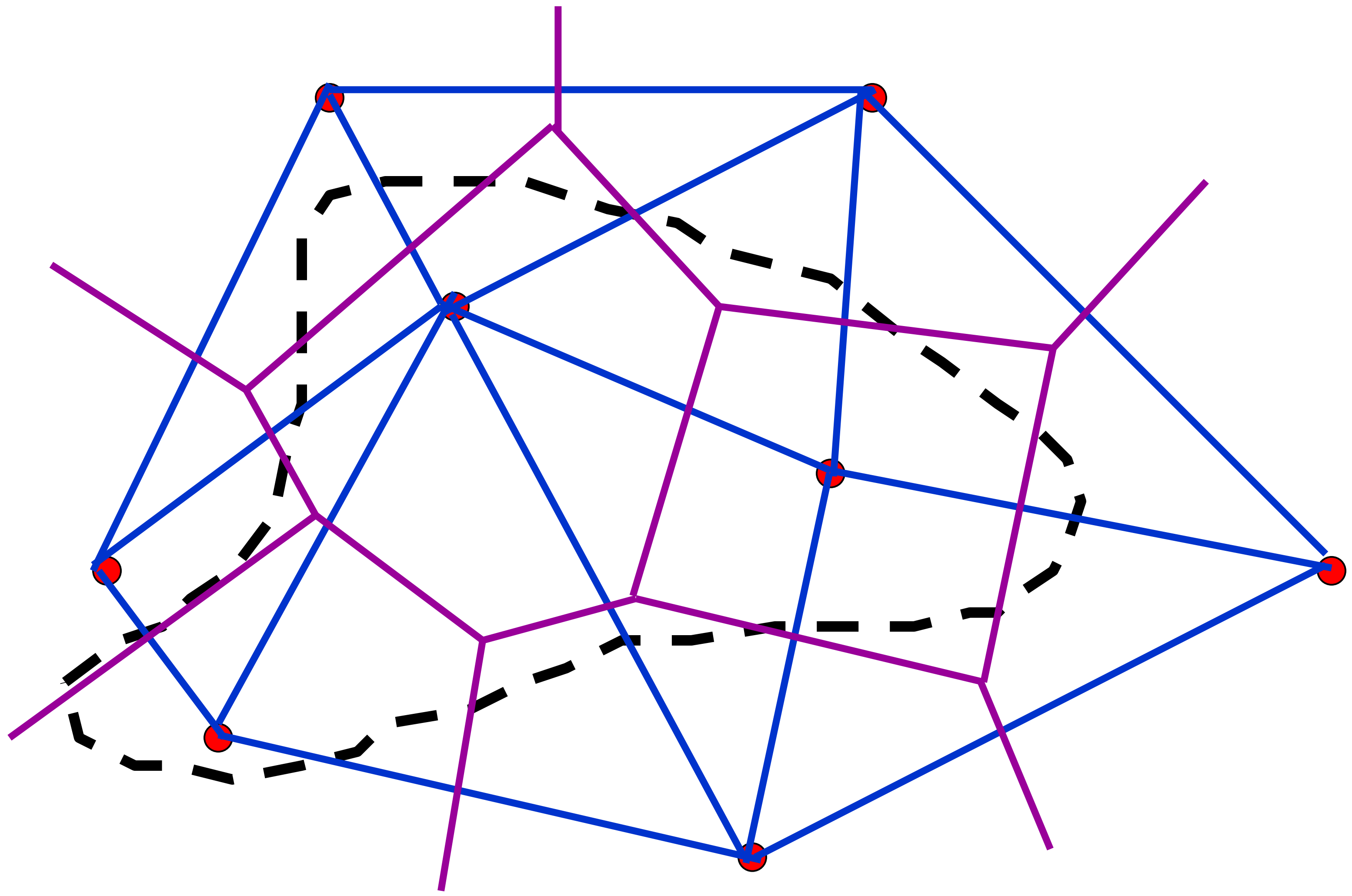
HYN-102

Lecture

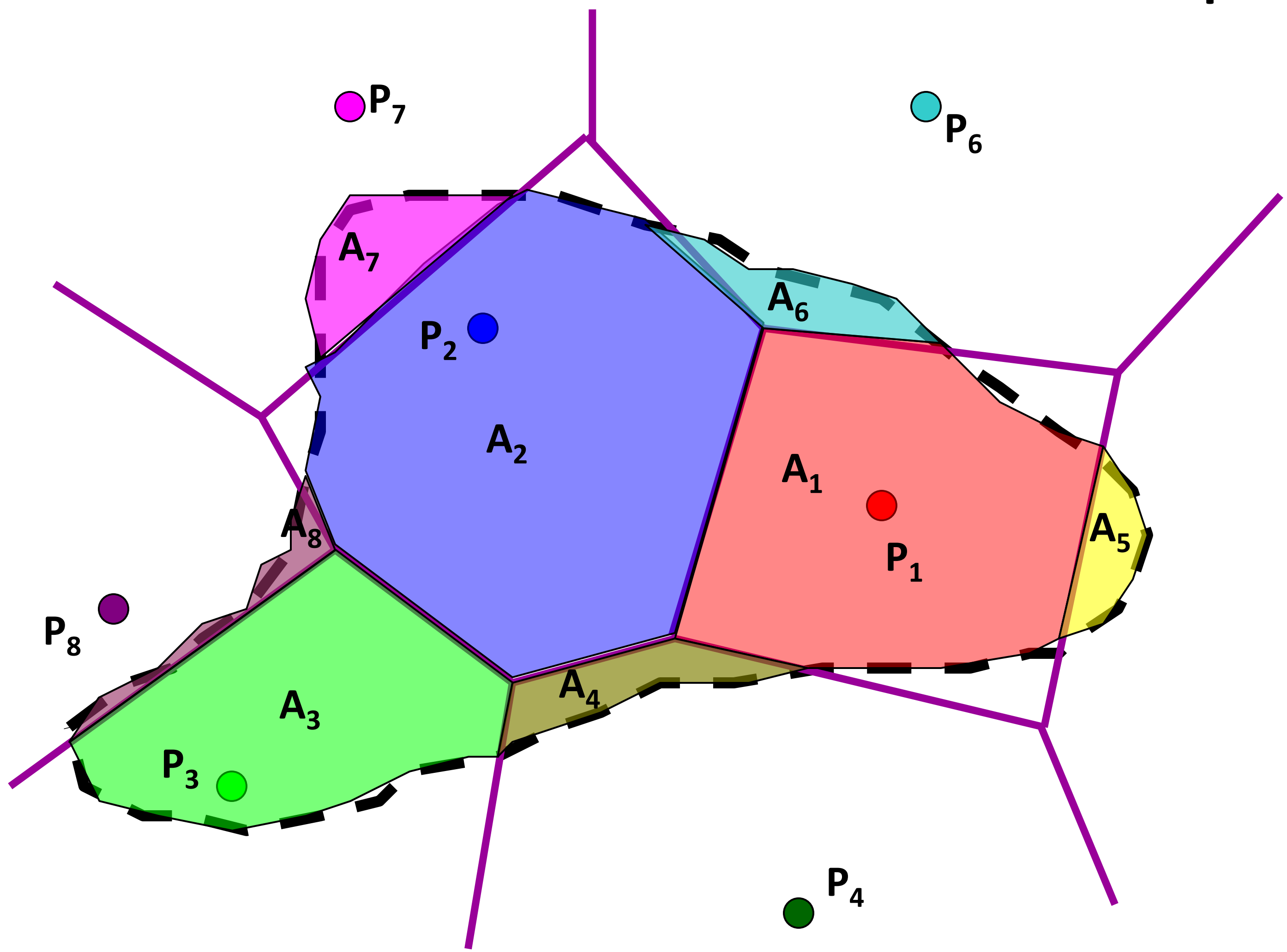
Method of Thiessen polygons

- The method of Thiessen polygons consists of attributing to each station an influence zone in which it is considered that the rainfall is equivalent to that of the station.
- The influence zones are represented by convex polygons.
- These polygons are obtained using the mediators of the segments which link each station to the closest neighbouring stations

Thiessen polygons ....



