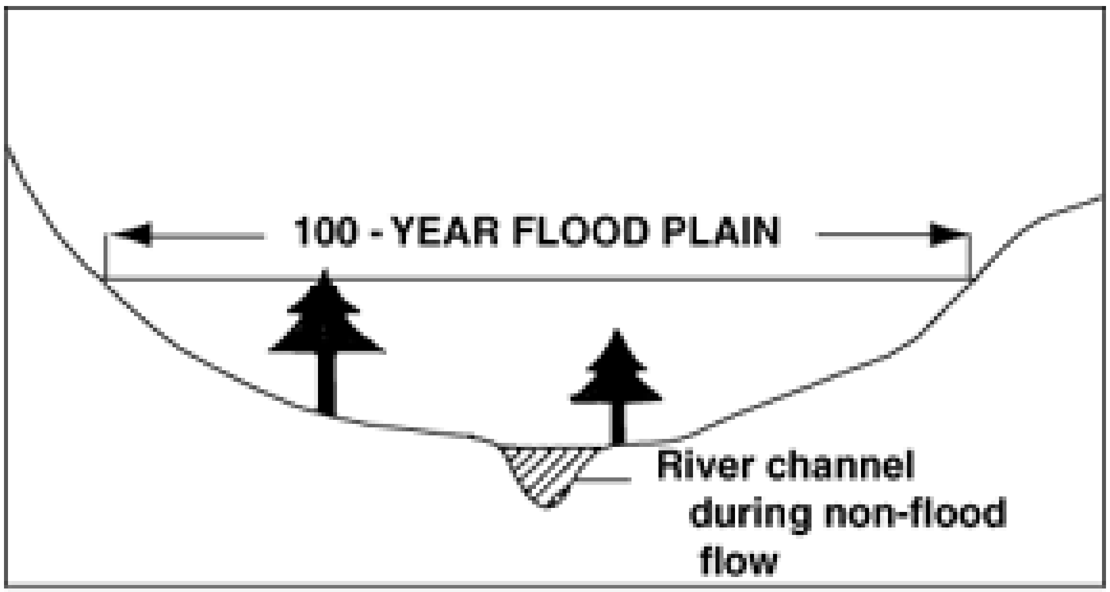
CHAPTER-8

Floods

Flood

- A high stage in a river, normally the level at which the river overflows its banks and inundates the adjoining area.
- Floods causes a lot of losses, like lives, properties, washing out of roads, culverts, crops, traffic problems, socioeconomic losses due to delays etc.
- Flood peak values are required to design hydraulic structures.



FLOOD PLAINS NORMALLY ARE DRY

Top Ten Disasters of the World by Number of deaths

Ten deadliest natural disasters

[edit

Rank	Death toll (estimate)	Event	Location	Date
1.	1,000,000–2,500,000*[1]	1931 China floods	China	July, November, 1931
2.	900,000–2,000,000[2]	1887 Yellow River flood	China	September, October, 1887
3.	830,000[3]	1556 Shaanxi earthquake	Shaanxi Province, China	January 23, 1556
4.	500,000[1]	1970 Bhola cyclone	East Pakistan (now Bangladesh)	November 13, 1970
5.	316,000[4]	2010 Haiti earthquake	Port-au-Prince, Haiti	January 12, 2010
6.	300,000[5]	1839 India Cyclone	India	November 25, 1839
7.	250,000–300,000	526 Antioch earthquake	Antioch, Byzantine Empire (now Turkey)	May 526
8.	242,419 (the death toll has been estimated to be as high as 665,000)[1]	1976 Tangshan earthquake	Tangshan, Hebei, China	July 28, 1976
9.	234,117[1]	1920 Haiyuan earthquake	Haiyuan, Ningxia-Gansu, China	December 16, 1920
10.	230,210	2004 Indian Ocean Tsunami	Sumatra, Indonesia and also affected India, Sri Lanka, Maldives	December 26, 2004

* Estimate by Nova's sources are close to 4 million and yet Encarta's sources report as few as 1 million. Expert estimates report wide variance.

An alternative listing is given by Hough in his 2008 book *Global Security*.[6]

Top Ten Disasters of the World by Number of deaths (last century)

Ten deadliest natural disasters of the past century

Rank	Maximum death toll	Event*	Location	Date
1.	145,000–2,500,000	1931 China floods	China	November 1931
2.	242,419–779,000	1976 Tangshan earthquake	China	July 1976
3.	300,000–500,000	1970 Bhola cyclone	East Pakistan (now Bangladesh)	November 1970
4.	316,000[7]	2010 Haiti earthquake	Haiti	January 2010
5.	234,000	1920 Haiyuan earthquake	China	December 1920
6.	230,210+	2004 Indian Ocean Tsunami	Indonesia	December 2004
7.	142,000	1923 Great Kanto earthquake	Japan	September 1923
8.	138,000+	2008 Cyclone Nargis	Myanmar	May 2008
9.	138,000	1991 Bangladesh cyclone	Bangladesh	April 1991
10.	120,000	1948 Ashgabat earthquake	Turkmenistan	October 1948

* Does not include industrial or technological accidents.

Top Ten Disasters of the World by Number of deaths in 2005

Natural Disaster	Month	Country	Number of causalities
Earthquake	October	Pakistan	73 338
Hurricane Stane	October	Guatemala	1 513
Hurricane Katrina	August	United States	1 322
Earthquake	October	India	1 309
Flood	July	India	1 200
Earthquake	March	Indonesia	915
Flood	June	China	771
Earthquake	February	Iran	612
Measles Epidemic		Nigeria	561
Flood	February	Pakistan	520

Source: International disaster data base

Disturbance in Traffic due to Floods

During flooding of 2003

Disturbance in Traffic due to Floods

Floods in Baluchistan, 2007

Floods in Baluchistan, 2007

Floods in Baluchistan, 2007

Floods in Baluchistan, 2007

Floods in Pakistan, 2010

Floods in Pakistan, 2010

Floods in Pakistan, 2010

Floods in Pakistan, 2010

Floods in Pakistan, 2010

Floods in Pakistan, 2010

Floods in Pakistan, 2010

Floods in Pakistan, 2010

Floods in Pakistan, 2010

Causes of Floods

1) Excessive Rainfall-Runoff
2) High Snow melt Runoff
3) Dam Failure (Shadi Core Dam Failure, 2005)
4) Landslide Lake Outburst Floods
5) Glacier Lake Outburst Floods (GLOFs)
   (1929, Khumdan Glacier Lake Outburst Flood)
6) Any Combination of the above

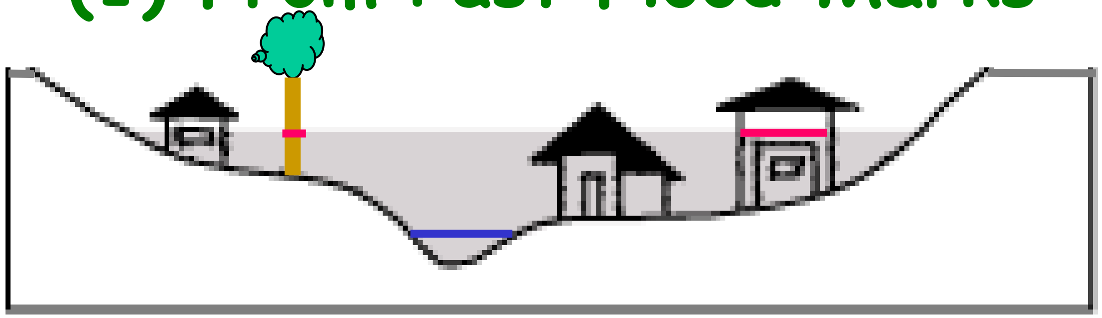
Methods to estimate Flood Peaks

1) From Past Flood marks
2) Rational Method
3) Empirical Methods
4) Unit Hydrograph Technique
5) Flood Frequency Studies
6) Probable Maximum Flood (PMF)

