Runoff

What is Runoff?

Runoff, in hydrology, quantity of water discharged in surface streams. Runoff includes not only the waters that travel over the land surface and through channels to reach a stream but also interflow, the water that infiltrates the soil surface and travels by means of gravity toward a stream channel (always above the main groundwater level) and eventually empties into the channel. Runoff also includes groundwater that is discharged into a stream; stream flow that is composed entirely of groundwater is termed base flow, or fair-weather runoff, and it occurs where a stream channel intersects the water table. The total runoff is equal to the total precipitation less the losses caused by evapotranspiration (loss to the atmosphere from soil surfaces and plant leaves), storage (as in temporary ponds), and other such abstractions.

Types of Runoff

There are three major types of runoff depending on the source: surface flow, interflow, and base flow.

- Surface Flow : Surface flow is water that has remained on the surface and moves as overland or channel flow.
- Interflow : Interflow is water that has entered the upper soil profile and then moves laterally through the soil profile and reappears as surface flow at a downstream point. The lateral flow is caused by a relatively impervious zone that prevents further downward movement. Interflow may be a significant part of total direct runoff under certain soil, geological and land use conditions. It is common in forested areas on moderate or steep slopes with permeable soils of moderate depth over bedrock. The forest and ground litter provide high infiltration for water to enter the soil, and the slope provides the energy for lateral flow. Significant amounts of interflow are not common in cultivated soils on small watersheds and are usually not considered in NRCS methods of estimating runoff. Interflow may return to the surface so quickly that it is not possible to separate surface flow and interflow.

•Base flow : Base flow is water from a saturated ground water zone that underlies most land areas. It usually appears at a downstream location where the channel elevation is lower than the ground water table. Ground water provides the stream flow during dry periods having minor or no precipitation. Ground water may enter a channel as seepage along the lower banks of the channel. This type of flow is not normally a big contributor to flood runoff.

Climatic Factors That Affect Runoff

- Rainfall Duration and Intensity : Total runoff for a storm is related to the rainfall duration and intensity. Duration is the length of the storm, and intensity is the rate at which it rains. Infiltration rate will usually decrease with time in the initial stages of a storm. Thus a storm of short duration may produce no runoff, whereas a storm of lesser intensity but of long duration could result in runoff.

- Season of the Year : In many areas, there is a definite seasonal pattern when major storms are likely to occur. During the dormant season, vegetative cover is significantly reduced for cultivated fields and deciduous woodlands or forests. Cultivated fields are bare or may be limited to surface residues for several weeks prior to and following planting. In humid and semi-humid areas, there is a gradual increase in soil moisture during the dormant season.

- Meteorologic Conditions Before the Storm : The climate during a period of 5 to 10 days before a storm may affect the soil moisture level at the time of the storm. High temperatures, winds, low humidity, and high solar radiation increase evaporation and transpiration. This reduces the soil moisture content, provides more storage, and increases infiltration.

Empirical equations

- **Binnie's Percentages :** In India the earliest efforts in estimating runoff from rainfall were those of Alexander Binnie.

  He made observation on two rivers in Madhya Pradesh and established certain percentages of runoff from rainfall which are given below.

Annual rainfall (mm)	500	600	700	800	900	1000	1100
Runoff %	15	21	25	29	34	38	40

•**Barlow's Tables :** Barlow, the first Chief Engineer of the Hydro-Electric Survey of India (1915) on the basis of his study in small catchments (area ~ 130 km^2) in Uttar Pradesh expressed runoff R as

$$R = K_b P$$

Where K_b is the runoff coefficient which depends upon the type of catchment and nature of monsoon and P is the rainfall.