Thiessen polygons ………



$$\overline{P} = \frac{P_1 A_1 + P_2 A_2 + \ldots\ldots + P_m A_m}{(A_1 + A_2 + \ldots\ldots + A_m)}$$

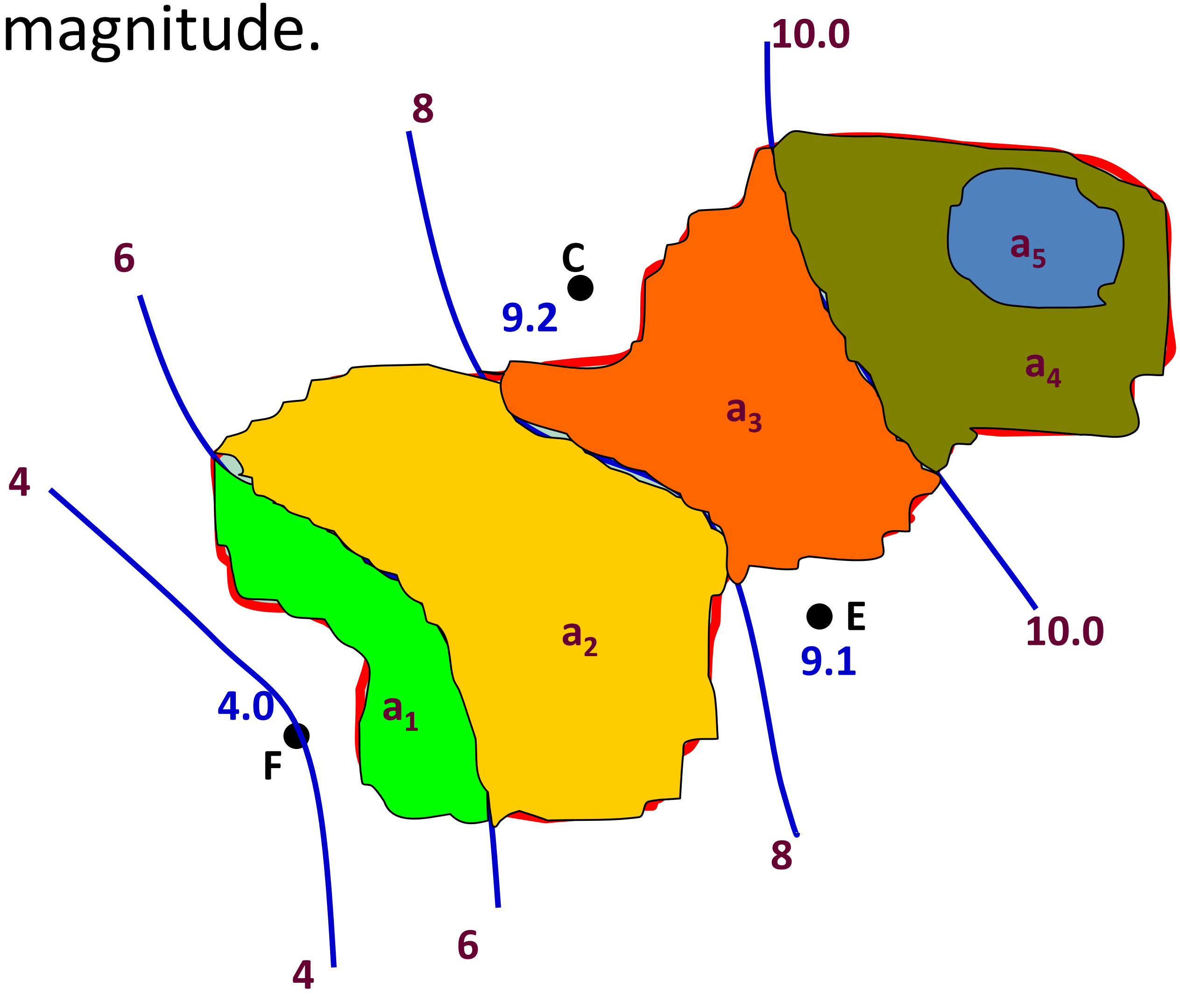
Generally for M station

$$\overline{P} = \frac{\sum_{i=1}^{M} P_i A_i}{A_{total}} = \sum_{i=1}^{M} P_i \frac{A_i}{A}$$

The ratio $\frac{A_i}{A}$ **is called the weightage factor of station i**

Isohyetal Method

- An isohyet is a line joining points of equal rainfall magnitude.



Isohyetal Method

- $P_1, P_2, P_3, \ldots, P_n$ – the values of the isohytes
- $a_1, a_2, a_3, \ldots, a_4$ – are the inter isohytes area respectively
- A – the total catchment area
- $\overline{P}$ - the mean precipitation over the catchment

$$\overline{P} = \frac{a_1\left(\frac{P_1 + P_2}{2}\right) + a_2\left(\frac{P_2 + P_3}{2}\right) + \ldots + a_{n-1}\left(\frac{P_{n-1} + P_n}{2}\right)}{A}$$

NOTE

The isohyet method is superior to the other two methods especially when the stations are large in number.

Example *In a catchment area, approximated by a circle of diameter 100 km, four rainfall stations are situated inside the catchment and one station is outside in its neighbourhood. The coordinates of the centre of the catchment and of the five stations are given below. Also given are the annual precipitation recorded by the five stations in 1980. Determine the average annual precipitation by the Thiessen-mean method.*

Centre: (100, 100) Diameter: 100 km.
Distance are in km

Station	1	2	3	4	5
Coordinates	(30, 80)	(70, 100)	(100, 140)	(130, 100)	(100, 70)
Precipitation (cm)	85.0	135.2	95.3	146.4	102.2

Solution: The catchment area is drawn to scale and the stations are marked on it (Fig. 2.15). The stations are joined to form a set of triangles and the perpendicular bisector of each side is then drawn. The Thiessen-polygon area enclosing each station is then identified. It may be noted that station 1 in this problem does not have any area of influence in the catchment. The areas of various Thiessen polygons are determined either by a planimeter or by placing an overlay grid.

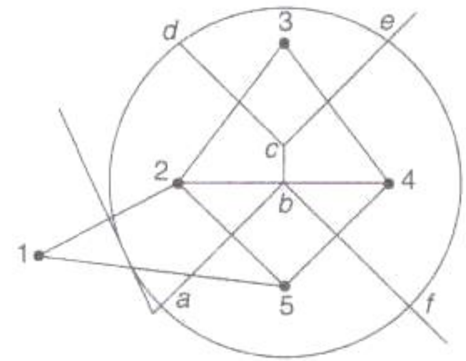


Fig. 2.15 Thiessen Polygons—Example 2.5

Station	Boundary of area	Area (km²)	Fraction of total area	Rainfall	Weighted P (cm) (col. 4 × col. 5)
1	—	—	—	85.0	—
2	abcd	2141	0.2726	135.2	36.86
3	dce	1609	0.2049	95.3	19.53
4	ecbf	2141	0.2726	146.4	39.91
5	fba	1963	0.2499	102.2	25.54
Total		7854	1.000		121. 84

Mean precipitation = 121.84 cm.

EXAMPLE *The isohyets due to a storm in a catchment were drawn (Fig. 2.14) and the area of the catchment bounded by isohyets were tabulated as below.*

Isohyets (cm)	**Area (km^2)**
Station–12.0	30
12.0–10.0	140
10.0–8.0	80
8.0–6.0	180
6.0–4.0	20

Estimate the mean precipitation due to the storm.

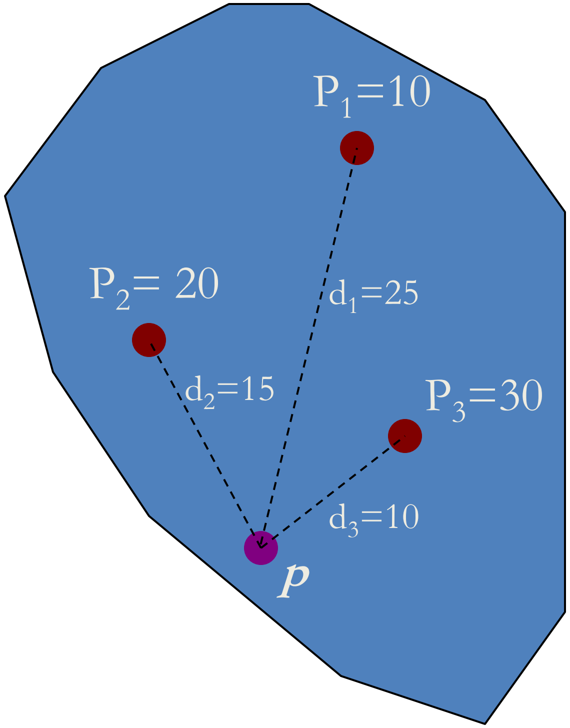
SOLUTION: For the first area consisting of a station surrounded by a closed isohyet, a precipitation value of 12.0 cm is taken. For all other areas, the mean of two bounding isohyets are taken.

Isohytes	**Average value of P (cm)**	**Area (km^2)**	**Fraction of total area (col. 3/450)**	**Weighted *P* (cm) (col. 2 × col. 4)**
1	2	3	4	5
12.0	12.0	30	0.0667	0.800
12.0–10.0	11.0	140	0.3111	3.422
10.0–8.0	9.0	80	0.1778	1.600
8.0–6.0	7.0	180	0.4000	2.800
6.0–4.0	5.0	20	0.0444	0.222
Total		450	1.0000	8.844

Mean precipitation $\overline{P} = 8.84$ cm

Inverse distance weighting

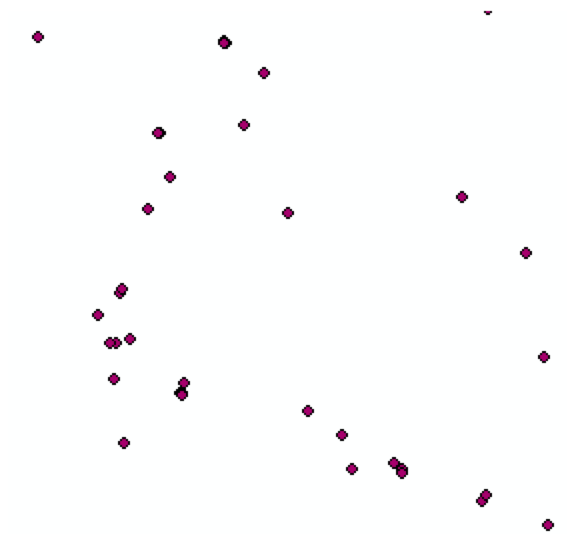
- Prediction at a point is more influenced by nearby measurements than that by distant measurements
- The prediction at an ungaged point is inversely proportional to the distance to the measurement points
- Steps
  - Compute distance (d_i) from ungaged point to all measurement points.
  - Compute the precipitation at the ungaged point using the following formula



$$d_{12} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

$$\hat{P} = \frac{\sum_{i=1}^{N} \left(\frac{P_i}{d_i^{\,2}} \right)}{\sum_{i=1}^{N} \left[\frac{1}{d_i^{\,2}} \right]} \qquad \hat{P} = \frac{\frac{10}{25^2} + \frac{20}{15^2} + \frac{30}{10^2}}{\frac{1}{25^2} + \frac{1}{15^2} + \frac{1}{10^2}} = 25.24 \ mm$$