Selection of the Method depends upon

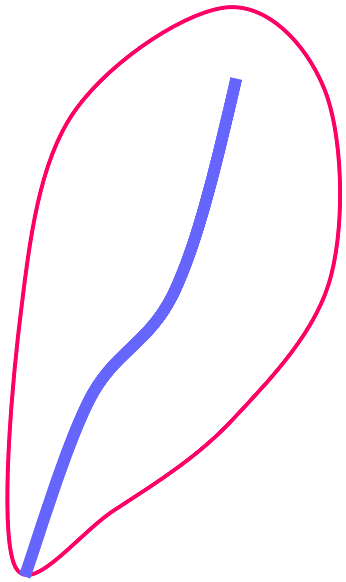
1) Objectives
2) Available Data
3) Level / Importance of the Project

(1) From Past Flood Marks



- The method is useful to approximate the peak flow when flow measurements are not available in the past.
- Filed Visit is essential.
- Information is collected by locating the past highest flood mark (last 30-35 years) on buildings, big trees and prominent places etc.
- Questionnaire surveys are carried out by consulting senior Citizens.
- R.L. is determined for the highest flood mark (stage)
- After surveying, river x-sections are plotted with HFL.
- For highest stage, area of flow, wetted perimeter and hydraulic radius are estimated.
- Longitudinal slope of the river b/w two sections is obtained by leveling.
- Manning's n is assumed for the river reach.
- Compute discharge by Manning's equation

(2) Rational Method



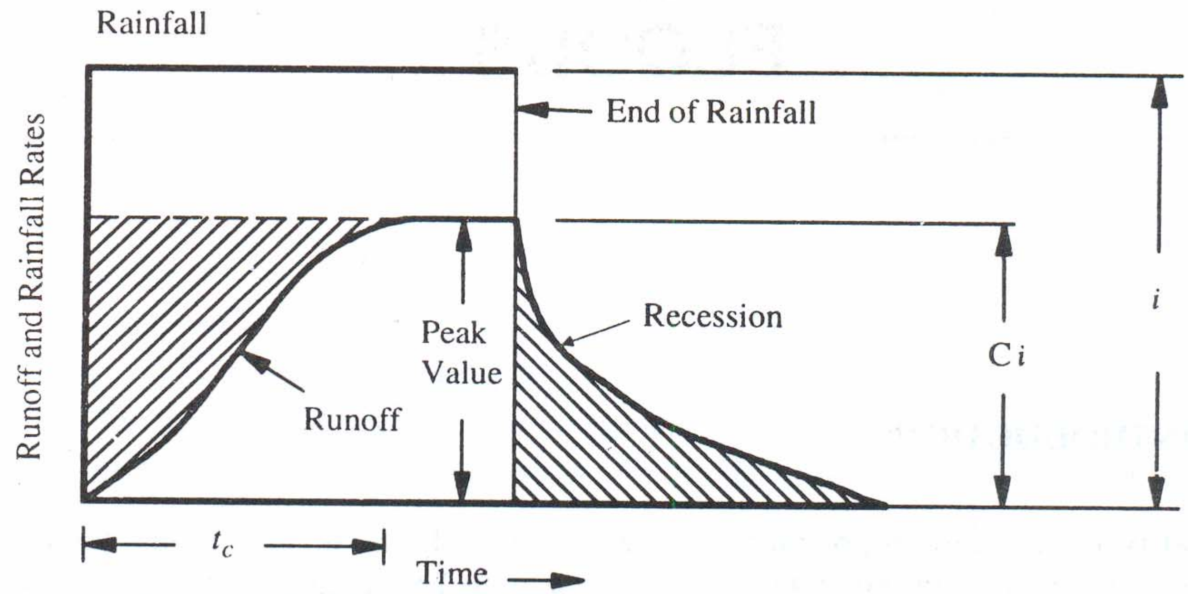


Figure: Runoff hydrograph due to uniform rainfall

Assumptions

- Temporal Rainfall distribution is uniform
- Rainfall amount over the watershed is uniform
- Watershed is of relatively smaller size (< 50 km^2)
- Runoff rate gradually increases up to time tc
- If rainfall rate continues from tc, the runoff rate will be constant

Time of concentration:

Time taken by a drop of water to reach at the outlet from the farthest part of the catchment

Peak value of runoff is given by

Where

$$Q_p = C\ i\ A \quad for \quad t \geq t_c$$

C = Coefficient of runoff = runoff/rainfall

i = intensity of rainfall

A = area of the catchment

For field applications

$$Q_p = \frac{1}{3.6}\ C\ \left(i_{tc,p}\right)\ A$$

Where

Q_p = Peak discharge (cumecs)

C = Coefficient of runoff

$i_{tc,p}$ = the mean intensity of rainfall (mm/hr)for a duration equal to tc and an exceedance probability P

A = area of the catchment in km^2

(1) Approaches to determine Time of Concentration

(a) US Practice

(b) Kirpich equation

(a) US Practice

For small drainage basins, the time of concentration is approximated equal
To the lag time of the peak flow.

$$t_c = t_p = C_{tL} \left[\frac{L\, L_{ca}}{\sqrt{S}} \right]^n$$

Where t_c = time of concentration (hrs)

C_{tL} = basin constant (1.715 for mountainous, 1.03 for foothill drainage area, 0.50 for valley drainage area)

L = Basin length measured along the watercourse

L_{ca} = distance along the main watercourse from the gauging stn opposite to watershed centroid

n = basin constant $\approx$ 0.38

S = basin slope

(b) Kirpich equation (1940)

$$t_c = (0.01947)\ L^{0.77}\ S^{-0.385}$$

Where t_c = time of concentration (min)

L = Maximum length of travel of water (m)

S = slope of catchment = $\frac{\Delta H}{L}$

ΔH = Difference in elevation between most remote point on the catchment and the outlet.