Table –Barlow's Runoff Coefficients, K_b in percentage

(Developed for use in UP) (Source: Subramanya, 2008)

Class	Description of catchment	K_b (percentage)		
		Season I	Season II	Season III
A	Flat, cultivated, and absorbent soil	7	10	15
B	Flat, partly cultivated, and stiff soil	12	15	18
C	Average catchment	16	20	32
D	Hills and plains with little cultivation	28	35	60
E	Very hilly, steep and no cultivation	36	45	81

Season I: Light rain, no heavy downpour

Season II: Average or varying rainfall, no continuous downpour

Season III: Continuous downpours

Runoff coefficient

Runoff coefficient is a dimensionless factor that is used to convert the rainfall amounts to runoff. It represents the integrated effect of catchment losses and hence depends upon the nature of land surface, slope, degree of saturation, and rainfall intensity. It is also affected by the proximity to water table, degree of soil compaction, porosity of soil, vegetation, and depression storage. The joint committee of the American Society of Civil Engineers and Water Pollution Control Federation has recommended values of runoff coefficient for a variety of land uses, soil types, and surface slopes.

HOW TO CALCULATE RUNOFF COEFFICIENT

Using a Runoff Coefficient Table

Step 1

Find a reputable runoff coefficient table.

Step 2

Determine what type of land you have. Some examples of land include business districts, residential areas, roofs and agricultural lands.

Step 3

Use the runoff coefficient chart to determine the runoff coefficient (C).

Ground Cover	Runoff Coefficient, c
Lawns	0.05 - 0.35
Forest	0.05 - 0.25
Cultivated land	0.08-0.41
Meadow	0.1 - 0.5
Parks, cemeteries	0.1 - 0.25
Unimproved areas	0.1 - 0.3
Pasture	0.12 - 0.62
Residential areas	0.3 - 0.75
Business areas	0.5 - 0.95
Industrial areas	0.5 - 0.9
Asphalt streets	0.7 - 0.95
Brick streets	0.7 - 0.85
Roofs	0.75 - 0.95
Concrete streets	0.7 - 0.95

RATIONAL METHOD

One of the most commonly used procedures for calculating peak flows from small drainages less than 200 acres is the Rational Method. This method is most accurate for runoff estimates from small drainages with large amounts of impervious area. Examples are housing developments, industrial areas, parking lots, etc.

Rational method is based on experimental idea proposing that the highest runoff produced in the stream is reliant on the watershed area that gives to the flow in the stream, and assuming that depth of runoff produced from the basin is a ratio of amount of rainfall.

The Rational method predicts the peak runoff according to the formula: Q= CiA, where C is a runoff coefficient, i is the rainfall intensity, and A is the subcatchment area. This formula is applicable to US or metric evaluation, as long as consistent units are employed. (In traditional US usage, the intensity and area are given in inches-per-hour and acres, respectively. Converting the units leaves a factor of approximately 1.01, which is usually omitted in manual calculations.

THE RATIONAL METHOD

$Q = CiA$

Where, Q = maximum rate of runoff (cfs),

C = Runoff coefficient,

i = avg. rainfall intensity (in/hr), and

A = Drainage area (acres).

Empirical Formulae

The importance of estimating the water availability from the available hydrologic data for purposes of planning water-resource projects was recognised by engineers even in the nineteenth century. With a keen sense of observation in the region of their activity, many engineers of the past have developed empirical runoff estimation formulae. However, these formulae are applicable only to the region in which they were derived. These formulae are essentially rainfall-runoff relations with additional third or fourth parameters to account for climatic or catchment characteristics.Some of the important formulae used in various parts of India are - Binnie's Percentages, Barlow's Tables, Stranges Tables, Inglis and DeSouza formula,Khosla's formula.

Binnie's Percentages

Sir Alexander Binnie measured the runoff from a small catchment near Nagpur (Area of 16 km2) during 1869 to 1872 and developed curves of cumulative runoff against cumulative rainfall. The two curves were found to be similar. From these, he established percentage of runoff from rainfall. These percentages have been used in Madhya Pradesh and Vidarbha region of Maharashtra for the estimation of yield.

