Floods

To estimate the magnitude of a flood peak the following alternative are available

1. Rational Method
2. Empirical Method
3. Unit-Hydrograph technique, and
4. Flood-Frequency Studies

1. Rational Method

$$Q_p = C A i \ ; \text{ for } t \geq t_c$$

where C = coefficient of runoff = (runoff/ rainfall), A = area of the catchment and i = intensity of rainfall. This is the basic equation of the *rational method*.

Rainfall Intensity ($i_{tc,p}$)

$$i_{tc,p} = \frac{K\,T^x}{(t_c + a)^m}$$

In which K, a, x and m are constant

Time of Concentration (tc)

Runoff Coefficient (C)

The coefficient C represents the integrated effect of the catchment looses and hence depends upon the nature of the surface. Some typical values of C are indicated in Table 7.1

TABLE 7.1 VALUE OF THE COEFFICIENT *C* IN EQ. (7.2)

Type of area	Value of *C*
A. *Urban area* (P = 0.05 to 0.10)	
Lawns: Sandy-soil, flat, 2%	0.05–0.10
Sandy soil, steep, 7%	0.15–0.20
Heavy soil, average, 2.7%	0.18–0.22
Residential areas:	
Single family areas	0.30–0.50
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

2. Empirical Method

Dickens Formula (1865)

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

where Q_p = maximum flood discharge (m^3/s)

A = catchment area (km^2)

C_D = Dickens constant with value between 6 to 30

The following are some guidelines in selecting the value of C_D :

	Value of C_D
North–Indian plains	6
North–Indian hilly regions	11–14
Central India	14–28
Coastal Andhra and Orissa	22–28

3. Unit- Hydrograph Technique

4. Flood Frequency Studies

$$P = \frac{m}{N+1}$$

where m = order number of the event and N = total number of events in the data. The recurrence interval, T (also called the *return period* or *frequency*) is calculated as

$$T = 1/P$$

Chow (1951) has shown that most frequency–distribution functions applicable in hydrologic studies can be expressed by the following equation known as the *general equation of hydrologic frequency analysis:*

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

where x_T = value of the variate X of a random hydrologic series with a return period T, $\bar{x}$ = mean of the variate, σ = standard deviation of the variate, K = frequency factor which depends upon the return period, T and the assumed frequency distribution. Some of the commonly used frequency distribution functions for the predication of extreme flood values are :