Rainfall interpolation in GIS

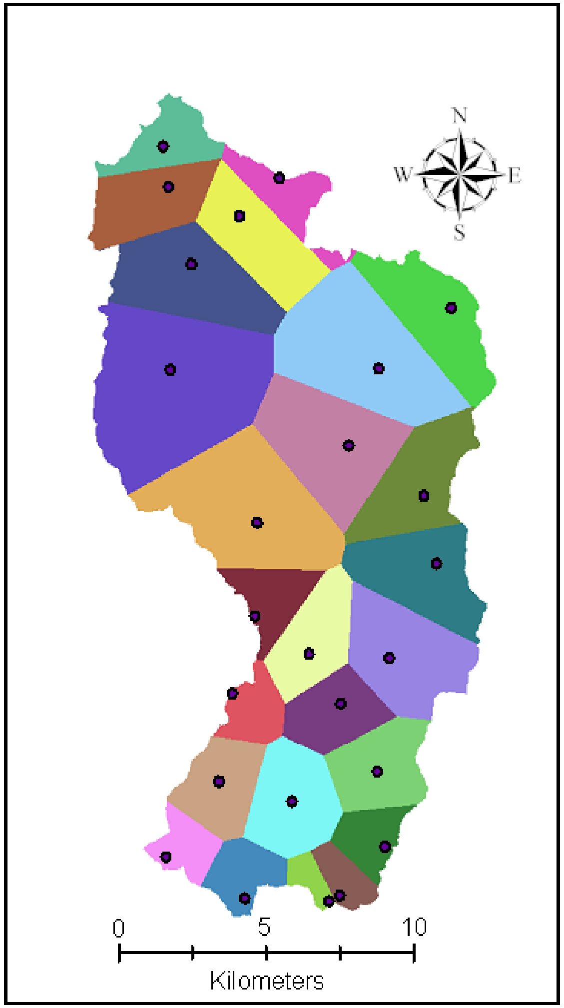


- Data are generally available as points with precipitation stored in attribute table.

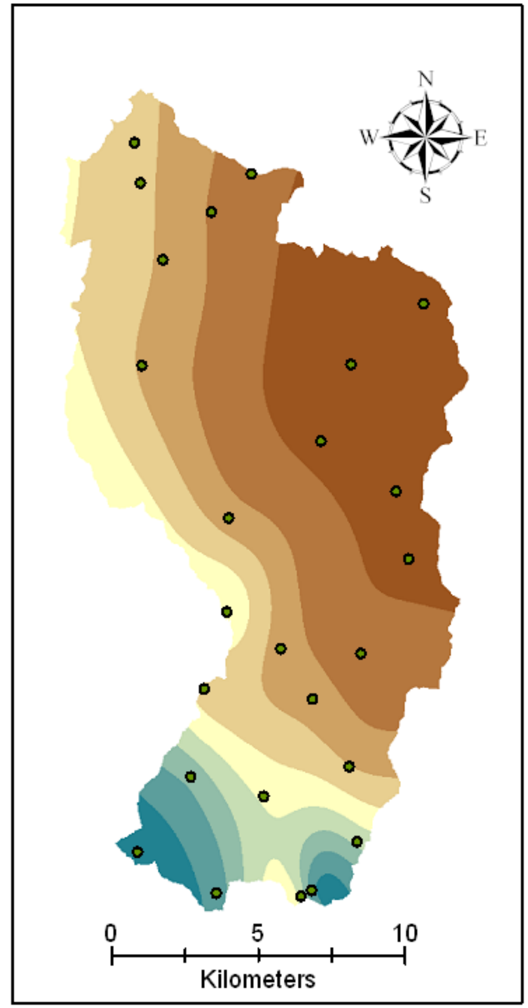
Attributes of reyprecip.txt

staid	long	lat	anntot	jan	feb
p012	-116.827040151	43.296918	558.62	83.58	40.71
p015	-116.778195562	43.287189	359.82	48.27	23.76
p023	-116.824585572	43.284514	546.35	69.92	44.77
p024	-116.79488694	43.275550	407.04	65.24	30.43
p033	-116.815215733	43.260925	504.02	83.5	38.95
p049	-116.706133516	43.247226	223.71	21.64	16.41
p053	-116.824105883	43.228522	507.89	57.88	43.09
p057	-116.736588983	43.228723	236.61	24.15	18.73

Rainfall maps in GIS



Nearest Neighbor “Thiessen” Polygon Interpolation



Spline Interpolation

Interpretation of rainfall data

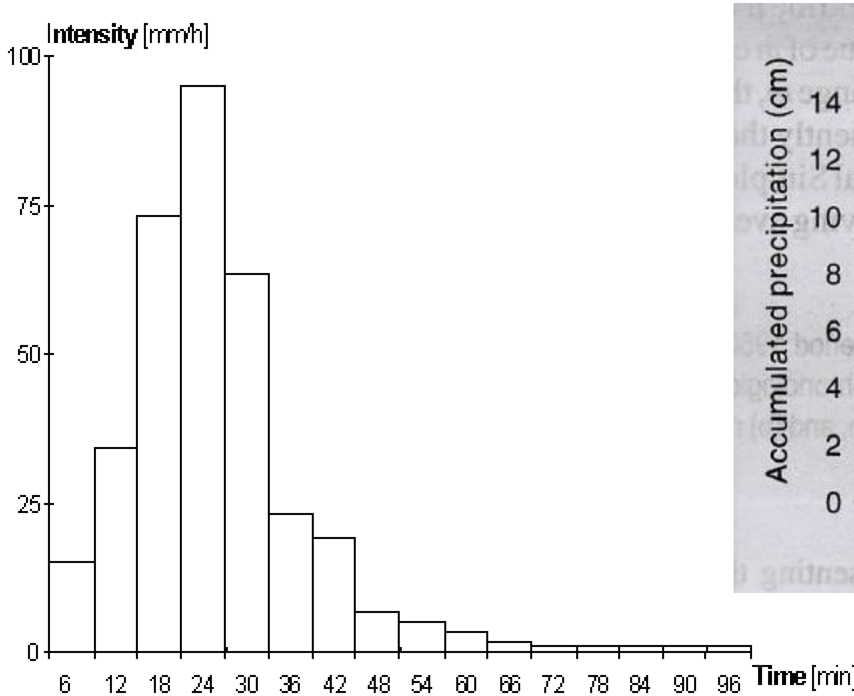
- Rainfall at any place can be adequately described if **the intensity, duration and frequency** of the various storms occurring at that place are known.
- Whenever rainfall occurs, its **magnitude and duration** are known from meteorological readings.
- Thus, at a given station the magnitudes of the rains of various durations, such as 5 minutes, 10 minutes, 15 minutes, etc., are generally known.
- These data can be used to determine **the Intensity-Duration-Frequency relations (IDF).**
- The IDF relation provide information on **Maximum Intensity** for a **particular duration** of **specified frequency** of occurrence.
- The IDF data are used for urban storm drainage design, design of hydraulic structures etc.

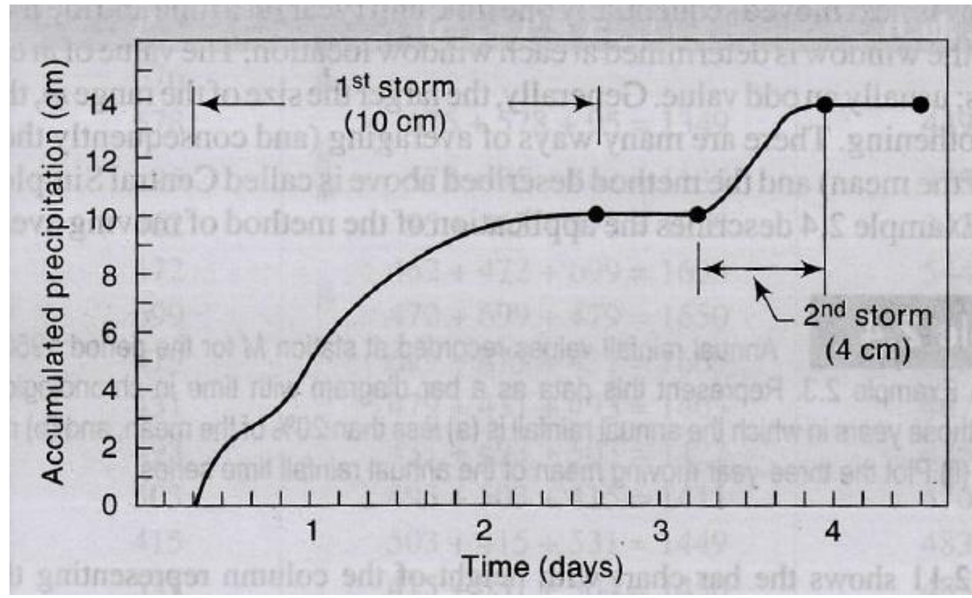
Interpretation of rainfall data

- **Intensity:** This is a measure of the quantity of rain falling in a given time or in other words, the intensity of rain is the rate at which rain is falling. It is expressed in inches/hr, mm/hr or cm/hr.
- **Duration:** The duration is the period of time during which rain falls.
- **Frequency:** This refers to how often a rainfall of a particular magnitude occurs in a given duration.

