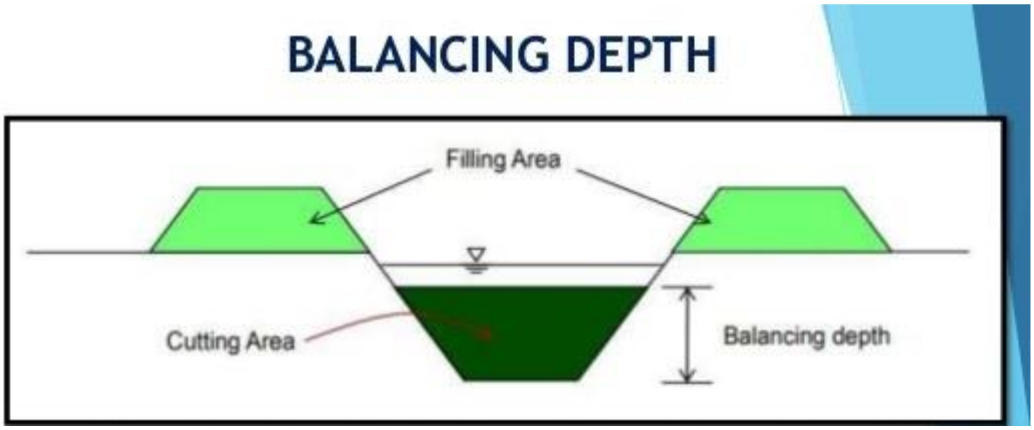

If for a channel section the depth of cutting is such that the quantity of excavation or cutting is equal to the earth filling required for making the banks, then depth of cutting is known as balancing depth or most economical depth of cutting.

The important methods involved in estimation of peak flow or Design discharge:

(1) Empirical Formulae, (2) Envelope Curves, (3) Rational Method, (4) Unit Hydrograph Method, and (5) Frequency Analysis!

1. Empirical Formulae:

In this method area of a basin or a catchment is considered mainly. All other factors which influence peak flow are merged in a constant.

A general equation may be written in the form:

$Q = CA^n$

Where Q is peak flow or rate of maximum discharge

C is a constant for the catchment

A is area of the catchment and n is an index

The constant for a catchment is arrived at, after taking following factors into account:

(a) Basin characteristics:

(i) Area,

(ii) Shape, and

(iii) Slope.

(b) Storm characteristics:

(i) Intensity,

(ii) Duration,

(iii) Distribution.

Limitations:

1. This method does not take frequency of flood into consideration.

2. This method cannot be applied universally.

3. Fixing of constant is very difficult and exact theory cannot be put forth for its selection.

However, they give fairly accurate idea about the peak flow for the catchments they represent. Some important empirical formulae are mentioned below.

(i) Dicken's formula:

It was formerly adopted only in Northern India but now it can be used in most of the States in India after proper modification of the constant.

$Q = C.M^{3/4}$

Where Q is discharge in m^3/sec.

M is area of catchment in km^2.
C is a constant.

According to the area of catchment and amount of rainfall, C varies from 11.37 to 22.04 as given in Table 5.1.

Table 5.1.

Region	*Value of C*
North India	11.37
Central India	11.77—19.28
Western India	22.04

(ii) Ryve's formula:
This formula is used only in Southern India.

$Q = C.M^{2/3}$
C = 6.74 for areas within 24 km from coast.

= 8.45 for areas within 24 —161 km from coast.

= 10.1 for limited hilly areas.

In worst cases it is found that value of C goes up to 40.5.

(iii) The Inglis Formula:

This formula is used only in Maharashtra. Here three different cases are taken into consideration.

(a) For small areas only (It is also applicable for fan shaped catchment).

$Q = 123.2\sqrt{A}$

(b) For areas between 160 to 1000 km^2
$Q= 123.2\sqrt{A}-2.62(A-259)$

(c) For large areas $Q = 123.2A/\sqrt{A} +10.36$

In all the equations A is area in km^2.

(*iv*) **Nawab Ali Nawaz's formula**

$$Q = C\left(\frac{A}{2.59}\right)(a - b.\log A)$$

where a, b and C are constants

$$a = 0.993 \text{ and } b = \frac{1}{14}$$

$C = 59.5$ for North India and 48.1 for south India.

(*v*) **Khosla's formula:** It is a very rational formula. It is based on the equation

$$P = R + L \quad \text{Or}$$

$$R = P - L \quad \text{where } R \text{ is runoff}$$

P is rainfall and L is loss.