Barlow's Tables

Barlow, the first Chief Engineer of the Hydro-Electric Survey of India (1915) on the basis of his study in small catchments (area ~ 130 km2) in Uttar Pradesh expressed runoff R as –

$$R = K_b P$$

Where Kb is the runoff coefficient which depends upon the type of catchment and nature of monsoon and P is the rainfall.

Table 1 – Barlow's Runoff Coefficients, Kb in percentage :

Class	Description of catchment	Kb (percentage)		
		Season 1	Season2	Season3
A	Flat, Cultivated and absorbent soil	7	10	15
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Strange's Tables

Strange (1892) studied the available rainfall and runoff in the border areas of present-day Maharashtra and Karnataka and has obtained yield ratios as functions of indicators representing catchment characteristics. Catchments lie classified as good, average and bad according to the relative magnitudes of yield they give. For example catchments with good forest/vegetal cover and having soils of high permeability would be classified as bad ,while catchments having soils of low permeability and having little or no vegetal cover is termed good .Two methods using tables for estimating the runoff volume in a season are –

(a) Runoff volume from total monsoon season rainfall.

(b) Estimating the runoff volume from daily rainfall.

Runoff Volume from Total Monsoon Season Rainfall

A table giving the runoff volumes for the monsoon period (i.e. yield during monsoon season) for different total monsoon rainfall values and for the three classes of catchments (viz. good, average and bad) is given in Table 2. The correlation equations of best fitting lines relating percentage yield ratio (Y) to precipitation (P)could be expressed as -

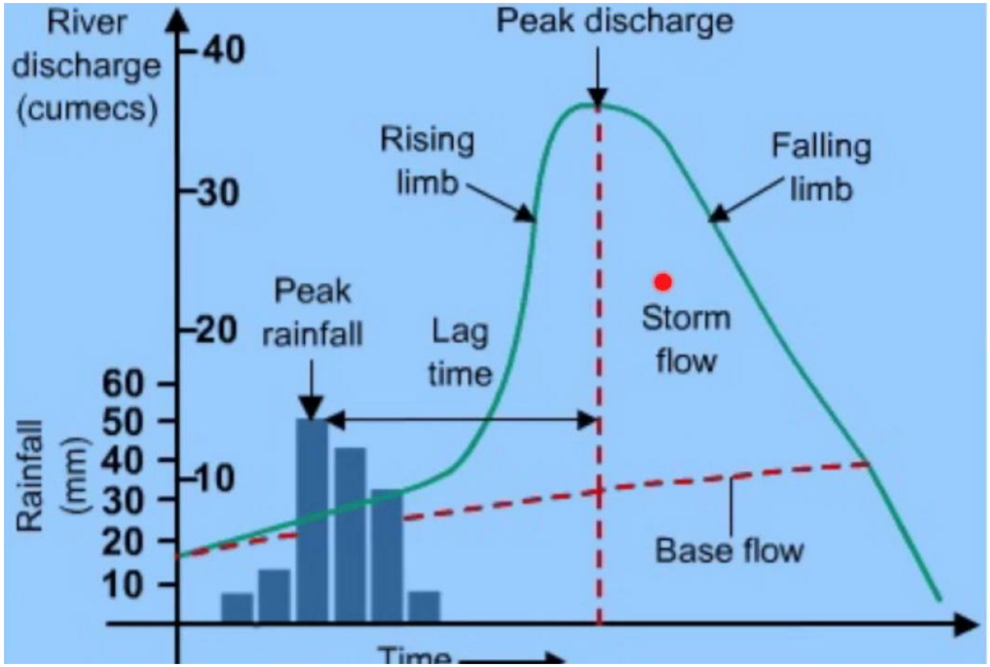
Table 2.Strange's Table of Total Monsoon Rainfall and estimated Runoff(Source: Subramanya, 2008)