(2) Rainfall intensity ($i_{tc,p}$)

For duration tc and desired probability of exceedance P, $i_{tc,p}$ is found from IDF curves.

$$i_{tc,p} = \frac{c}{T_d^e + f}$$

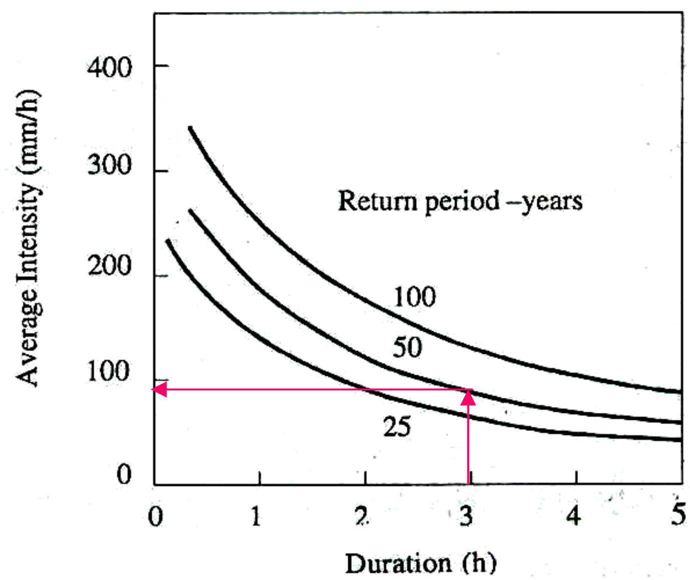


Fig. 2.15 (a) Intensity–duration–frequency curves

(3) Runoff Coefficient

- Integrated effect of catchment losses
- Depends on climate and basin characteristics
- Effect of climate is not considered in Table 7.1

	Type of Area	Value of *C*
A.	**Urban area:**	
	Lawns: sandy soil, flat, 2 %	0.05–0.10
	Sandy soil, steep, & %	0.15-0.20
	Heavy soil, average, 2.7 %	0.18-0.22
	Residential areas:	
	Single family areas	0.3-0.50
	Multi Units, attached	0.60-0.75
	Industrial:	
	Light	0.50-0.80
	Heavy	0.60-0.90
	Streets	0.70-0.95
B.	**Agricultural area**	
	Flat: tight clay; cultivated	0.50
	Woodland	0.40
	Sandy loam; cultivated	0.20
	woodland	0.10
	Hilly: Tight clay; cultivated	0.70
	woodland	0.60
	Sandy loam; cultivated	0.40
	woodland	0.30

For Non homogenous catchments, Runoff Coefficient

Weighted equivalent runoff coefficient

$$C_e = \frac{\sum_{i=1}^{N} \left(C_i \; A_i \right)}{A}$$

Where, N_j = Number of sub areas in the catchment

Limitations of Rational Formula

(1) Applicable for small catchments upto 50 km^2 area
(2) Urban drainage design
(3) Culverts and bridges

(3) Empirical Formulae

- Empirical relationships developed using past peak flow (flood) data.
- Usually, peak flow is correlated with basin characteristics (A, S).
- These are regional formulae, usually applicable to the same region.
- Can be applied to other regions if they have similar hydro-meteorological characteristics.

Various Flood discharge formulae

(1) Dicken's Formula

(2) Ryves Formula

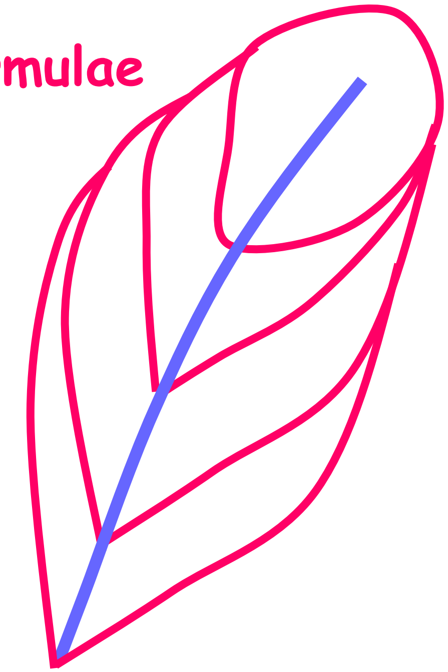
(3) Inglis Formula

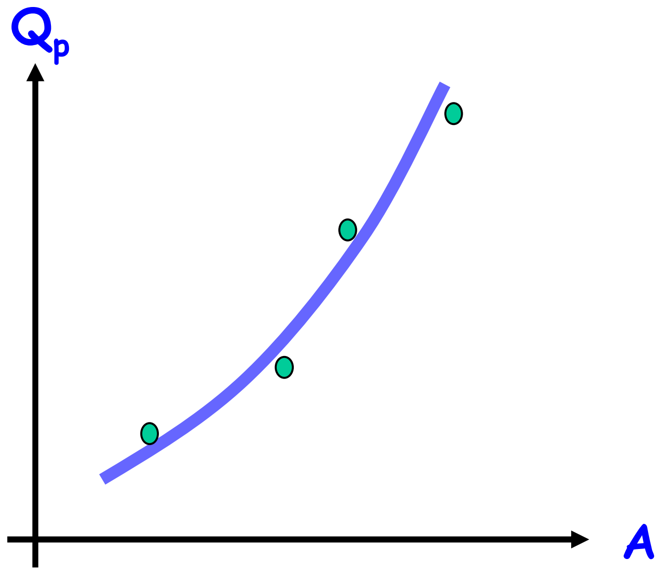
(4) Fuller's Formula

(5) Baird & McIllwraith Formula

(6) Hafiz Asif Arshad Formula

(7) Usman Naeem Formula





$$Q_p = f(A)$$

Various Flood discharge formulae

(1) Dicken's Formula

(2) Ryves Formula

(3) Inglis Formula

(4) Fuller's Formula

(5) Baird & McIllwraith Formula

(6) Hafiz Asif Arshad Formula

(7) Usman Naeem Formula

(1) Dicken's Formula (1865)

- For Central and Northern Part of India

$$Q_p = C_D \ A^{3/4}$$

Where Q_p = Maximum flood discharge (cumecs)

A = Catchment area (km²)

C_D = Dicken's constant (6-30)

(2) Ryves Formula (1884)

- For Tamil Nadu Region

$$Q_p = C_R \ A^{2/3}$$

Where Q_p = Maximum flood discharge (cumecs)

A = Catchment area (km²)

C_R = Ryves Coefficient (6.8-10.2)

(3) Inglis Formula (1930)

- For western Ghats in Maharashtra

$$Q_p = \frac{124\ A}{\sqrt{A+10.4}}$$

(4) Fuller's Formula (1914)

- For catchments in USA

$$Q_{TP} = C_f\ A^{0.8}\left(1+0.80\ \log T\right)$$

Where Q_{TP} = Maximum 24 hr flood with a frequency of T years (cumecs)

A = Catchment area (km^2)

C_f = a constant (0.18-1.88)

(5) Baird & McIllwraith Formula (1951)

- Based on maximum recorded floods throughout the world

$$Q_{mp} = \frac{3025\ A}{\left(278+A\right)^{0.78}}$$

(6) Hafiz Asif Arshad Formula (2007)

- For Upper River Jhelum
- Developed by using Multiple Non-linear Regression Analysis

$$Q_p = A^{0.72} \ S^{0.32}$$

Where Q_p = Maximum flood discharge (cumecs)

A = Catchment area (km^2)

S = Average Slope (%)

(7) Usman Naeem Formula (2007)

- For Upper River Chenab
- Developed by using Multiple Non-linear Regression Analysis

$$Q_p = 1.005 \ A^{2.46} \ S^{4.22}$$

Where Q_p = Maximum flood discharge (cumecs)

A = Catchment area (km^2)

S = Average Slope (%)