1. Gumbel's extreme–value distribution,
2. log–Pearson Type III distribution, and
3. log normal distribution.

Gumbel's Method

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

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

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

K = frequency factor expressed as

$$K = \frac{y_T - \bar{y}_n}{S_n}$$

in which y_T = reduced variate, a function of T and is given by

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

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

N = sample size

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									

Gumbel Probability Paper

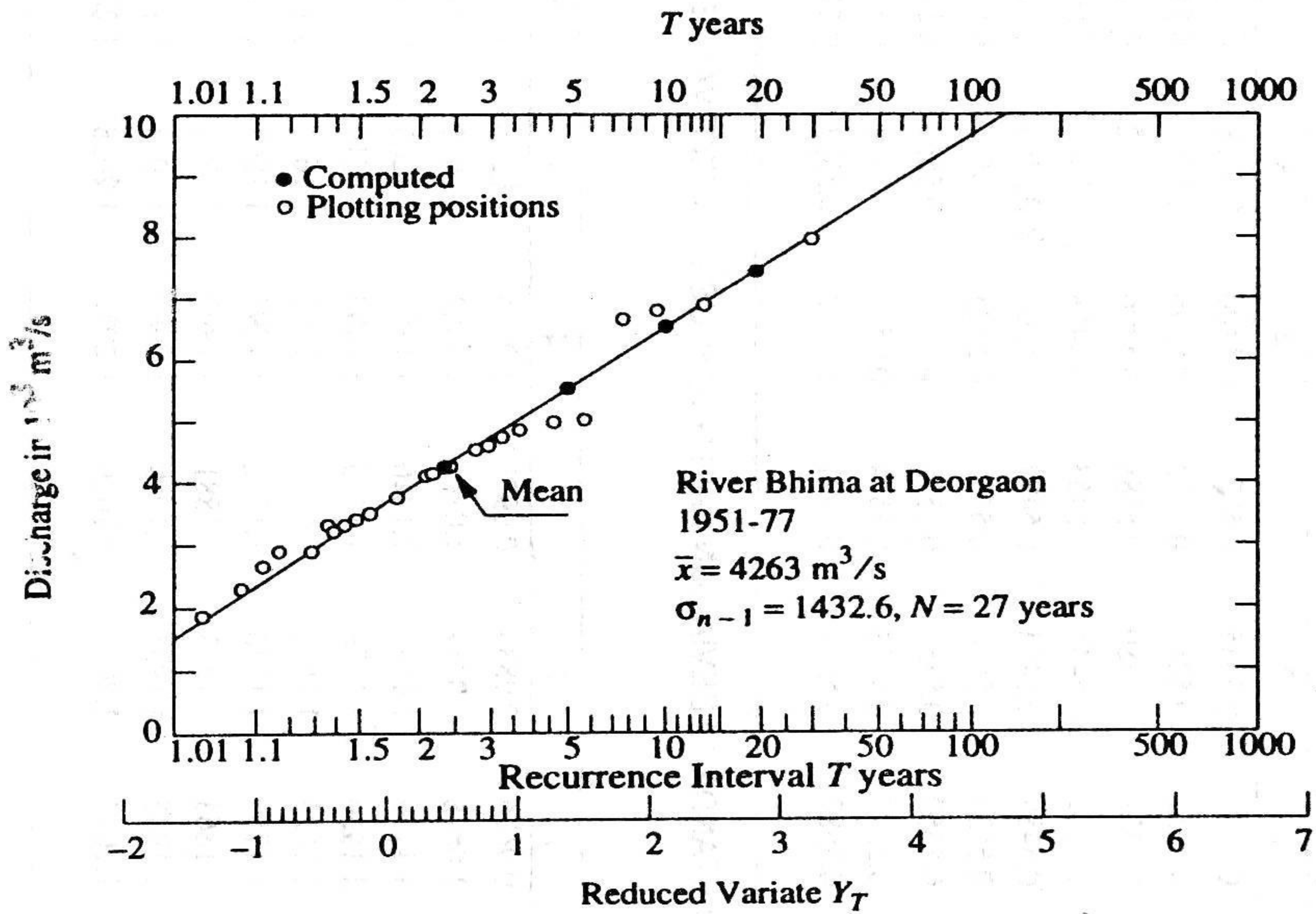

Fig. 7.3 Flood probability analysis by Gumbel's distribution

EXAMPLE 7.3. *Annual maximum recorded floods in the river Bhima at Deorgaon, a tributary of the river Krishna, for the period 1951 to 1977 is given below. Verify whether the Gumbel extreme-value distribution fit the recorded values. Estimate the flood discharge with recurrence interval of (i) 100 years and (ii) 150 years by graphical extrapolation.*

Year	1951	1952	1953	1954	1955	1956	1957	1958	1959
Max. flood (m^3/s)	2947	3521	2399	4124	3496	2947	5060	4903	3757
Year	1960	1961	1962	1963	1964	1965	1966	1967	1968
Max. flood (m^3/s)	4798	4290	4652	5050	6900	4366	3380	7826	3320
Year	1969	1970	1971	1972	1973	1974	1975	1976	1977
Max. flood (m^3/s)	6599	3700	4175	2988	2709	3873	4593	6761	1971

SOLUTION: The flood discharge values are arranged in descending order and the plotting position recurrence interval T_p for each discharge is obtained as

$$T_p = \frac{N+1}{m} = \frac{28}{m}$$

where m = order number. The discharge magnitude Q are plotted against the corresponding T_p on a Gumbel extreme probability paper (Fig. 7.3).

The statistics $\bar{x}$ and σ_{n-1} for the series are next calculated and are shown in Table 7.5. Using these the discharge x_T for some chosen recurrence interval is calculated by using Gumbel's formulae [Eqs. (7.22), (7.21) and (7.20)].