According to Mr. Khosla main factor influencing losses is temperature. He expressed losses in mean temperature T_m in Fahrenhite. On the right hand side formula in CGS system is given.

$$L = \frac{T_m - 32}{9.5} \text{ here } L \text{ is in inches.} \qquad L = 4.82\, T_m \text{ here } L \text{ is in mm}$$

$$R = P - \frac{T_m - 32}{9.5} \qquad \text{and } T_m \text{ in centigrade.}$$

The abovementioned formula of losses cannot be used for the values of temperature less than 40°F. For lower temperatures he gave following Table 5.2.

Table 5.2.

T_m °F	40	30	20	10	0
L inches	0.84	0.70	0.60	0.50	0.40

Khosla formula is useful in assessing water potential of a basin in a river valley project.

(*vi*) **Besson's formula:** This formula is very rational and can be used in any case.

$$Q_m = \frac{P_m \times Q_r}{P_r}$$

where Q_m is peak flow expected.
Q_r is some observed peak flow.
P_r is observed rainfall.
P_m is expected rainfall.

2. Envelope Curve:

It is another method of estimation of peak flow. It is based on the assumption that highest known peak flow per unit area registered in the past in one basin in a region may occur in future in another basin in the same region or a region possessing similar hydrologic characteristics.

A graph is constructed by plotting the highest peak flows observed per unit area of the catchment against their catchment areas in the region. The points obtained on the graph are joined by an envelope curve. The curve once constructed can be used to calculate the probable maximum peak flow for any basin in that region.

This method was given formerly by Creager Justin and Hinds in USA.

The equation to the curve was of the type:
$q = C. A^n$ where q represents the peak flow per unit area
A represents the catchment area

C is a constant, and

n is some index.

By multiplying both sides of the above equation by area of the basin 'A', we get

$Q = C.A^{n+1}$
where Q represents the peak flow.

Kanwar Sain and Karpov have developed two envelope curves to suit Indian conditions as shown in Fig. 5.4. One curve has been developed for the rivers in South India and the other for Northern and Central Indian Rivers.