Envelope Curves for Rivers

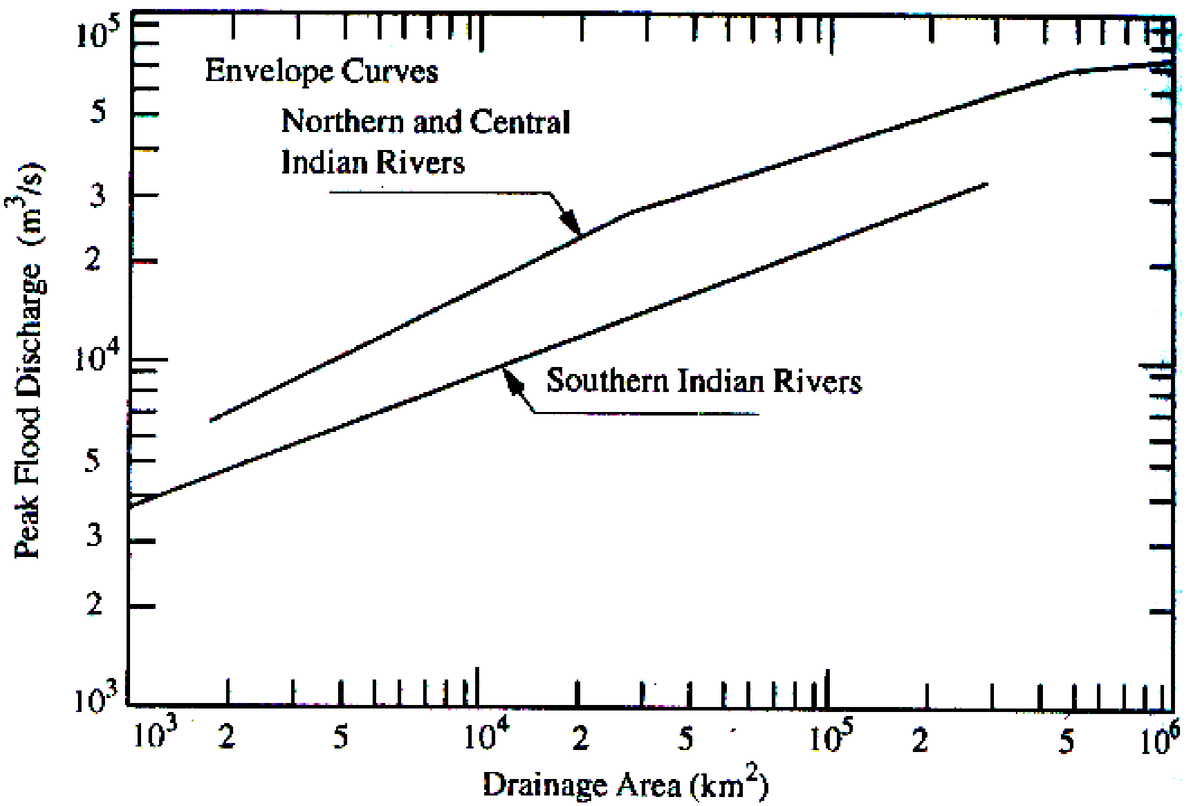
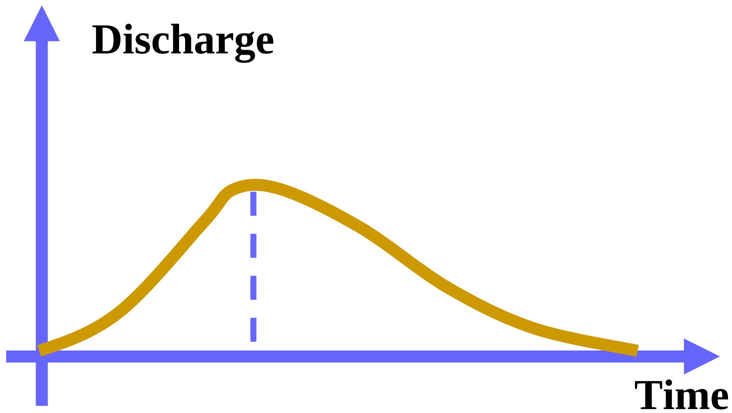


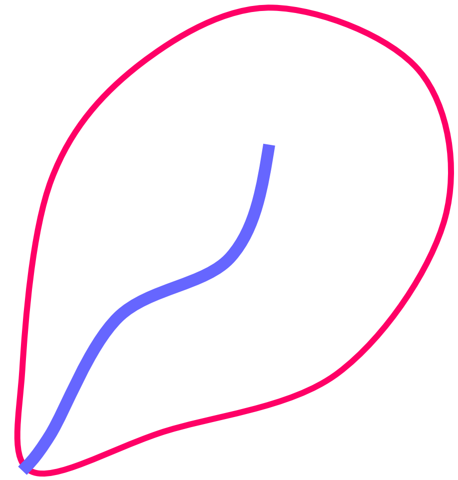
Fig. 7.2 Enveloping curves for Indian rivers

(4) Unit Hydrograph Method

Unit Hydrograph

DRO Hydrograph resulting from unit effective precipitation over the watershed for a particular duration of the effective rainfall.





- ❑ Applicable for smaller areas (25-500 km^2)
- ❑ All limitations of the UHG are applicable.
- ❑ A UHG gives peak discharge due to unit effective precipitation.

Procedure

(1) Determine time of concentration tc for the watershed.
(2) Select severe most rainstorm for the duration equal to or greater than tc.
(3) Derive a UHG for a watershed of known rainstorm duration (tc)
(4) Determine effective precipitation subtracting losses (P_{eff}).
(5) Determine peak flow due to x cm effective ppt.

$$Q_p = P_{eff}\,\left(Q_p\right)_{due\ to\ unit\ \ ppt}$$

(5) Flood Frequency Studies

- Statistical method of flood analysis
- Statistical approach to compute flood magnitude for a given return period based on the past data available.
- Requires long past flood data record (30 years)
- Data records less than 30 years are not suitable for frequency analysis
- Floods are complex natural events
- Depends on number of parametrs

Methods of compiling flood peak data

(i) Annual flood series

(ii) Partial duration flood series

Using Annual Flood Series Approach for compiling data

- Data is arranged in descending order of magnitude
- Using Plotting Position formula, probability P being equalled or exceeded is calculated.

$$P = \left[\frac{m}{N+1} \right]$$

Weibull Method (plotting position)

Where m = order number of the event.
N = Total number of events in the data
T = Return period or Frequency

$$T = \frac{1}{P}$$

Probability Distribution

- A plot of Q ~ T yields the Probability distribution
- For small return periods a simple best fitting curve through plotted points can be used as the probability distribution.
- A log scale for T is often advantageous.
- For larger extrapolations, theoretical probability distributions have to be used.
- For extreme flood events, specific extreme value distributions are assumed and statistical parameters are calculated from the available data.