Maximum Intensity – Duration Relation

- The intensity of rainfall at which the rain falls changes continuously throughout the storm.
- The variation of rainfall depth or intensity with time (duration) can be analysed using
  - a hyetograph and
  - a mass curve.
- The maximum rainfall depth or intensity recorded in a given time interval in a storm is found by computing a series of running totals of rainfall depth for that time interval starting at various points in the storm, then selecting the maximum value of this series.


Intensity [mm/h]
100
75
50
25
0
6 12 18 24 30 36 42 48 54 60 66 72 78 84 90 96
Time [min]


1st storm
(10 cm)
2nd storm
(4 cm)
Accumulated precipitation (cm)
0 2 4 6 8 10 12 14
1 2 3 4
Time (days)

Example 2.11 The mass curve of rainfall in a storm of total duration 270 minutes is given below. (a) Draw the hyetograph of the storm at 30 minutes time step. (b) Plot the maximum intensity-duration curve for this storm. (c) Plot the maximum depth-duration curve for the storm.

Times since Start in Minutes	0	30	60	90	120	150	180	210	240	270
Cumulative Rainfall (mm)	0	6	18	21	36	43	49	52	53	54

Solution

(a) **Hyetograph:** The intensity of rainfall at various time durations is calculated as shown below:

Time since Start (min)	30	60	90	120	150	180	210	240	270
Cumulative Rainfall (mm)	6.0	18.0	21.0	36.0	43.0	49.0	52.0	53.0	54.0
Incremental depth of rainfall in the interval (mm)	6.0	12.0	3.0	15.0	7.0	6.0	3.0	1.0	1.0
Intensity (mm/h)	12.0	24.0	6.0	30.0	14.0	12.0	6.0	2.0	2.0

The hyetograph of the storm is shown in Fig. 2.25

(b) Various durations $\Delta t = 30, 60, 90 \ldots 240, 270$ minutes are chosen. For each duration Δt a series of running totals of rainfall depth is obtained by starting from various points of the mass curve. This can be done systematically as shown in Table 2.11(a and b). By inspection the maximum depth for each t_j is identified and corresponding maximum intensity is calculated. In Table 2.11(a) the maximum depth is marked by bold letters and maximum intensity corresponding to a specified duration is shown in Row No. 3 of Table 2.11(b). The data obtained from the above analysis is plotted as maximum depth *vs* duration and maximum intensity *vs* duration as shown in Fig. 2.26.

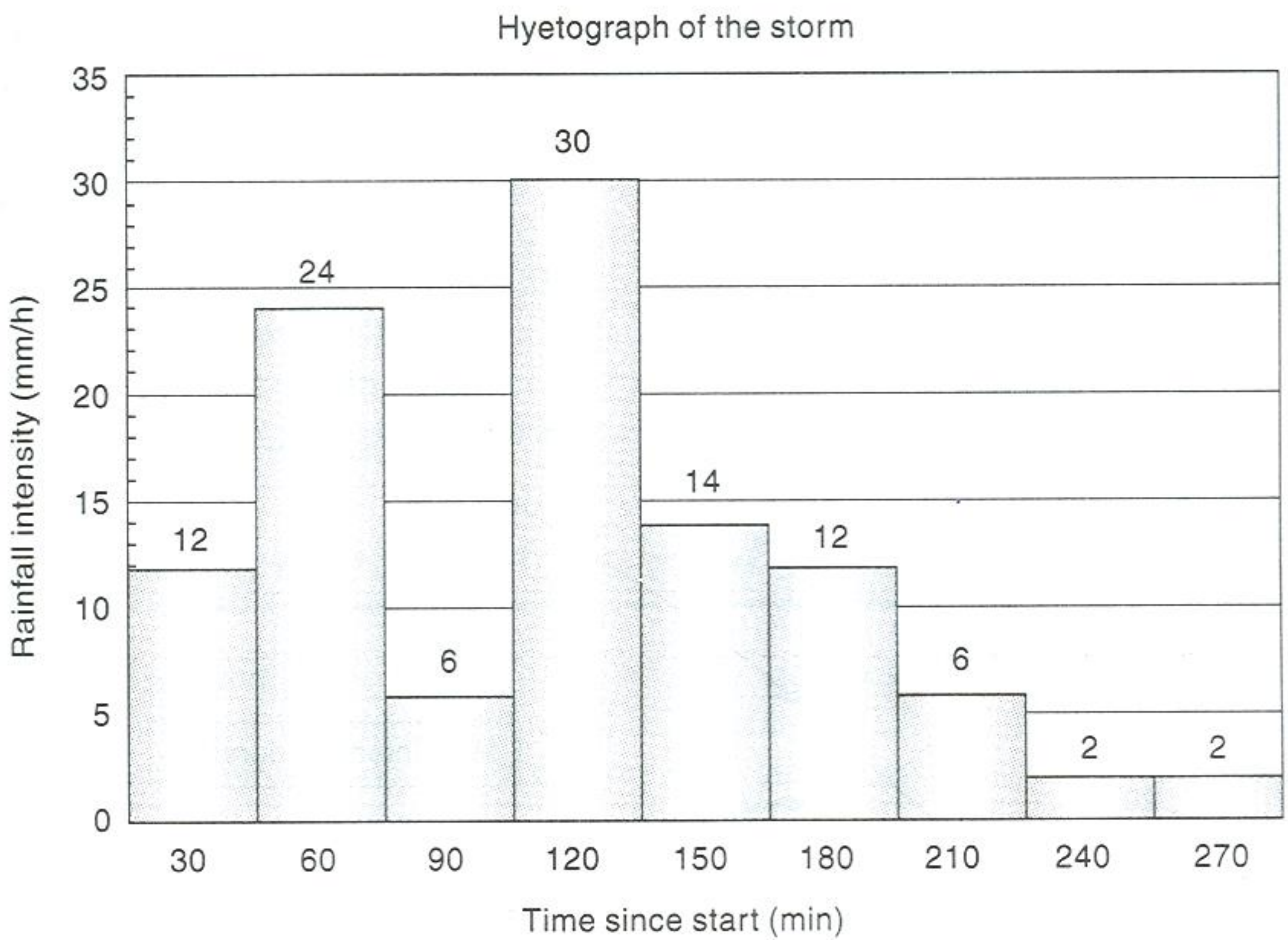


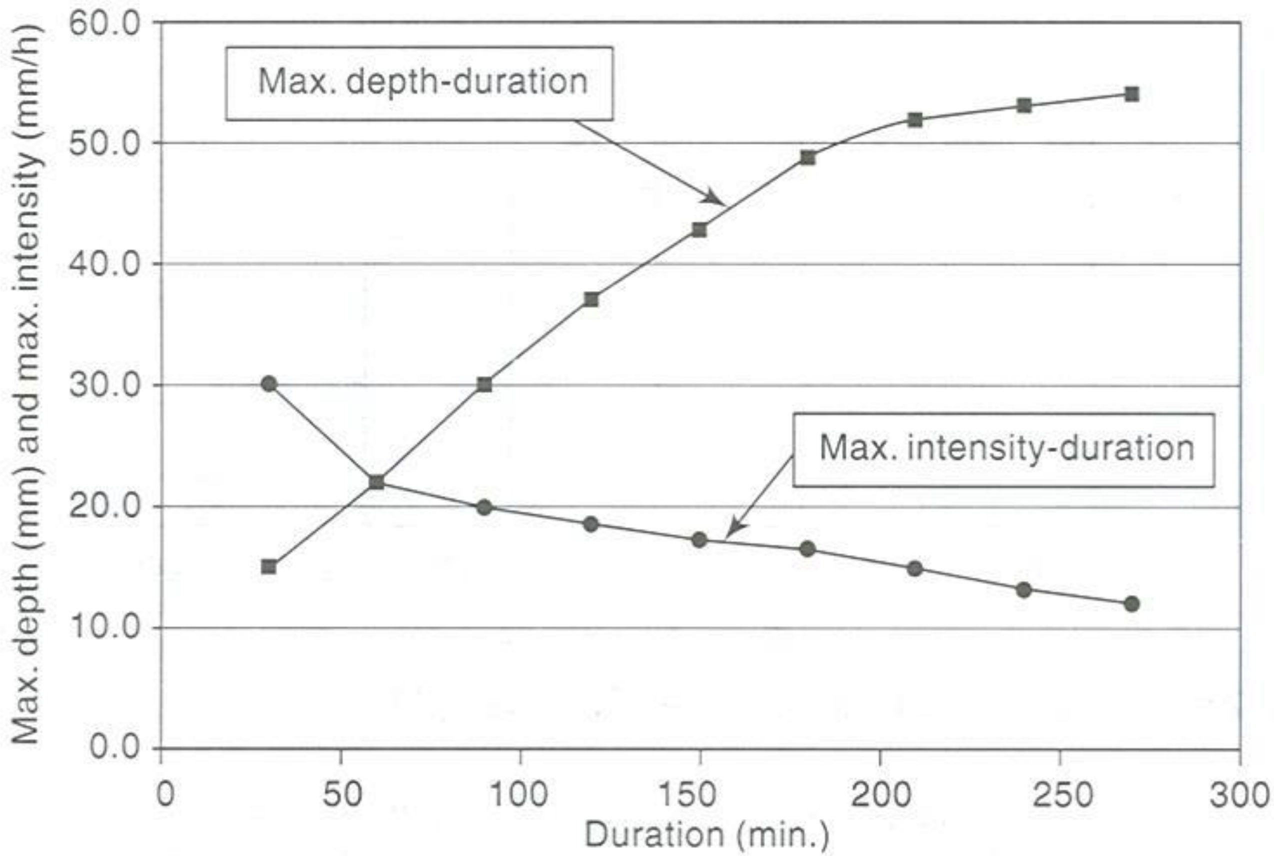
Fig. 2.25 ***Hyetograph of the Storm — Example 2.11***