Total Monsoon rainfall (inches)	Total Monsoon rainfall (mm)	Percentage of Runoff to rainfall			Total Monsoon rainfall (inches)	Total Monsoon rainfall (mm)	Percentage of Runoff to rainfall		
		Good catchment	Average catchment	Bad catchment			Good catchment	Average catchment	Bad catchment
1.0	25.4	0.1	0.1	0.1	31.0	787.4	27.4	20.5	13.7
2.0	50.8	0.2	0.2	0.1	32.0	812.8	28.5	21.3	14.2
3.0	76.2	0.4	0.3	0.2	33.0	838.2	29.6	22.2	14.8
4.0	101.6	0.7	0.5	0.3	34.0	863.6	30.8	23.1	15.4
5.0	127.0	1.0	0.7	0.5	35.0	889.0	31.9	23.9	15.9
6.0	152.4	1.5	1.1	0.7	36.0	914.4	33.0	24.7	16.5
7.0	177.8	2.1	1.5	1.0	37.0	939.8	34.1	25.5	17.0
8.0	203.2	2.8	2.1	1.4	38.0	965.2	35.3	26.4	17.6
9.0	228.6	3.5	2.6	1.7	39.0	990.6	36.4	27.3	18.2
10.0	254.0	4.3	3.2	2.1	40.0	1016.0	37.5	28.1	18.7
11.0	279.4	5.2	3.9	2.6	41.0	1 041.4	38.6	28.9	19.3
12.0	304.8	6.2	4.6	3.1	42.0	1066.8	39.8	29.8	19.9
13.0	330.2	7.2	5.4	3.6	43.0	1092.2	40.9	30.6	20.4
14.0	355.6	8.3	6.2	4.1	44.0	1117.6	42.0	31.5	21.0
15.0	381.0	9.4	7.0	4.7	45.0	1143.0	43.1	32.3	21.5
16.0	406.4	10.5	7.8	5.2	46.0	1168.4	44.3	33.2	22.1
17.0	431.8	11.6	8.7	5.8	47.0	1193.8	45.4	34.0	22.7
18.0	457.2	12.8	9.6	6.4	48.0	1219.2	46.5	34.8	23.2
19.0	482.6	13.9	10.4	6.9	49.0	1244.6	47.6	35.7	23.8
20.0	508.0	15.0	11.3	7.5	50.0	1270.0	48.8	36.6	24.4
21.0	533.4	16.1	12.0	8.0	51.0	1295.4	49.9	37.4	24.9
22.0	558.8	17.3	12.9	8.6	52.0	1320.8	51.0	38.2	25.5
23.0	584.2	18.4	13.8	9.2	53.0	1346.2	52.1	39.0	26.0
24.0	609.6	19.5	14.6	9.7	54.0	1371.6	53.3	39.9	26.6
25.0	635.0	20.6	15.4	10.3	55.0	1397.0	54.4	40.8	27.2
26.0	660.4	21.8	16.3	10.9	56.0	1422.4	55.5	41.6	27.7
27.0	685.8	22.9	17.1	11.4	57.0	1447.8	56.6	42.4	28.3
28.0	711.2	24.0	18.0	12.0	58.0	1473.2	57.8	43.3	28.9
29.0	736.6	25.1	18.8	12.5	59.0	1498.6	58.9	44.4	29.41
30.0	762.0	26.3	19.7	13.1	60.0	1524.0	60.0	45.0	30.0

Since there is no appreciable runoff due to the rains in the dry (non-monsoon) period, the monsoon season runoff volume is recommended to be taken as annual yield of the catchment. This table could be used to estimate the monthly yields also in the monsoon season. However, it is to be used with the understanding that the table indicates relationship between cumulative monthly rainfall starting at the beginning of the season and cumulative runoff, i.e. a double mass curve relationship.

HYDROGRAPH

A **hydrograph** is a graph or plot that shows the rate of water flow in relation to time, given a specific point or cross section. These graphs are often used to evaluate storm water runoff on a particular site considering a development project.