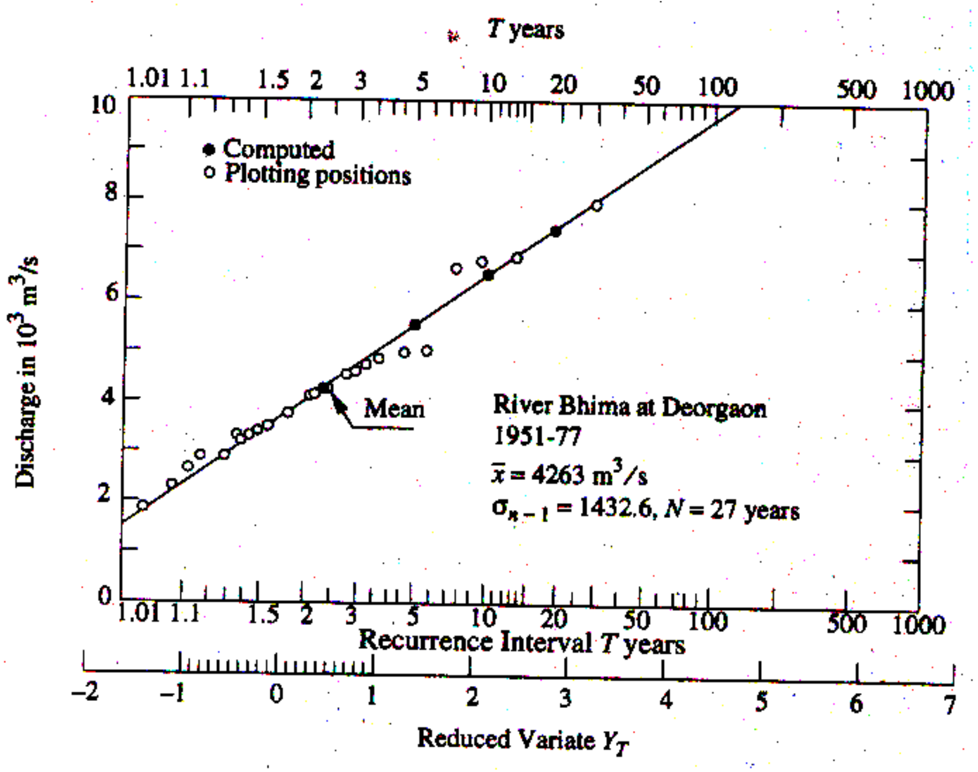


Fig. 7.3 Flood probability analysis by Gumbel's distribution

Computation of Return Period (T)

- Methods for computation of return periopds

(1) Empirical Approach [for short extrapolations, up to twice]

(2) Analytical Approach [for long extrapolations]

- Empirical Approaches

(1) California Method $T = \frac{N}{m}$

(2) Allen Hazen Method $T = \frac{N}{m - 0.5}$

(3) Weibull Method $T = \frac{N+1}{m}$

(4) Gumbel's Method $T = \frac{N}{m + c - 1}$

(5) Blom Method $T = \frac{(N + 0.12)}{(m - 0.44)}$

(6) Gringorten Method $T = \frac{(N + 0.25)}{\left(m - \frac{3}{8}\right)}$

m/N	c
1	1
0.9	0.95
0.8	0.88
0.7	0.845
0.6	0.78
0.5	0.73
0.4	0.66
0.3	0.59
0.2	0.52
0.1	0.40
0.08	0.38
0.04	0.28

Where

m is the order number when arranged in descending order and *N* total number of records

❑ Analytical Methods

Commonly used Frequency distribution functions for the prediction of extreme floods are:

(i) Gumbel's Extreme Value Distribution

(ii) Log Pearson Type-III Distribution

(iii) Log Normal Distribution

General Equation of Hydrologic Frequency Analysis

Chow (1951) has shown that most frequency distribution functions applicable in hydrologic studies can be expressed by the following equation.

$$x_T = \bar{x} + K\ \sigma$$

Where,

x_T = value of variate x of a random hydrologic series with a return period T.

$\bar{x}$ = mean value of the variate

σ = standard deviation of the variate

K = frequency factor [f(T, assumed frequency distribution)]

(1) Gumbel's Method

- Introduced in 1941
- Most widely used method for hydrological and Meteorological studies.
- Peak floods, max. rainfalls, maximum wind speed.
- According to his theory of extreme events, the probability of occurrence of an event equal to or larger than a value x_o is

$$P(x \geq x_o) = 1 - e^{-e^{-y}} \qquad (1)$$

Where y = dimensionless variable

$$y = \alpha \; (x - a) \qquad (2)$$

$$a = \bar{x} - 0.45005 \; \sigma_x \qquad (3)$$

$$\alpha = \left[\frac{1.2825}{\sigma_x} \right] \qquad (4)$$

$$y = \frac{1.2825 \; (x - \bar{x})}{\sigma_x} + 0.577 \qquad (5)$$

Where $\bar{x}$ = mean of variate x $= \frac{1}{N}\sum_{i=1}^{N}(x_i)$

σ_x = standard deviation of variate x

Eqn (1) is transposed as (value of x for a given P)

$$y_P = -\ln[-\ln(1-P)] \quad (6)$$

$$T = \frac{1}{P} \quad (7)$$

$$= -\ln\left[-\ln\left(1-\frac{1}{T}\right)\right] = \ln\left[-\ln\left(\frac{T-1}{T}\right)\right] \quad (8)$$

$$y_T = -\left[\ln\ \ln\left(\frac{T}{T-1}\right)\right] \quad (9)$$

y_T = reduced variate for given T

Now rearranging eqn (5), the value of variate x with a return period T is

$$\sigma_x\left(\frac{y-0.577}{1.2825}\right) = (x-\bar{x}) \quad (10)$$

$$x = \bar{x} + \left(\frac{y - 0.577}{1.2825} \right) \sigma_x \qquad (11)$$

$$x_T = \bar{x} + K \ \sigma_x \qquad (12)$$

Where

$$K = \left[\frac{y_T - 0.577}{1.2825} \right] \qquad (13)$$

Eqn (13) is of the same form as general equation of hydrologic-frequency analysis.

$$x_T = \bar{x} + K \ \sigma$$

Eqn (12) & (13) are the basic Gumbel's equations and are applicable to an infinite Sample size (N -> ∞).

Since annual data series (flood & rainfall) all have finite lengths of records, eqn (11) is modified to account for finite N as given on next slide.

Gumbel's equation for Practical Use

$$x_T = \bar{x} + K\ \sigma_{n-1}$$

where σ_{n-1} = standard deviation of the sample size N

$$\sigma_{n-1} = \sqrt{\frac{\sum (x - \bar{x})^2}{N - 1}}$$

K = frequency factor

$$K = \left[\frac{y_T - \bar{y}_n}{S_n} \right]$$

In which y_T = reduced variate, a function of T

$$y_T = -\left[\ln \ln \left(\frac{T}{T - 1} \right) \right]$$

$\bar{y}_n$ = reduced mean, f(sample size N), given in Table 7.3

For $N \to \infty$ $\bar{y}_n \to 0.577$

S_n = reduced standard deviation, a function of sample size N, given in Table 7.4

For $N \to \infty$ $S_n \to 1.2825$

Demerits of Gumbel's Method

Alexeev (1961) has shown that, Gumbel's distribution gives erroneous results if sample has a value of Cs very much different from 1.14. (Cs = coefficient of skew).

Procedure

(1) Assemble discharge data, note down the sample size N annual flood value is variate x. Find $\overline{x}$, σ_{n-1} for the given data.

(2) Using Tables 7.3 & 7.4, determine $\overline{y}_n$ and S_n appropriate to given N.

(3) Find y_T for given T by using equation

$$y_T = -\left[\ln \ln\left(\frac{T}{T-1}\right)\right]$$

(4) Find frequency factor (K) by using equation

$$K = \left[\frac{y_T - \overline{y}_n}{S_n}\right]$$

(5) Determine the required x_T by equation

$$x_T = \overline{x} + K\ \sigma_{n-1}$$

To verify whether the given data follow the assumed Gumbel's distribution.

