as: (i) Agronomical measures (ii) Engineering measures.

The agronomic measures are adopted when the land slopes are small (less than 2% in general) and erosion problems are not severe. When the land slopes are more than 2%, engineering measures may become necessary. Agronomic measures are also adopted in conjunction with engineering measures.

1. Agronomic Methods for Erosion Control

The methods used for controlling soil erosion through crops or vegetation and through agronomical practices are known as biological methods. The biological methods for controlling water erosion consist of (1) Contour cultivation, (2) Cropping systems, and (3) Tillage Practices.

(1) Contour Cultivation

Contour cultivation means carrying out agricultural operations like planting, tillage and intercultivation very nearly on the contours.

cultivation reduces the velocity of overland flow and 10
aids soil erosion. In some cases, after the intercultivation operations a ridge and furrow system or the contour develops and offers greater resistance to surface runoff. Crops like maize, Sorghum, Pearl millet which are normally grown in rows are ideally suited for contour cultivation. To layout the system in the field, guidelines are marked across the slope using a Dumpy level or even a hand level. All the subsequent agricultural operations are carried out making use of the guidelines.

(ii) Strip Cropping

Strip cropping means growing different crops in alternate strips across the slope such that they serve as vegetative barriers to erosion. The alternate strips consist of close growing erosion resisting crops to erosion permitting crops like row crops. To achieve the best results, strip cropping is to be done in combination with other farming practices, like good crop rotations, contour cultivation etc. There are four types of strip cropping systems. They are (a) Contour strip cropping.

(b) Field strip cropping.

(c) Buffer strip cropping and

(d) Wind strip cropping.

(a) Contour Strip Cropping

Contour strip cropping means growing alternate strips of erosion permitting and erosion resisting crops along the contours. Depending upon the topography the widths of the strips will vary.

(b) Field Strip Cropping

In field strip cropping, the strips are laid across the slope in uniform width without taking into consideration the exact contours. This method is useful on regular slopes and with the soils of high infiltration rates.

(c) Buffer strip Cropping

In buffer strip cropping, Permanent strips of grasses are located either in badly eroded areas or in areas that do not fit into a regular rotation.

(d) Wind Strip Cropping

In wind strip cropping, the crop strips are laid out at right angles to the direction of the prevailing winds irrespective of the direction of the land slope. The objective here is to control wind erosion rather than water erosion.

The widths of the strips of erosion resisting and erosion Permitting crops depends upon several factors like slope, soil texture, rainfall characteristics, types of crops etc. These widths are determined based largely on the local conditions. In general, the steeper the slope the greater is the width of the erosion resisting crop and smaller the width of erosion -Permitting crop.

Crop widths for strip cropping (Basu et. al., 1960).

Slope	width of erosion Permitting - crop	width of erosion resisting crop.
1%	50 m	10 m
2%	30 m	6 m
3%	15 m	5 m

However, strip cropping on a large scale has not been adopted in India because of small size holdings.

Cropping Systems

Cropping system refers to a sequence of crops grown on a given area over a period of time. The cropping system for an area is designed to achieve objectives like maintenance of soil fertility, Protecting the soil from erosion & making the best use of available soil moisture. Crop rotations, strip cropping, inter cropping and crop mixtures are terms used for describing different cropping systems.

(a) Crop Rotations

Crop rotations for a given area serve one or more of the following purposes. These are (etc)

(1) Prevention or Control of soil erosion,

(2) building up of soil fertility,

(3) building up the organic matter and thus improving the Physical Conditions of the soil, and

(4) Control of weeds.

Crop rotations for an area can be chosen in such a way that during the rainy period there is a vegetative cover over the soil surface. A vegetative cover controls splash erosion by intercepting the rain drops, and absorbing their energy. It also helps in maintaining the infiltration rate of the soil as on bare soil the beating action of rainfall breaks down the clods and forms a tight layer.

Legumes when included in the crop rotation help in maintaining soil fertility. Crops like groundnut, soyabean, green gram, checkpea etc., are legumes commonly used in crop rotations. Inclusion of suitable green manuring crops in crop rotations is also beneficial for adding organic matter to the soil. Crop rotations are developed to suit particular soil and climatic conditions and hence differ from region to region.

(b) Mixed Cropping

Mixed cropping is the system of growing more than one crop together on the same land. Crops may be grown as homogeneous mixtures by mixing seeds of various crops before sowing. Different crops may be sown in separate rows according to a pattern in which case it is referred to as intercropping.

The benefits of mixed cropping

1. Mixed crops varying in root system help in better utilization of plant nutrients in the profile.
2. Mixed crops requiring different spacing for growth, help in better utilization of space and profile moisture.

-tives like erosion control by growing erosion resisting (12)
and erosion permitting crops, reducing wind affects by growing tall and short crops, etc., can be achieved.

Crop mixtures usually consist of
(i) tall & short crops,
(ii) shallow rooted and deep rooted crops,
(iii) early maturing and late maturing crops,
(iv) wide spaced and close spaced crops.
(v) legumes and non-legumes, &
(vi) erosion permitting and erosion resisting crops.

The mixed cropping ~~sys~~ patterns have to be chosen depending upon the soil and climatic conditions.

2. Engineering measures

The engineering measures consist of some land surface modification for retention and disposal of rainfall.
The engineering measures adopted are.
(1) Contours & graded bunding,
(2) broad based terraces,
(3) bed and furrow system, and
(4) ridge and furrow system.

Suitable water disposal forms a part of all these methods.

Engineering / mechanical measures

- Arable land
  - Bunding
    - Contour
    - Graded
  - Terracing
    - Level or bench
    - Inward sloping
    - outward sloping
    - Puertorican type
  - Conservation bench terraces.
  - Conservation ditches.
  - land Levelling / grading.
  - Dugout Ponds
  - waterways or disposal drains
  - Stone walls
    - Contour
    - Graded
  - measures for Surface / Subsurface drainage.
- Non-arable land.
  - Trenching
    - Contour
      - Staggered
      - Continuous
    - Graded
      - Uniform
      - Variable
  - Diversion drains
  - Stone wall
    - Contour
    - Graded
  - Check dams.
  - Gully control structures
    - Drop Spillway
    - Chute Spillway
    - Drop inlet Spillway
  - Crib Structure
  - Wattling
  - Retaining walls
  - Geotextiles
  - Percolation tanks.