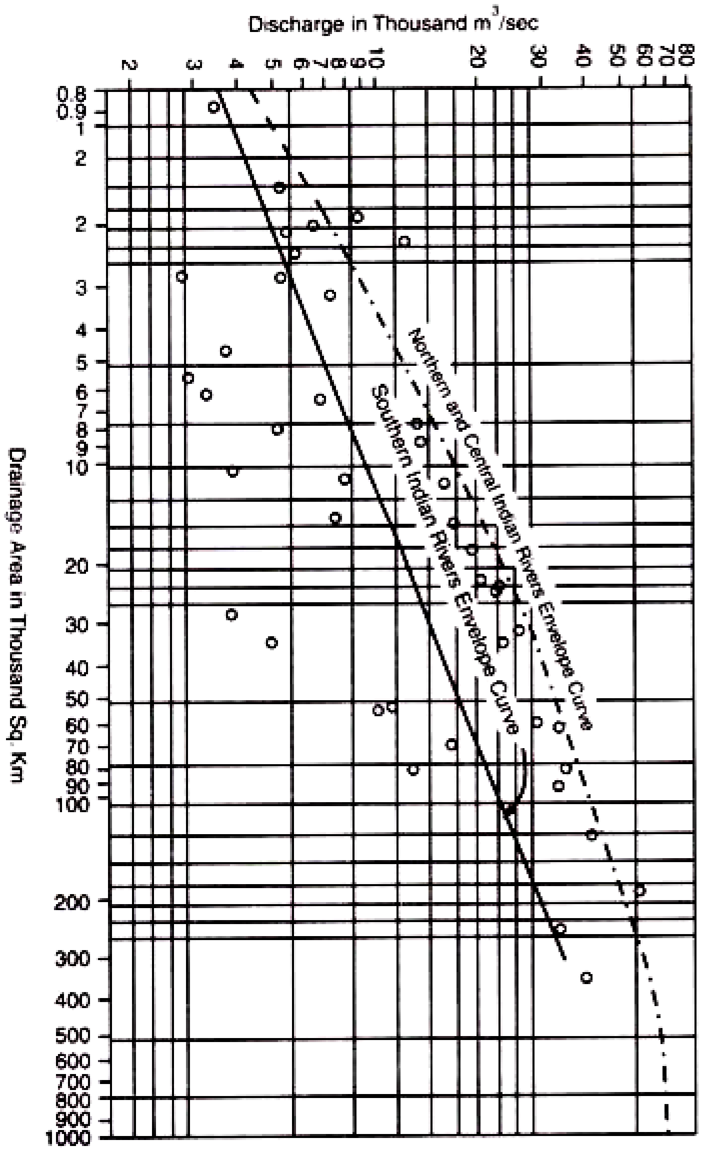

Fig. 5.4. Envelope curves for river basins of India

3. Rational Method:

This method is also based on the principle of the relationship between rainfall and runoff and hence can be considered to be similar to empirical method. It is, however, called rational method because the units of the quantities used are approximately numerically consistent. This method has become popular because of its simplicity.

The formula is expressed as follows:

Q = PIA

where Q is peak discharge in cumec

P is runoff coefficient which depends on the characteristics of the catchment area. It is a ratio of runoff: rainfall. (P values are given later).

I is the intensity of rainfall in m/sec for the duration at least equal to “time of concentration”.

And A is area of the catchment in m^2.

Time of concentration:

It is the time taken by the rain water falling at the remotest point of the drainage basin to reach the discharge measurement point. It is given by the formula

$t_c = 0.000324\ L^{0.77}/S^{0.358}$

where t_c is time of concentration in hours,

L is length of the drainage basin in m measured along river channel upto the farthest point on the periphery of the basin.

S is average slope of the basin from the farthest point to the discharge measuring point under consideration.

Assumptions:

The rational formula is given on the following assumptions:

(i) A peak flow is produced on any drainage basin by a rainfall intensity which continues for a period equal to the time of concentration of the flow at the point under consideration.

(ii) The peak flow resulting from any rainfall intensity attains maximum value when the rainfall intensity lasts for the time equal to or greater than the time of concentration.

(Hi) The maximum peak flow resulting from long duration rainfall intensity as mentioned above is its simple fraction.

(iv) The coefficient of runoff is same for all storms of varying frequencies on a given drainage basin.

(v) The frequency of peak flow is same as that of the rainfall intensity for a given drainage basin.

While defining the peak flow. When rainfall continues for such long enough time that all portions of the drainage area simultaneously contribute runoff to an outlet peak flow is reached. Obviously the rainfall must continue till water falling at the farthest point also reaches the discharge measurement point. If the rainfall occurs at uniform rate right from the beginning the time of concentration will be equal to the time of equilibrium when effective rainfall equals direct runoff.

Limitations of the Rational Method:
(i) It is clear that as the extent of the catchment area increases all assumptions cannot be fulfilled. Hence, for large catchment areas the utility of rational formula is questionable.

(ii) For very large and complex catchment areas before the water reaches outlet from the farthest point if the rainfall ceases then there is no possibility of whole catchment contributing its share of runoff to the outlet simultaneously. In such cases the lag time of peak flow is smaller than the time of concentration. In the above circumstances the rational formula does not give maximum peak flow.

Obviously the rational formula is applicable for small and simple drainage basins for which time of concentration is nearly equal to the lag time of the peak flow.

(iii) It is seen that rational formula gives better results for paved areas with drainages having fixed and stable dimensions. Therefore, it is popularly used for urban areas and small catchments only when detailed study of the problem is not justified. (The catchment area best suited is of the order of 50 to 100 ha). Since flood records are not available for small areas this method is found convenient.

(iv) The choice and selection of value of (P) the runoff coefficient is the most subjective thing and requires good judgment. Otherwise it is likely to introduce substantial inaccuracy.

Refinement of rational method:
As a refinement sometimes the drainage basin is divided into zones by contours. Each zone is so selected that the time of concentration of each zone is same. Each zone is then assigned appropriate value of (P) the runoff coefficient depending upon the imperviousness of the area. The total discharge is taken as summation of discharges from various zones. Using this value of total discharge average runoff coefficient for the drainage basin can be worked out.

Table 5.3: Typical values of the runoff coefficient 'P'

Basin characteristics	*Runoff coefficient*
Sandy soil covered with bushes heavily	0.10
Sandy soil covered with bushes lightly	0.20
Gravel paving and bare soil	0.15 to 0.30
Loamy soils largely cultivated	0.40
Asphalt macadam paving	0.50
Concrete paving and flat roof surfaces	0.80
Clayey soils stiff and bare, steep rock bare Pitched roof surfaces	0.90

Problem:

The areas of the small drainage basin are 500 ha.