Computation of rainfall depth for different durations

Incremental depth of rainfall (mm) in various durations										
		Durations(min)								
Time (min.)	*Cumulative Rainfall (mm)*	*30*	*60*	*90*	*120*	*150*	*180*	*210*	*240*	*270*
0	0									
30	6	6								
60	18	12	18							
90	21	3	15	21						
120	36	**15**	18	**30**	36					
150	43	7	**22**	25	**37**	43				
180	49	6	13	28	31	**43**	**49**			
210	52	3	9	16	31	34	46	**52**		
240	53	1	4	10	17	32	35	47	**53**	
270	54	1	2	5	11	18	33	36	48	**54**

Maximum Depth, Maximum Intensity for different durations

Maximum Intensity (mm/h)	30.0	22.0	20.0	18.5	17.2	16.3	14.9	13.3	12.0
Duration in min.	30	60	90	120	150	180	210	240	270
Maximum Depth (mm)	15.0	22.0	30.0	37.0	43.0	49.0	52.0	53.0	54.0



Maximum Intensity-Duration and Maximum Depth-Duration Curve

INTENSITY-DURATION RELATIONSHIPS

- The greater the intensity of rainfall, in general, the shorter length of time it continues for.
- Many formulas have been derived to express the relationship between intensity and duration of point rainfall for durations of 5 to 120 minutes.
- A formula expressing the relationship between intensity and duration for durations of 5 to 120 minutes is of the type:

$$i = \frac{a}{t+b}$$

i = the average intensity for duration *t*, and *a* and *b* are locality dependent constants.

INTENSITY-DURATION RELATIONSHIPS

- For durations of over 120 minutes, the relationship between the average rainfall intensity and duration is expressed by a formula of the type:

$$i = \frac{C}{t^n}$$

- in which *C* and *n* are locality-dependent constants.
- The relation between the rainfall intensity and duration can be obtained as a straight line by plotting the intensity against duration in time on a **double log paper**.

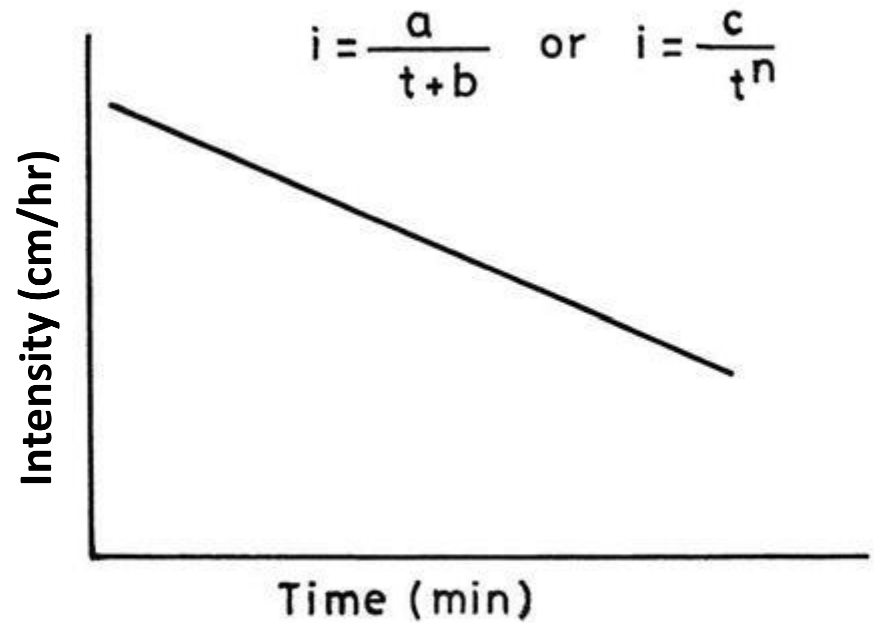
INTENSITY-DURATION RELATIONSHIPS

$$i = \frac{a}{t+b}$$

$$\log i = \log a - \log (t+b)$$

$$i = \frac{C}{t^n}$$

$$\log i = \log C - n \log t$$



On double log paper

FREQUENCY ANALYSIS OF POINT RAINFALL

In many engineering applications such as those concerned with floods, the probability of occurrence of a particular extreme rainfall, e.g., 24-h maximum rainfall will be important.

- To obtain such information we use frequency analysis of the point-rainfall data.

- If the extreme values of a specified event occurring in each year is listed, it constitutes an annual series.

for e.g. one may list the maximum of 24-hr rainfall occurring in an year at a station to prepare an annual series of 24-h maximum rainfall values.

The probability of occurrence of an event in this series is studied using frequency analysis of this annual data series. A brief description of this analysis is presented herein.

Firstly, it is necessary to correctly understand the terminology used in frequency analysis.

- The probability of occurrence of an event of a random variable (e.g. rainfall) whose magnitude is equal to or in excess of a specified magnitude x is denoted by P.

- The recurrence interval (or return period) is defined as $T = \frac{1}{P}$

  This represents the average interval between the occurrence of a rainfall of magnitude equal to or greater than X.

Thus if its stated that the return period of rainfall of 20cm in 24 h is 10 years at a certain station , it implies that on an average rainfall magnitudes equal to or greater than 20 cm in 24 h occur once in 10 years.

i.e., in a long period of 100 years, 10 such events can be expected.

- The probability of a rainfall of 20 cm in 24 hr occurring in anyone year at a station A is $\frac{1}{T} = \frac{1}{10} = 0.1$

- If the probability of an event occurring is p, the probability of the event not occurring in a given year is

$$q = (1-P)$$

- The binomial distribution can be used to find the probability of occurrence of the event r times in n successive years. Thus

$$P_{r,n} = nC_r P^r q^{n-r} = \frac{n!}{n-r! * r!} P^r q^{n-r}$$

where $P_{r,n}$= Probability of a random hydrologic event (rainfall) of given magnitude and exceedance probability P occurring r times in n successive years.

For example,

a) The probability of an event exceeding probability P occurring 2 times in n successive years is

$$P_{2,n} = \frac{n!}{n - 2! * 2!} P^2 q^{n-2}$$

b) The probability of the event not occurring at all in n successive years is

$$P_{2,n} = q^n = (1 - P)^n$$

c) The probability of the event occurring at least once in n successive years

$$P_1 = 1 - q^n = 1 - (1 - P)^n$$

2.11.1 Plotting Position

The purpose of the frequency analysis of an annual series is to obtain a relation between the magnitude of the event and its probability of exceedence. The probability analysis may be made either by empirical or by analytical methods.

A simple empirical technique is to arrange the given annual extreme series in descending order of magnitude and to assign an order number m. Thus, for the first entry $m = 1$, for the second entry $m = 2$, and so on, till the last event for which $m = N =$ number of years of record. The probability P of an event equalled to or exceeded is given by the *Weibull formula*

$$P = \left(\frac{m}{N+1}\right) \tag{2.14}$$

Equation (2.14) is an empirical formula and there are several other such empirical formulae available to calculate the probability P. Table 2.8 lists a few popular empirical formulae for calculating P. The exceedence probability of the event obtained by the use of the empirical formula, such as Equation (2.14) is called *plotting position*.

Table 2.8 ***Plotting-Position Formulae***

m = order number, N = number of Years of record

Name of the Method	Equation for P
California	$P = \dfrac{m}{N}$
Hazen	$P = \dfrac{(m-0.5)}{N}$
Weibull	$P = \dfrac{m}{(N+1)}$
Chegodayev	$P = \dfrac{(m-0.3)}{(N+0.4)}$
Blom	$P = \dfrac{(m-0.44)}{(N+0.12)}$
Gringoten	$P = \dfrac{(m-0.375)}{(N+0.25)}$

Having calculated P (and hence, T) for all events in the series, the variation of the rainfall magnitude is plotted against the corresponding T on a semi-log graph or on a log-log graph. By suitable extrapolation of this plot, within appropriate limits, the rainfall magnitude of specific duration for any recurrence interval can be estimated.