Procedure

- The value of x_T for some return period (T<N) are calculated by using Gumbel's formula & plotted as x_T vs T on a convenient paper (semi log, log-log or Gumbel probability paper).
- Gumbel probabilty paper -> results in a straight line for x_T vs T
- Gumbel's distribution has the property which gives T = 2.33 years for the average of the annual series when N is very large.
- Thus the flood value with T = 2.33 years is called the mean annual flood.
- By extrapolation of the straight line x_T ~ T values of x_T for $T > N$ can be determined.

Gumbel's Probability Paper

- Abscissa -> Return period T
- Construct an arithmatic scale of y_T values, say from –2 to +7.
- For selected values of T, say 2, 10, 50, 100, 1000 years, find the values of y_T using equation.

$$y_T = -\left[\ln \ln\left(\frac{T}{T-1}\right)\right]$$

Mark off the positions on the abscissa. The T scale is now ready for use.

- The ordinate of Gumbel paper on which the value of variate, $x_T\left(Q_P,\ R_P\right)$ are plotted have either arithmatic or log scale.
- As equations

$$x_T = \bar{x} + K\ \sigma_x \qquad K = \left[\frac{y_T - 0.577}{1.2825}\right]$$

- x_T varies linearly with y, a Gumbel distribution with plot a straight line on Gumbel probability paper.
- This property can be used for extrapolations.

Gumbel's Probability Paper (contd.)

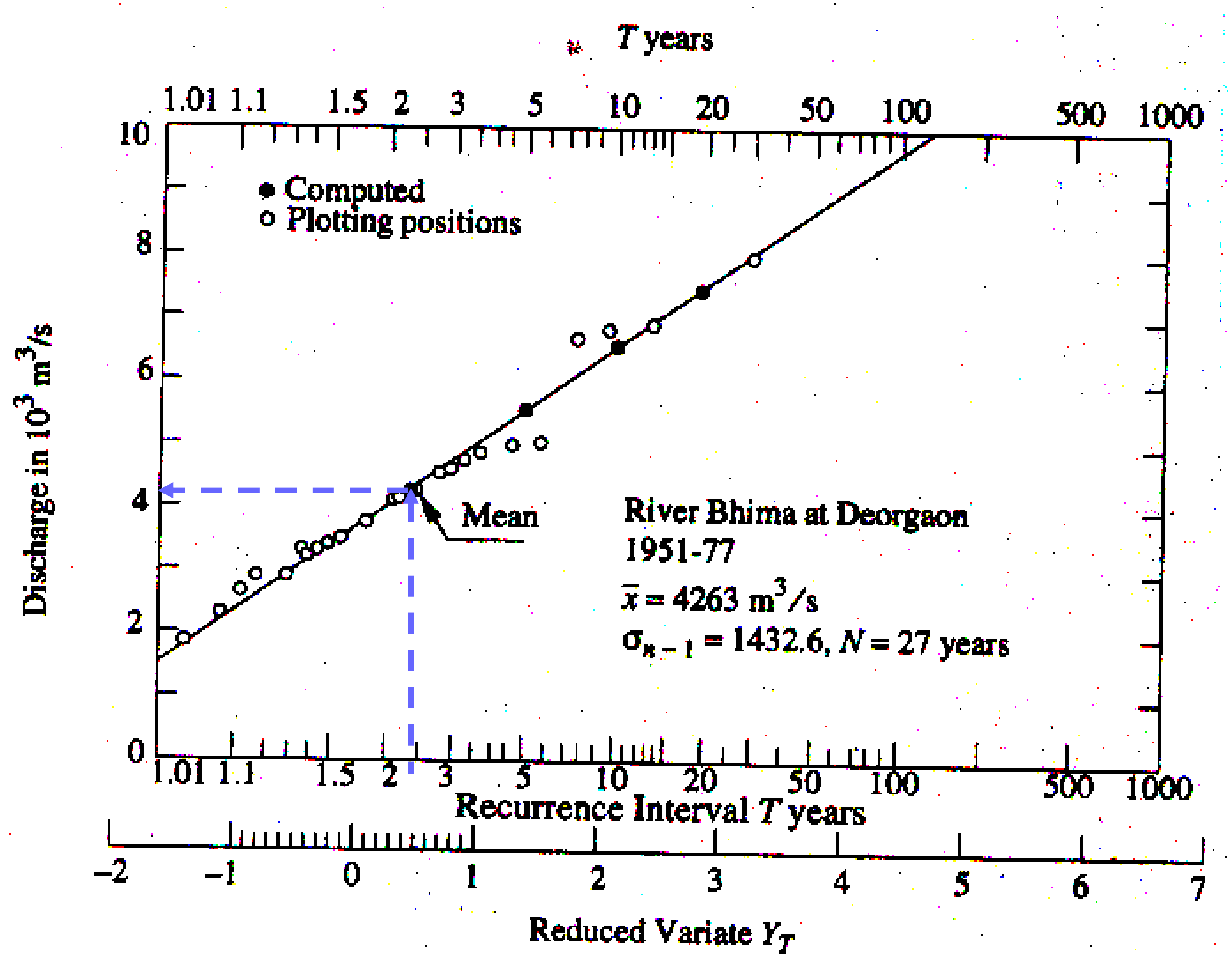


Fig. 7.3 Flood probability analysis by Gumbel's distribution

Confidence Limits

- Since the value of variate for a given return period (x_T) determined by Gumbel's method can have errors due to the limited sample data used, an estimate of confidence limits of the estimate is desireable.

- It indicates the limits about a calculated value between which the true value can be said to lie with a specific probability based on sampling errors only.

- For a confidence probability C, the confidence interval of the variate x_T is bounded by values x_1 & x_2 given by

$$x_{1,2} = x_T \pm f(c)\ S_e$$

Where $f(c)$ = function of the confidence probability c determined by using the Table of normal variates as:

c(%)	**50**	**68**	**80**	**90**	**95**	**99**
***f*(c)**	0.674	1.00	1.282	1.645	1.96	2.58

Where S_e = probable error $= \dfrac{b\sigma_{n-1}}{\sqrt{N}}$

$$b = \sqrt{1 + 1.3\ K + 1.1\ K^2}$$

$$K = \left[\frac{y_T - \bar{y}_n}{S_n}\right]$$

N = Sample size

Confidence Limits

MAIN POINTS

- 95% & 80% confidence limits for various values of *T* are computed and shown in the Figure.
- With increase in confidence probability (%), the confidence interval increases.
- With increase in Return Period *T*, the Confidence band spreads.