TABLE 7.5 CALCULATION OF T_p FOR OBSERVED DATA —*EXAMPLE 7.3*

Order number m	Flood discharge x (m^3/s)	T_p (years)	Order number m	Flood discharge x (m^3/s)	T_p (years)
1	7826	28.00	15	3873	1.87
2	6900	14.00	16	3757	1.75
3	6761	9.33	17	3700	1.65
4	6599	7.00	18	3521	1.56
5	5060	5.60	19	3496	1.47
6	5050	4.67	20	3380	1.40
7	4903	4.00	21	3320	1.33
8	4798	3.50	22	2988	1.27
9	4652	3.11	23	2947	—
10	4593	2.80	24	2947	1.17
11	4366	2.55	25	2709	1.12
12	4290	2.33	26	2399	1.08
13	4175	2.15	27	1971	1.04
14	4124	2.00			

$N = 27$ years, $\bar{x} = 4263\ m^3/s$, $\sigma_{n-1} = 1432.6\ m^3/s$

From Tables 7.3 and 7.4, for $N = 27$, $y_n = 0.5332$ and $S_n = 1.1004$.
Choosing $T = 10$ years, by Eq. (7.22),

$$y_T = -[\ln . \ln (10/9)] = 2.25037$$

$$K = \frac{2.25307 - 0.5332}{1.1004} = 1.56$$

$$\bar{x}_T = 4263 + (1.56 \times 1432.6)$$

$$= 6499 \text{ m}^3/\text{s}$$

Similarly, values of x_T are calculated for two more T values as shown below.

T (years)	x_T [obtaained by Eq. (7.20)] (m^3/s)
5.0	5522
10.0	6499
20.0	7436

By extrapolation of the theoretical x_T *vs* T relationship, from Fig. 7.3,

At $T = 100$ years, $x_T = 9600$ m^3/s

At $T = 150$ years, $x_T = 10{,}700$ m^3/s

[By using Eq. (7.20) to (7.22), $x_{100} = 9558$ m^3/s and $x_{150} = 10088$ m^3/s.]

EXAMPLE 7.4. *Flood-frequency computations for the river Chambal at Gandhisagar dam, by using Gumbel's method, yielded the following results:*

Return period T (years)	Peak flood (m^3/s)
50	40,809
100	46,300

Estimate the flood magnitude in this river with a return period of 500 years.

SOLUTION : By Eq. (7.20),

$$x_{100} = \bar{x} + K_{100}\,\sigma_{n-1}$$

$$x_{50} = \bar{x} + K_{50}\,\sigma_{n-1}$$

$$(K_{100} - K_{50})\,\sigma_{n-1} = x_{100} - x_{50} = 46300 - 40809 = 5491$$

But $$K_T = \frac{y_T}{S_n} - \frac{\bar{y}_n}{S_n}$$

where S_n and $\bar{y}_n$ are constants for the given data series.

$$\therefore \qquad (y_{100} - y_{50})\frac{\sigma_{n-1}}{S_n} = 5491$$

By Eq. (7.22)

$$y_{100} = -[\ln . \ln (100/99)] = 4.60015$$

$$y_{50} = -[\ln . \ln (50/49)] = 3.90194$$

$$\frac{\sigma_{n-1}}{S_n} = \frac{5491}{(4.60015 - 3.90194)} = 7864$$

For T = 500 years, by Eq. (7.22),

$$y_{500} = -[\ln . \ln (500/499)] = 6.21361$$

$$(y_{500} - y_{100})\frac{\sigma_{n-1}}{S_n} = x_{500} - x_{100}$$

$$(6.21361 - 4.60015) \times 7864 = x_{500} - 46300$$

$$x_{500} = 58988, \quad \text{say } 59{,}000 \text{ m}^3/\text{s}$$

Confidence Limits

For a confidence probability c, the confidence interval of the variate XT is bounded by values X1 and X2 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 in per cent	50	68	80	90	95	99
$f(c)$	0.674	1.00	1.282	1.645	1.96	2.58

$$S_e = \text{probable error} = b\,\frac{\sigma_{n-1}}{\sqrt{N}}$$

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

K = frequency factor give by Eq. (7.21)

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

N = sample size.