This simple empirical procedure can give good results for small extrapolations and the errors increase with the amount of extrapolation. For accurate work, various analytical calculation procedures using frequency factors are available. Gumbel's extreme value distribution and Log Pearson Type III method are two commonly used analytical methods

If P is the probability of exceedance of a variable having a magnitude M, a common practice is to designate the magnitude M as having (100 P) percent dependability. For example "75% dependable annual rainfall" at a station means the value of annual rainfall at the station that can be expected to be equalled to or exceeded 75% times (i.e., on an average 30 times out of 40 years). Thus, 75% dependable annual rainfall means the value of rainfall in the annual rainfall time series that has $P = 0.75$, i.e., $T = 1/P = 1.333$ years.

Example 2.10 The record of annual rainfall at station *A* covering a period of 22 years is given below. (a) Estimate the annual rainfall with return periods of 10 years and 50 years. (b) What would be the probability of an annual rainfall of magnitude equal to or exceeding 100 cm occurring at station *A*? (b) What is the 75% dependable annual rainfall at station *A*?

Year	Annual rainfall (cm)	Year	Annual rainfall (cm)
1960	130.0	1971	90.0
1961	84.0	1972	102.0
1962	76.0	1973	108.0
1963	89.0	1974	60.0
1964	112.0	1975	75.0
1965	96.0	1976	120.0
1966	80.0	1977	160.0
1967	125.0	1978	85.0
1968	143.0	1979	106.0
1969	89.0	1980	83.0
1970	78.0	1981	95.0

Solution

The data are arranged in descending order and the rank number assigned to the recorded events. The probability P of the event being equalled to or exceeded is calculated by using Weibull formula (Eq. 2.14). Calculations are shown in Table 2.9. It may be noted that when two or more events have the same magnitude (as for $m = 13$ and 14 in Table 2.9) the probability P is calculated for the largest m value of the set. The return period T is calculated as $T = 1/P$.

Table 2.9 ***Calculation of Return Periods–Example 2.10***

$N = 22$ years

m	Annual Rainfall (cm)	Probability $P = m/(N+1)$	Return Period $T = 1/P$ (years)	m	Annual Rainfall	Probability $P = m/(N+1)$	Return Period $T = 1/P$ (Years)
1	160.0	0.043	23.000	12	90.0	0.522	1.917
2	143.0	0.087	11.500	13	89.0	0.565	
3	130.0	0.130	7.667	14	89.0	0.609	1.643
4	125.0	0.174	5.750	15	85.0	0.652	1.533
5	120.0	0.217	4.600	16	84.0	0.696	1.438
6	112.0	0.261	3.833	17	83.0	0.739	1.353
7	108.0	0.304	3.286	18	80.0	0.783	1.278
8	106.0	0.348	2.875	19	78.0	0.826	1.211
9	102.0	0.391	2.556	20	76.0	0.870	1.150
10	96.0	0.435	2.300	21	75.0	0.913	1.095
11	95.0	0.478	2.091	22	60.0	0.957	1.045

A graph is plotted between the annual rainfall magnitude as the ordinate (on arithmetic scale) and the return period T as the abscissa (on logarithmic scale), (Fig. 2.19).

The equation of the best-fit line (trend line) is obtained as $P_r = 29.326 \ln(T) + 72.024$. In this, P_r = annual precipitation and T = return period. Use of a spreadsheet like MS Excel is very convenient for this type of problem: for computation, plotting of graph and for obtaining the trend line. The trendline equation is used for calculating the various required values:

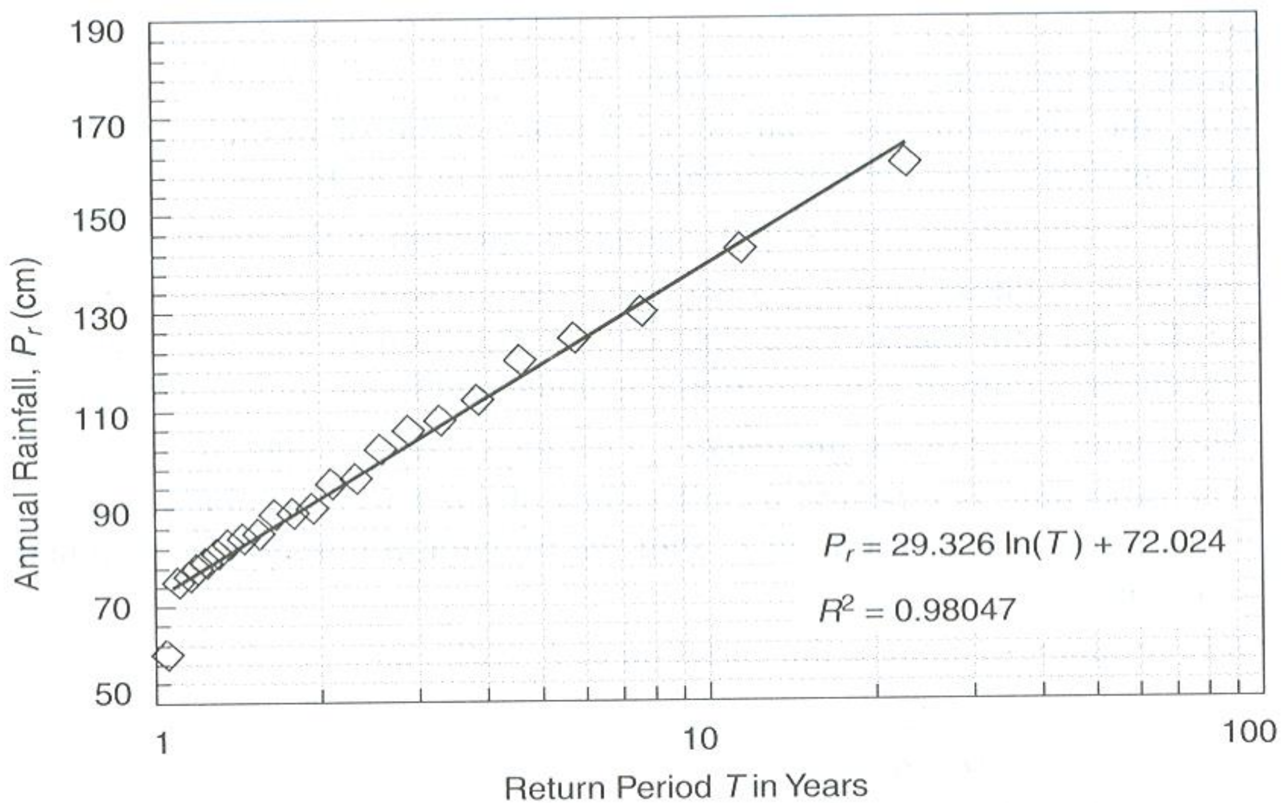


Fig. 2.19 ***Return Period of Annual Rainfall at Station—Example 2.10***

(a) (i) For $T = 10$ years, by using the equation of the derived trend line,

$P_r = 29.326 \ln(10) + 72.024 = 139.5$ cm

(ii) For $T = 50$ years, by using the equation of the derived trend line,

$P_r = 29.326 \ln(50) + 72.024 = 186.7$ cm.

(b) Return period of an annual rainfall magnitude (P_r) equal to or exceeding 100 cm, by using the equation of the derived trend line,

$100 = 29.326 \ln(T) + 72.024$

$T = 2.596$ years and the exceedance probability $P = 1/2.596 = 0.385$.

(c) 75% dependable annual rainfall at station A = Annual rainfall P_r with probability of exceedance $P = 0.75$, i.e., $T = 1/P = 1/0.75 = 1.333$ years.

By using the equation of the derived trend line,

$P_r = 29.326 \ln(1.333) + 72.024 = 80.4$ cm.

Creating an IDF Curve

- Locate your particular area of interest
- Calculate average intensities for:

  - 2-yr frequency (5, 15, and 60, …… minutes)
  - 5-yr
  - 10-yr
  - 25-yr
  - 50-yr
  - 100-yr frequency (5, 15, and 60, …… minutes)

- The results are plotted as maximum intensity *vs* return period with the *Duration* as the third parameter (Fig. 2.20). Alternatively, maximum intensity *vs* duration with frequency on return period as the third variable can also be adopted (Fig. 2.21).