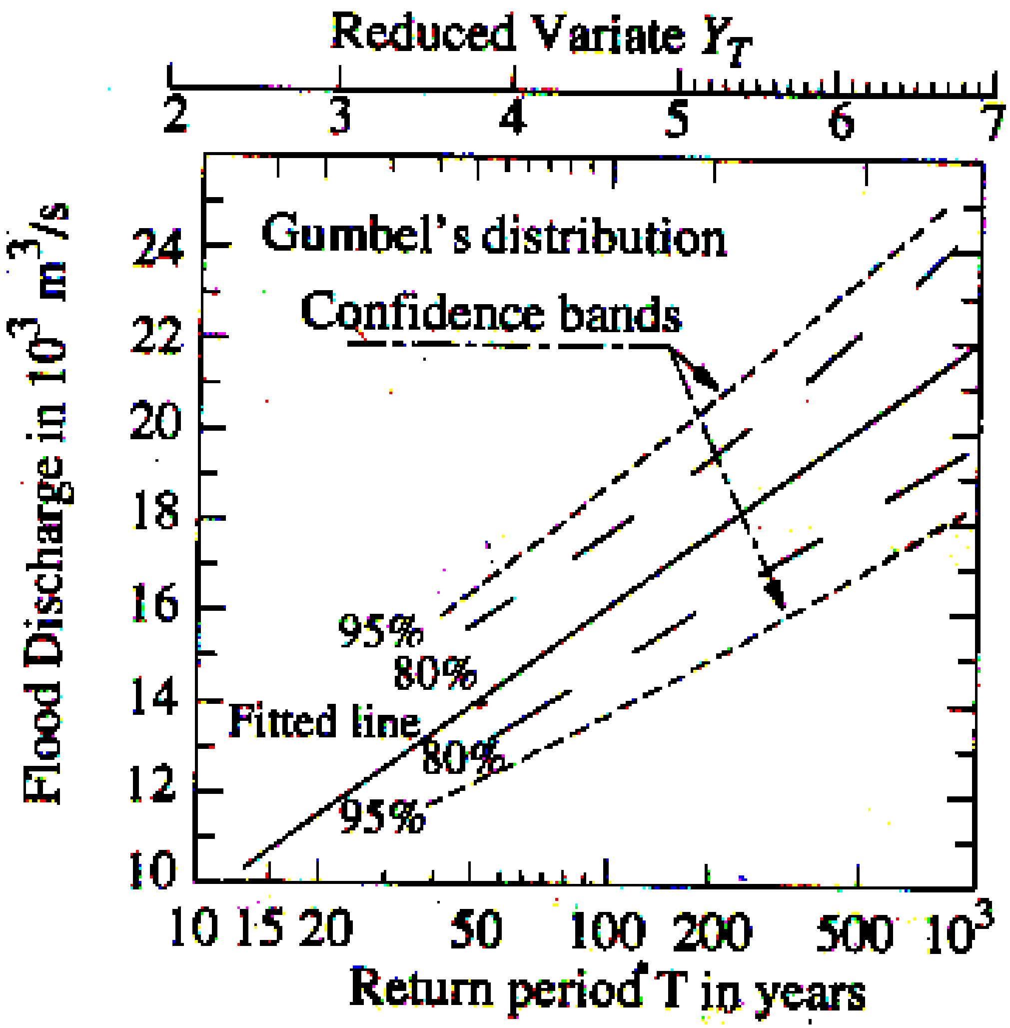


Table 7.3 & 7.4

Table 7.3: REDUCED MEAN $\bar{y}_n$ IN GUMBEL'S EXTREME VALUE DISTRIBUTION

N	0	1	2	3	4	5	6	7	8	9
10	0.4952	0.4996	0.5035	0.5070	0.5100	0.5128	0.5157	0.5181	0.5202	0.5220
20	0.5236	0.5252	0.5268	0.5283	0.5296	0.5309	0.5320	0.5332	0.5343	0.5353
30	0.5362	0.5371	0.5380	0.5388	0.5396	0.5402	0.5410	0.5418	0.5424	0.5430
40	0.5436	0.5442	0.5448	0.5453	0.5458	0.5463	0.5468	0.5473	0.5477	0.5481
50	0.5485	0.5489	0.5493	0.5497	0.5501	0.5504	0.5508	0.5511	0.5515	0.5518
60	0.5521	0.5524	0.5527	0.5530	0.5533	0.5535	0.5538	0.5540	0.5543	0.5545
70	0.5548	0.5550	0.5552	0.5555	0.5557	0.5559	0.5561	0.5563	0.5565	0.5567
80	0.5569	0.5570	0.5572	0.5574	0.5576	0.5578	0.5580	0.5581	0.5583	0.5585
90	0.5586	0.5587	0.5589	0.5591	0.5592	0.5593	0.5595	0.5596	0.5598	0.5599
100	0.5600									

TABLE 7.4 REDUCED STANDARD DEVIATION S_n IN GUMBEL'S EXTREME VALUE DISTRIBUTION

N = sample size

N	0	1	2	3	4	5	6	7	8	9
10	0.9496	0.9676	0.9833	0.9971	1.0095	1.0206	1.0316	1.0411	1.0493	1.0565
20	1.0628	1.0696	1.0754	1.0811	1.0864	1.0915	1.0961	1.1004	1.1047	1.1086
30	1.1124	1.1159	1.1193	1.1226	1.1255	1.1285	1.1313	1.1339	1.1363	1.1388
40	1.1413	1.1436	1.1458	1.1480	1.1499	1.1519	1.1538	1.1557	1.1574	1.1590
50	1.1607	1.1623	1.1638	1.1658	1.1667	1.1681	1.1696	1.1708	1.1721	1.1734
60	1.1747	1.1759	1.1770	1.1782	1.1793	1.1803	1.1814	1.1824	1.1834	1.1844
70	1.1854	1.1863	1.1873	1.1881	1.1890	1.1898	1.1906	1.1915	1.1923	1.1930
80	1.1938	1.1945	1.1953	1.1959	1.1967	1.1973	1.1980	1.1987	1.1994	1.2001
90	1.2007	1.2013	1.2020	1.2026	1.2032	1.2038	1.2044	1.2049	1.2055	1.2060
100	1.2065									

(2) Log Pearson Type-III Distribution

- Extensively used in United States.

- In this the variate is first transformed into logarithmic form (base 10) and the transformed data is then analyzed.

- If X is the variate of a random hydrologic series, then the series of Z variates where $z = \log x$ are obtained.

For z series, for any recurrence interval T

$$x_T = \bar{x} + K\ \sigma$$ reduces to

$$z_T = \bar{z} + K_z\ \sigma_z$$

K_z = a frequency factor which is function of recurrence interval T and the coefficient of skewness (Table 7.6).

σ_Z = standard deviation of the Z variate sample

$$\sigma_z = \sqrt{\frac{\sum (z - \bar{z})^2}{(N-1)}}$$

C_s = coefficient of skew of variate z

$$C_s = \frac{N \sum (z - \bar{z})^3}{(N-1)(N-2)(\sigma_z)^3}$$

$\bar{z}$ = mean of the z values

N = Sample size = number of years of record.

The variate $K_z = f(C_s,\ T)$ is given in Table 7.6.