INFILTRATION METHOD

- Infiltration is the process of water entering into the ground whereas runoff is the process of water flowing over the ground.
- Runoff can only occur when the rate of precipitation exceeds the soil infiltration rate.

TYPES OF COMPUTING RUNOFF BY INFILTRATION METHOD

- By infiltration capacity curve.
- By infiltration indices.

BY INFILTRATION CAPACITY CURVE

- In this method infiltration capacity curve is used.
- This infiltration capacity curve for a given soil and moisture condition is subtracted from the curve of rainfall pattern to derive the excess rainfall which represent the runoff.

BY INFILTRATION INDICES

- Infiltration indices method is used to calculate runoff, when the catchment area is greater.
- Infiltration index is the average rate of loss such that the volume of rainfall in excess of that rate will be equal to direct runoff.

TYPES OF INFILTRATION INDEX

- Φ – Index
- W – Index

Φ – Index

- It is the rate of rainfall above which rainfall volume is equal to runoff volume.

$$\phi = \frac{P - R}{t_e}$$

- Where, P is precipitation
  R is runoff
  t_e is the effective time

W – Index

- It is the average infiltration rate during the time when rainfall intensity exceeds the infiltration capacity rate

$$W = \frac{P - R - I_a}{t_e}$$

- Where, P is the total Precipitation in cm

  R is total runoff in cm

  t_e is effective rainfall in hours

  I_a is initial losses in cm

ESTIMATING THE RUNOFF VOLUME FROM DAILY RAINFALL

In this method, strange is a most intuitive way recognizes the role of antecedent moisture in modifying the runoff volume due to rainfall event in a given catchment. Daily rainfall event are considered and three states of antecedent moisture conditions prior to the rainfall vent as dry, damp and wet are recognized. The classification of these three states are as follows:

WETTING PROCESS

1. Transition from dry to damp
   - 6mm rainfall in the last 1 day
   - 12mm in the last 3 days
   - 25mm in last 7 days
   - 38mm in the last 10 days
2. Transition from damp to wet
   - 8mm rainfall in the last 1 day
   - 12mm in last 2 days
   - 25mm in last 3 days
   - 38mm in last 5 days
3. Direct transition from dry to wet
   - Whenever 64 mm falls on the previous day or on the same day

DRYING PROCESS

1. Transition from wet to damp
   - 4mm rainfall in last 1 day
   - 6mm rainfall in the last 2 day
   - 12 mm rainfall in the last 4 days
   - 6mm rainfall in the last 2 days
2. Transition from damp to dry
   - 3mm rainfall in the last 1 day
   - 6mm in the last 3 days
   - 12mm in the last 7 days
   - 15 mm in the last 10 days

Use of Strange’s table

The Strange's table provides the run-off in terms of percentage of the monsoon rainfall for Good, Average and Bad catchments. One more method is Dry Damp Wet method to compute the run-off. In this method, the condition of the catchment can be considered as Dry, Damp or Wet based on the occurrence of daily rainfall.

INGLIS AND DESOUZA FORMULA

Inglis and Desouza (1929)evolved two reginonal formula

Between annual runoff R in cm and annual rainfall P in cm as follows:

1. For Ghat regions of western India

   $R=0.85P-30.5$

2. For Deccan plateau

   $R=1/254P(P-17.8)$

KHOSLA'S FORMULA

According to this formula for monthly runoff

$R_m = P_m - L_m$

$L_m = 0.48 T_m$ for $T_m > 4.5°C$

Where,

R_m=monthly runoff in cm and $R_m \geq 0$

P_m=monthly rainfall in cm

L_m=monthly losses in cm

T_m=mean monthly temperature of the catchment in °C

For $T_m \leq 4.5°C$, the loss L_m may provisionally be assumed as

T°C	4.5	-1	-6.5
Lm(cm)	2.17	1.78	1.52

Annual runoff=$\sum R_m$