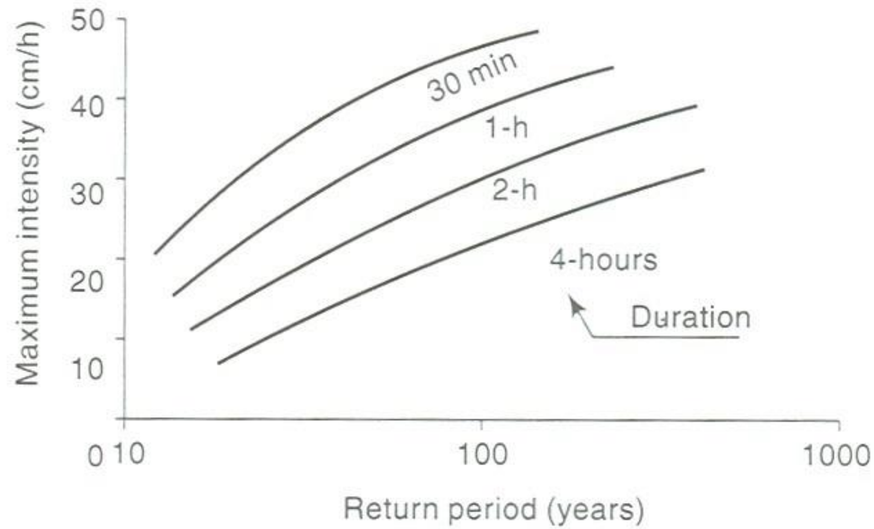


Fig. 2.20 *Maximum Intensity-Return Period-Duration Curves*

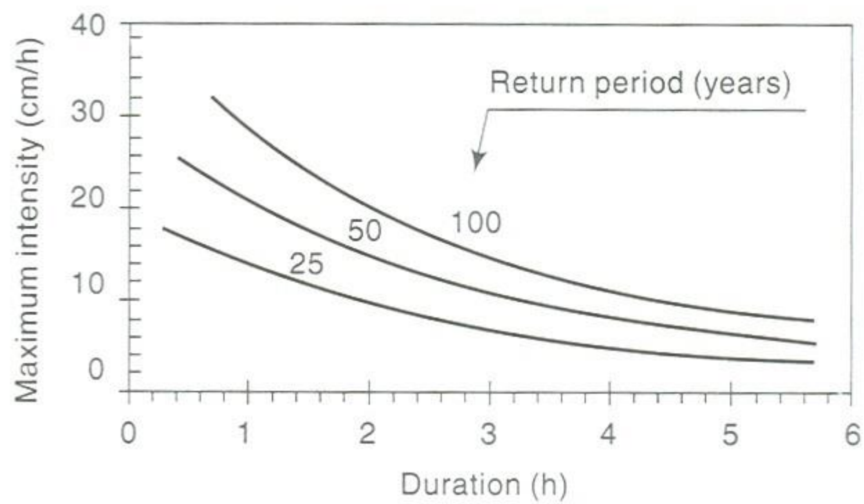
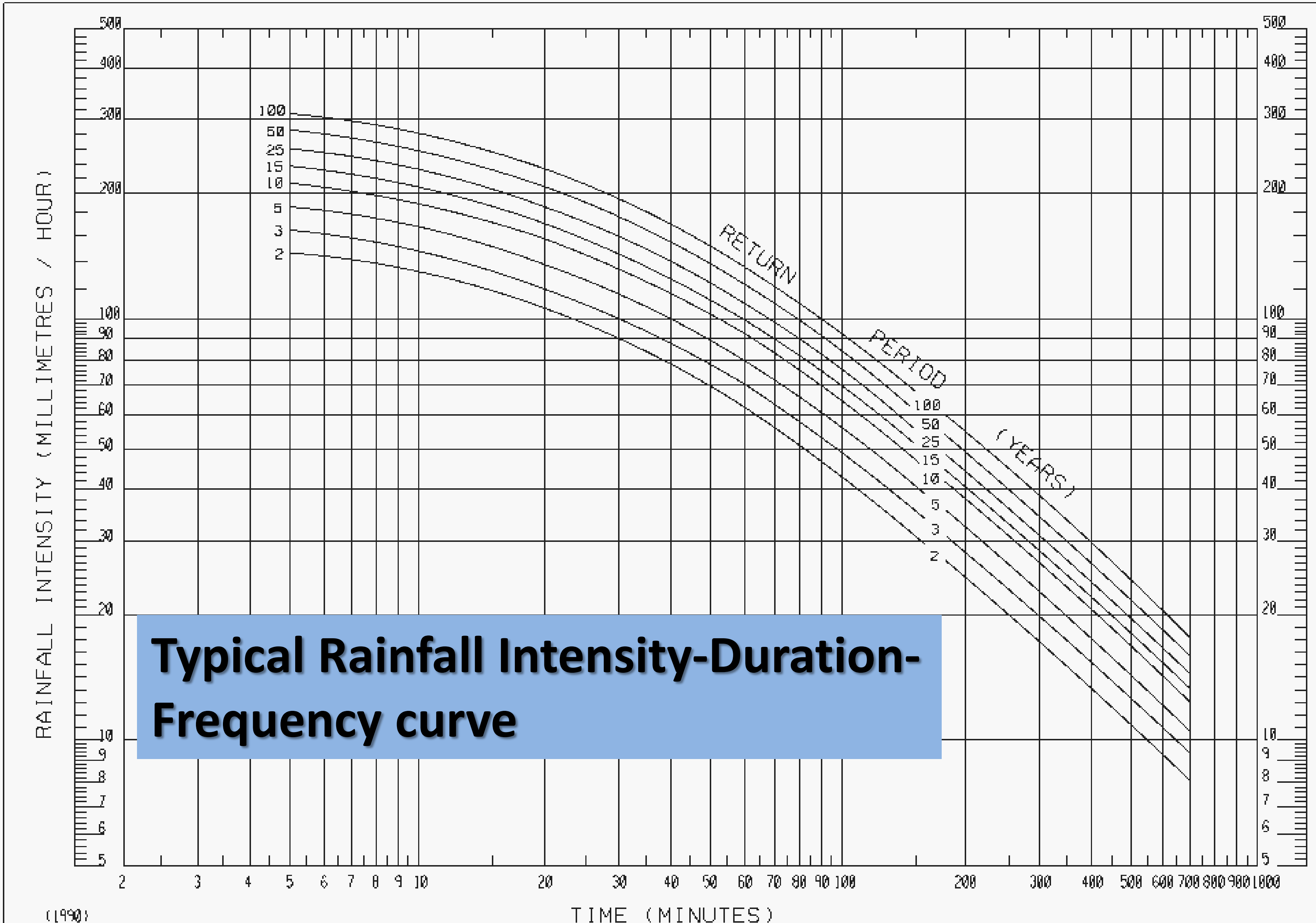


Fig. 2.21 *Maximum Intensity-Duration-Frequency Curves*

Typical Rainfall Intensity-Duration-Frequency curve



2.12 *Maximum Intensity/Depth-Duration-Frequency Relationship*

2.12.1 Maximum Intensity-Duration Relationship

In any storm, the actual intensity as reflected by the slope of the mass curve of rainfall varies over a wide range during the course of the rainfall. If the mass curve is considered divided into N segments of time interval Δt such that the total duration of the storm $D = N\,\Delta t$ then the intensity of the storm for various subdurations $t_j = (1.\,\Delta t), (2.\,\Delta t), (3.\,\Delta t), \ldots (j.\,\Delta t) \ldots$ and $(N.\,\Delta t)$ could be calculated. It will be found that for each duration (say t_j), the intensity will have a maximum value and this could be analysed to obtain a relationship for the variation of the maximum intensity with duration for the storm.

This process is basic to the development of maximum intensity-duration-frequency relationship for the station discussed later on.

Briefly, the procedure for analysis of a mass curve of rainfall for developing maximum intensity-duration relationship of the storm is as follows.

- Select a convenient time step Δt such that duration of the storm $D = N.\,\Delta t$.
- For each duration (say $t_j = j.\Delta t$), the mass curve of rainfall is considered to be divided into consecutive segments of duration t_j. For each segment, the incremental rainfall d_j in duration t_j is noted and intensity $I_j = d_j/t_j$ obtained.
- Maximum value of the intensity (I_{mj}) for the chosen t_j is noted.
- The procedure is repeated for all values of $j = 1$ to N to obtain a data set of I_{mj} as a function of duration t_j. Plot the maximum intensity I_m as function of duration t.
- It is common to express the variation of I_m with t as

  $$I_m = \frac{c}{(t + a)^b}$$

  where a, b and c are coefficients obtained through regression analysis. Example 2.11 describes the procedure in detail.

2.12.2 Maximum Depth-Duration Relationship

Instead of the maximum intensity I_m in a duration t, the product $(I_m . t) = d_m$ = maximum depth of precipitation in the duration t could be used to relate it to the duration. Such a relationship is known as the maximum depth-duration relationship of the storm. The procedure of developing this relationship is essentially same as that for maximum intensity-duration relationship described earlier.