$$z_T = \bar{z} + K_z\ \sigma_z$$

$$x_T = anti\log(z_T)$$

TABLE 7.6 $K_z = F(C_s, T)$ FOR USE IN LOG–PEARSON TYPE III DISTRIBUTI

Coefficient of skew, C_s	Recurrence interval T in years						
	2	10	25	50	100	200	1000
3.0	–0.396	1.180	2.278	3.152	4.051	4.970	7.250
2.5	–0.360	1.250	2.262	3.048	3.845	4.652	6.600
2.2	–0.330	1.284	2.240	2.970	3.705	4.444	6.200
2.0	–0.307	1.302	2.219	2.912	3.605	4.298	5.910
1.8	–0.282	1.318	2.193	2.848	3.499	4.147	5.660
1.6	–0.254	1.329	2.163	2.780	3.388	3.990	5.390
1.4	–0.225	1.337	2.128	2.706	3.271	3.828	5.110
1.2	–0.195	1.340	2.087	2.626	3.149	3.661	4.820
1.0	–0.164	1.340	2.043	2.542	3.022	3.489	4.540
0.9	–0.148	1.339	2.018	2.498	2.957	3.401	4.395
0.8	–0.132	1.336	1.998	2.453	2.891	3.312	4.250
0.7	–0.116	1.333	1.967	2.407	2.824	3.223	4.105
0.6	–0.099	1.328	1.939	2.359	2.755	3.132	3.960
0.5	–0.083	1.323	1.910	2.311	2.686	3.041	3.815
0.4	–0.066	1.317	1.880	2.261	2.615	2.949	3.670
0.3	–0.050	1.309	1.849	2.211	2.544	2.856	3.525
0.2	–0.033	1.301	1.818	2.159	2.472	2.763	3.380
0.1	–0.017	1.292	1.785	2.107	2.400	2.670	3.235
0.0	**0.000**	**1.282**	**1.751**	**2.054**	**2.326**	**2.576**	**3.090**
–0.1	0.017	1.270	1.716	2.000	2.252	2.482	2.950
–0.2	0.033	1.258	1.680	1.945	2.178	2.388	2.810
–0.3	0.050	1.245	1.643	1.890	2.104	2.294	2.675
–0.4	0.066	1.231	1.606	1.834	2.029	2.201	2.540
–0.5	0.083	1.216	1.567	1.777	1.955	2.108	2.400
–0.6	0.099	1.200	1.528	1.720	1.880	2.016	2.275
–0.7	0.116	1.183	1.488	1.663	1.806	1.926	2.150
–0.8	0.132	1.166	1.448	1.606	1.733	1.837	2.035
–0.9	0.148	1.147	1.407	1.549	1.660	1.749	1.910
–1.0	0.164	1.128	1.366	1.492	1.588	1.664	1.880
–1.4	0.225	1.041	1.198	1.270	1.318	1.351	1.465
–1.8	0.282	0.945	1.035	1.069	1.087	1.097	1.130
–2.2	0.330	0.844	0.888	0.900	0.905	0.907	0.910
–3.0	0.396	0.660	0.666	0.666	0.667	0.667	0.668

[Note : C_s = 0 corresponds to log–normal distribution]

TABLE 7.7 VARIATE Z—*EXAMPLE 7.6*

Year	Flood x (m^3/s)	$z = \log x$	Year	Flood x (m^3/s)	$z = \log x$
1951	2947	3.4694	1965	4366	3.6401
1952	3521	3.5467	1966	3380	3.5289
1953	2399	3.3800	1967	7826	3.8935
1954	4124	3.6153	1968	3320	3.5211
1955	3496	3.5436	1969	6599	3.8195
1956	2947	3.4694	1970	3700	3.5682
1957	5060	3.7042	1971	4175	3.6207
1958	4903	3.6905	1972	2988	3.4754
1959	3751	3.5748	1973	2709	3.4328
1960	4798	3.6811	1974	3873	3.5880
1961	4290	3.6325	1975	4593	3.6621
1962	4652	3.6676	1976	6761	3.8300
1963	5050	3.7033	1977	1971	3.2947
1964	6900	3.8388			

(3) Log-normal Distribution

- Special case of Log Pearson Type-III distribution with coefficient of skew Cs = 0.

- For Cs = 0, Frequency factor K_z = f(T) only.

- The log-normal distribution plots as a straight line on logarithmic probability paper.

- If the coefficient of skew is –ve, the log-normal distribution method gives consistently higher values than those obtained by the Log Pearson Type-III method.

Partial Duration Series

- In some catchments, there are more than one independent floods of high magnitude in an year.
- In partial duration series, all flood magnitudes larger than an arbitrary base value are included in the analysis.
- In several cases, one year may carry many floods or no flood.
- Partial duration series is mainly adopted for rainfall analysis.
- Its use in flood study are rather rare.
- The recurrence interval of an event obtained by annual series (T_A) and by the partial duration series (T_P) are related by:

$$T_P = \frac{1}{\ln(T_A) - \ln(T_A - 1)}$$

- The difference between T_A and T_P is significant for $T_A < 10$ years
- For $T_A > 20$ years, the difference is negligibly small.

Limitations of Frequency Studies

- The results of the Frequency Analysis depends on the length of the data record.

- The minimum number of years of record required to obtain the satisfactory estimates depends on:

  The variability of the data, which depends upon:
  (a) Climatalogical characteristics of the basin
  (b) Physical characteristics of the basin

- Generally, a minimum of 30 years of data is considered as essential.

- Smaller lengths of records may be used when unavoidable.

- Frequency analysis should not be adopted if the length of the data record is less than 10 years.

- Long lengths of the data records give more reliable results.

Design Flood

Flood magnitude adopted for the design of a hydraulic structure

Probable Maximum Flood (PMF)

The extreme flood that is physically possible in a region as a result of severe most combinations, including rare combinations of metereological and hydrological factors.

PMF is used in situations where the failure of the structure would result in loss of life and catastrophic damage and as such complete security from potential floods is sought.

PMF Estimation Steps

1. Delineation of watershed boundary for the dam site.
2. Divide watershed in segments based on similar Metreological characteristics
3. Generate Rain gauge point coverage
4. Select Probable Maximum Storm (PMS) based on past data
5. Compute Time of concentrations for the each segment of WS.
6. Compute Average precipitation over the segments and WS for PMS.
7. Compute 'Maximization Factor'.
8. Compute PMP.
9. Derive UHG for the outlets of the Segments for duration Tc.
10. Calibrate UHGs, if Senthetic.
11. Generate flood hydrographs for each segment's outlets.
12. Route all flood hydrographs to the dam site by any method (Muskigham)
13. Sum all ordinates of flood hydrographs.
14. It is the PMF hydrograph.
15. Determine the peak, it is PMF at dam site.

Risk, Reliability and Safety Factor

The design flood discharges have uncertainties, so there is a risk of failure.

Risk and Reliability:

The probability of occurrence of an event ($x \geq x_T$) at least once over a period of n successive years is called the Risk, $\bar{R}$

Thus the Risk is given by

$$\bar{R} = 1 - \left(probability\ of\ \ non\ occurence\ of\ \ the\ event\ \ x \geq x_T\ \ in\ \ n\ \ years \right)$$

$$\bar{R} = 1 - (1 - P)^n \quad = 1 - \left(1 - \frac{1}{T}\right)^n$$

Where

P = probability $\quad P(x \geq x_T) = \frac{1}{T}$

n = expected life

T = Return Period

The Reliability (Re) is defined as

$$R_e = 1 - \bar{R} = 1 - \left[1 - \left(1 - \frac{1}{T}\right)^n\right] = \left(1 - \frac{1}{T}\right)^n$$

It shows the probability of non occurrence of the event $x \geq x_T$ once over a period of n years.

The Return Period T may depends upon:

(1) Expected Life of the structure

(2) The acceptable degree of the risk

Safety Factor:

Uncertainties may arise out of:

(1) Technical reasons

structural, constructional, operational and environmental reasons.

(2) Non technical causes

economic, sociological and political

Safety Factor for a given hydrological parameter (M) is defined as:

$$(SF)_m = \frac{C_{am}}{C_{hm}} \geq 1$$

C_{am} = Actual value of the parameter M adopted in the design of the project.

C_{hm} = Value of the parameter M obtained from hydrological considerations only.

The parameter M includes such items as flood discharge magnitude, maximum river stage, maximum rainfall etc.

Safety Margin:

The difference between C_{am} and C_{hm} is known as Safety Margin.

$$(SM)_m = \left[C_{am} - C_{hm}\right]$$