EXAMPLE 7.5 *Data covering a period of 92 years for the river Ganga at Raiwala yielded the mean and standard derivation of the annual flood series as 6437 and 2951* m^3/s *respectively. Using Gumbel's method estimate the flood discharge with a return period of 500 years. What are the (a) 95% and (b) 80% confidence limits for this estimate.*

SOLUTION: From Table 7.3 for N = 92 years, $\bar{y}_n = 0.5589$ and $S_n = 1.2020$ from Table 7.4.

$$y_{500} = -[\ln . \ln (500/499)]$$

$$= 6.21361$$

$$K_{500} = \frac{6.21361 - 0.5589}{1.2020} = 4.7044$$

$$x_{500} = 6437 + 4.7044 \times 2951 = 20320 \text{ m}^3/\text{s}$$

From Eq. (7.33 a)

$$b = \sqrt{1 + 1.3\,(4.7044) + 1.1\,(4.7044)^2}$$

$$= 5.61$$

$$S_e = \text{probable error} = 5.61 \times \frac{2951}{\sqrt{92}} = 1726$$

(a) For 95% confidence probability $f(c)$ = 1.96 and by Eq. (7.23)

$$x_{1/2} = 20320 \pm (1.96 \times 1726)$$

$$x_1 = 23703 \text{ m}^3/\text{s} \quad \text{and} \quad x_2 = 16937 \text{ m}^3/\text{s}$$

Thus estimated discharge of 20320 m^3/s has a 95% probability of lying between 23700 and 16940 m^3/s

(b) For 80% confidence probability, $f(c) = 1.282$ and by Eq. (7.23)

$$x_{1/2} = 20320 \pm (1.282 \times 1726)$$

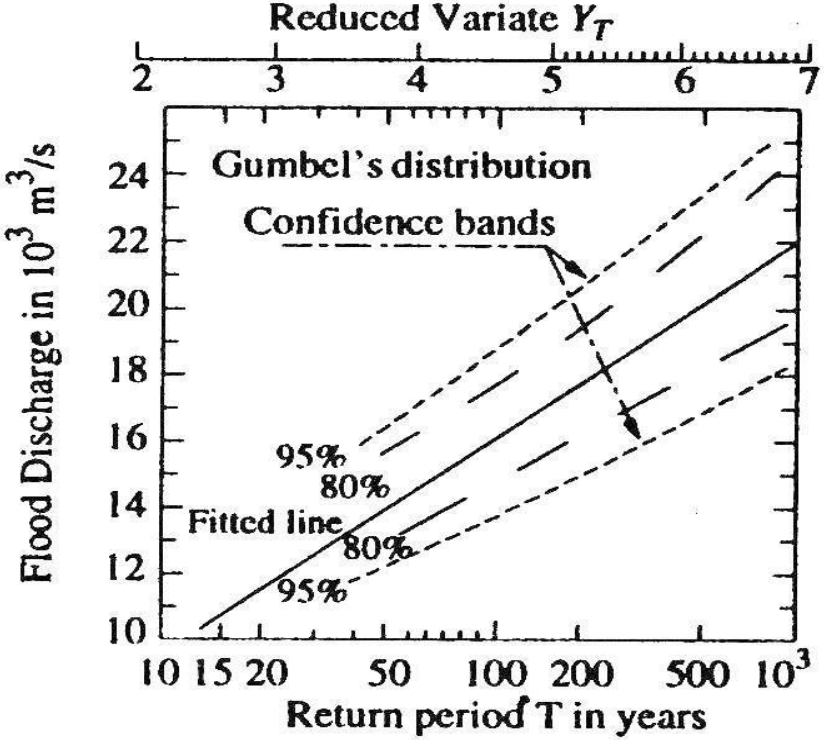

Fig. 7.4 Confidence bands for Gumbels distribution–Example 7.5

$$x_1 = 22533 \text{ m}^3/\text{s} \quad \text{and} \quad x_2 = 18107 \text{ m}^3/\text{s}$$

The estimated discharge of 20320 m^3/s has a 80% probability of lying between 22530 and 18110 m^3/s.