Using rational formula and making use of the following data calculate peak flow: The catchment area is under different land use and value of 'P' for various categories is as follows:

Land use category	*Area (ha)*	*runoff coeff.*
Wooded steep rocky land	130	0.8
Lightly covered plateau land	60	0.7
Lightly covered clayey soil	110	0.5
Cultivated loamy soil	90	0.3
Sandy soil covered sparsely	110	0.2

The rain storm continued for 5 hours and gave 30 cm of rainfall during this period. The farthest point from the drainage outlet is 10 km away and the difference of elevation between the locations is 100 m.

Solution: **Step 1.** Time of concentration is given by formula

$$t_c = 0.000324 \frac{(L)^{0.77}}{S^{0.385}} = 0.000324 \frac{(10{,}000)^{0.77}}{(0.01)^{0.385}} = 2.3 \text{ hours.}$$

Since t_c is less than the duration of rain storm maximum peak flow will be given by the rational formula.

Step 2. In the example different 'P' values are given for different land use classes. So weighted average value of 'P' can be calculated as below

$$\begin{aligned} \frac{A \times P}{130 \times 0.8} &= \frac{AP}{104} \\ 60 \times 0.7 &= 42 \\ 110 \times 0.5 &= 55 \\ 90 \times 0.3 &= 27 \\ 110 \times 0.2 &= 22 \\ &\Sigma\ 250 \end{aligned}$$

Average $\qquad P = \frac{250}{500} = 0.5$

Step 3. Putting values in rational formula

Q= P.I.A = 0.5 X {0.3/(5X6X0X60)} X 500 X 10^4 = (0.15 / 36) X 10^4 = 41.6 cumec

4. Unit Hydrograph Method:

In the last chapter it is already mentioned that the largest ordinate of the unit hydrograph multiplied by the effective rainfall (in cm) occurring in the unit duration gives the peak flow. To this amount base flow may also be added to get total peak flow. The method is fully explained and examples solved in the last chapter to make the procedure clear. In case of ungauged basins Snyder's Snythetic unit hydrograph may be developed to estimate the peak flow.

5. Frequency Analysis:

Definition of frequency analysis:

Frequency analysis is a method which involves study and analysis of past records (historical data) of hydrologic events to predict the future probabilities (chances) of occurrence. It is based on the assumption that the past data are indicative of the future.

Frequency analysis is done to estimate various things like annual runoff variations, frequencies of floods, droughts, rainfall etc. In other words the primary objective of the frequency analysis of hydrologic data (say flood events) is to determine the recurrence interval of the hydrologic event of a given magnitude.

For such analysis so called probability curves have been used. Given the observed data (for example maximum discharges for estimating maximum flood, average annual discharges for annual variations etc.) the task is to find a theoretical curve the ordinates of which will coincide with those observed. Good agreement of a theoretical curve with an empirical one ensures that the extrapolation can be rightly done.

When stream flood records of sufficient length and reliability are available they may yield satisfactory estimates. The accuracy of the estimates reduces with the degree of extrapolation. It is considered by some that extrapolation may be done only up to double the period for which data is available. For example, to get a 100 year flood 50 years record is necessary. However, insufficiency of recorded data makes it obligatory to use short term data to predict 1000 and 10,000 year floods also.

Frequency analysis is a method which involves statistical analysis of recorded data to estimate flood magnitude of a specified frequency. It, therefore, requires knowledge of statistics to clearly appreciate the methods of frequency analysis.

Recurrence Interval (T):

A return period, also known as a **recurrence interval** or repeat **interval**, is an average time or an estimated average time between events such as earthquakes, floods, landslides, or a river discharge flows to occur.

OR

Recurrence Interval denotes the number of years in which a flood can be expected once. $T=100/F$ where F=Flood frequency

Flood frequency denotes the likelyhood of flood being equalled or exceeded. A 10% frequency (F) means that the flood has 10 out of 100 chances of being equaled or exceeded.

The recurrence Interval(T) can be found by any of the following methods:

1) California Method: $T=N/m$
2) Hazens Method: $T=2N/(2m-1)$
3) Gumbel's method: $T=N/(m+C-1)$

Where N=No.of years, m=Serial number in the order, C = Gumbel' correction given as mentioned below:

m/N:	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.08	0.04
C:	1	0.95	0.88	0.845	0.78	0.73	0.66	0.59	0.52	0.4	0.38	0.28