Example 2.11 describes the procedure in detail

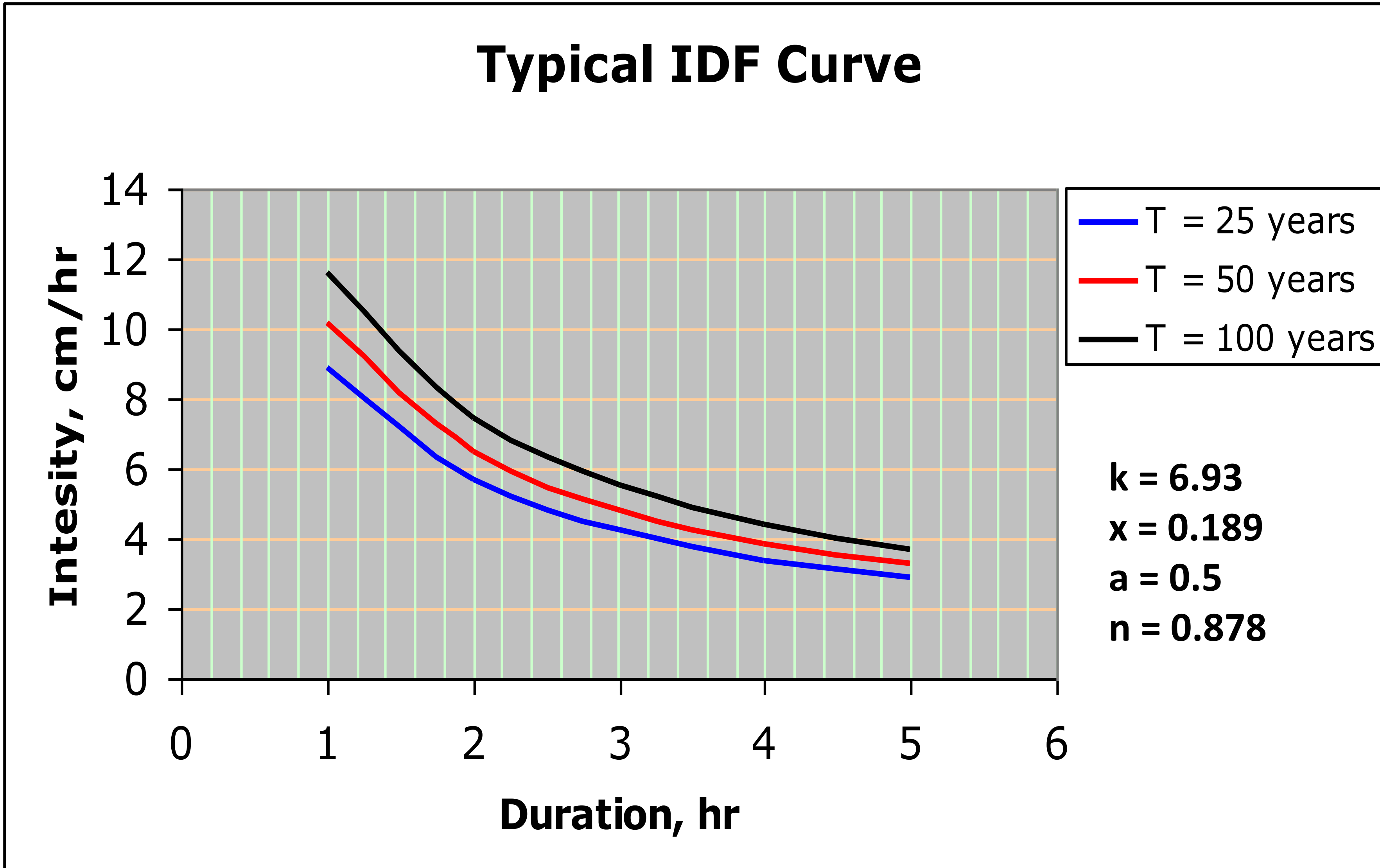
2.12.3 Maximum Intensity-Duration-Frequency Relationship

If the rainfall data from a self-recording raingauge is available for a long period, the frequency of occurrence of maximum intensity occurring over a specified duration can be determined. A knowledge of maximum intensity of rainfall of specified return period and of duration equal to the critical time of concentration is of considerable practical importance in evaluating peak flows related to hydraulic structures.

Briefly, the procedure to calculate the intensity-duration-frequency relationship for a given station is as follows.

- M numbers of significant and heavy storms in a particular year Y_1 are selected for analysis. Each of these storms are analysed for maximum intensity duration relationship as described in Sec. 2.12.1
- This gives the set of maximum intensity I_m as a function of duration for the year Y_1.
- The procedure is repeated for all the N years of record to obtain the maximum intensity $I_m (D_j)_k$ for all $j = 1$ to M and $k = 1$ to N.
- Each record of $I_m (D_j)_k$ for $k = 1$ to N constitutes a time series which can be analysed to obtain frequencies of occurrence of various $I_m (D_j)$ values. Thus there will be M time series generated.

IDF ….


Typical IDF Curve
Intesity, cm/hr
14
12
10
8
6
4
2
0
0
1
2
3
4
5
6
Duration, hr
T = 25 years
T = 50 years
T = 100 years
k = 6.93
x = 0.189
a = 0.5
n = 0.878

IDF ….

- In many design problems related to watershed such as runoff disposal, erosion control, highway construction, culvert design, it is necessary to know the rainfall intensities of different durations and different return periods.
- The curve that shows the inter-dependency between i (cm/hr), D (hour) and T (year) is called IDF curve.
- The relation can be expressed in general form as:

$$i = \frac{k\,T^{x}}{(D+a)^{n}}$$

i – Intensity (cm/hr)

D – Duration (hours)

K, x, a, n – are constant for a given catchment

Analytically, these relationships are commonly expressed in a condensed form by general form

$$i = \frac{KT^{X}}{(D+a)^{n}} \tag{2.15}$$

where i = maximum intensity (cm/h), T = return period (years), D = duration (hours) K, x, a and n are coefficients for the area represented by the station.

Sometimes, instead of maximum intensity, maximum depth is used as a parameter and the results are represented as a plot of maximum depth *vs* duration with return period as the third variable (Fig. 2.22).

[*Note:* While maximum intensity is expressed as a function of duration and return period, it is customary to refer this function as intensity-duration-frequency relationship. Similarly, in the depth-duration-frequency relationship deals with maximum depth in a given duration.]

Rambabu et al. (1979)[10] have analysed the self-recording raingauge rainfall records of 42 stations in the country and have obtained the values of coefficients K, x, a, and n of Eq. 2.15. Some typical values of the coefficients for a few places in India are given in Table 2.10.

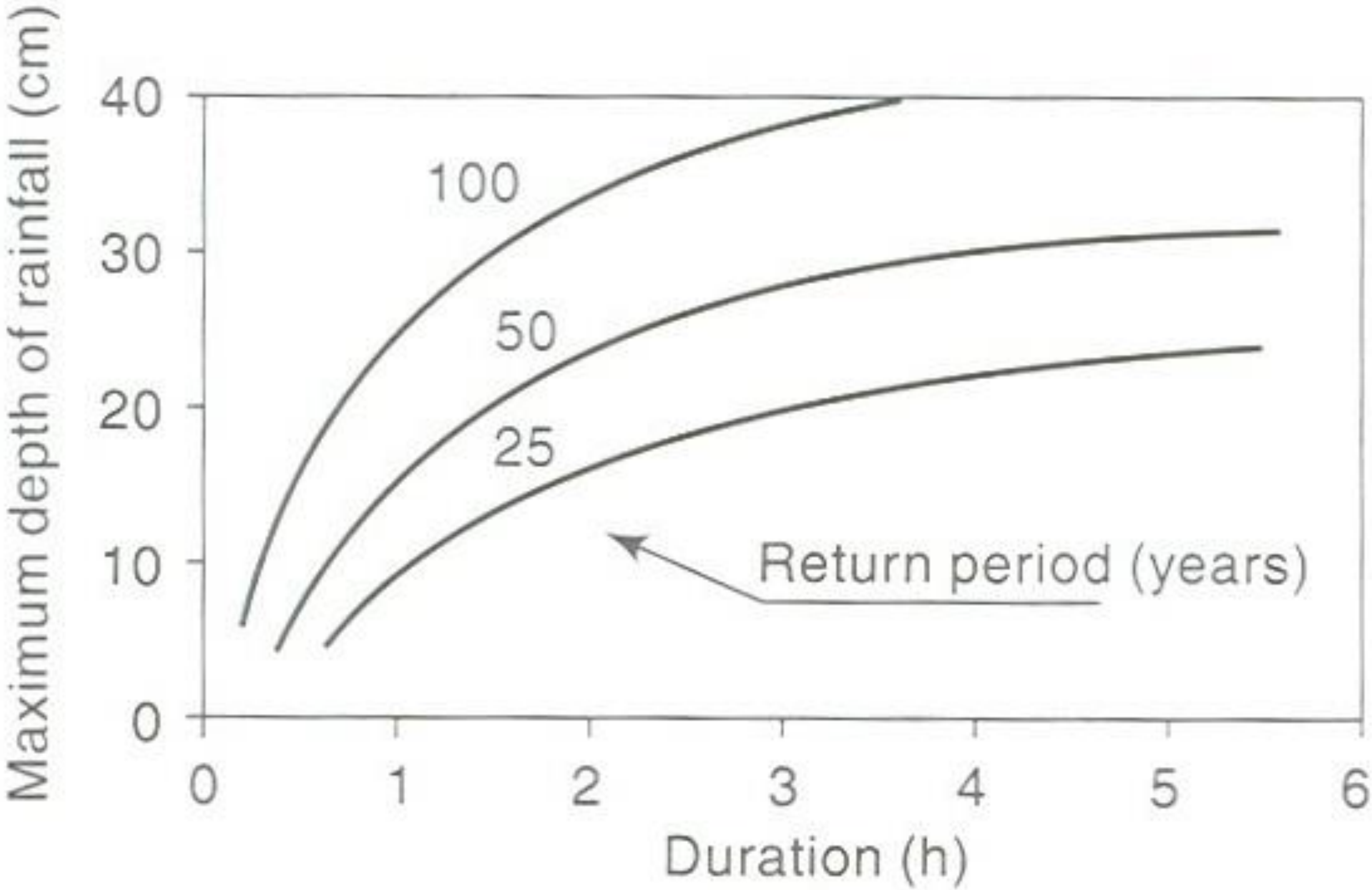


Fig. 2.22 *Maximum Depth-Duration-Frequency Curves*

Table 2.10 *Typical values of Coefficients K, x, a and n in Eq. (2.15)*

[Ref. 10]

Zone	Place	K	x	a	n
Northern Zone	Allahabad	4.911	0.1667	0.25	0.6293
	Amritsar	14.41	0.1304	1.40	1.2963
	Dehradun	6.00	0.22	0.50	0.8000
	Jodhpur	4.098	0.1677	0.50	1.0369
	Srinagar	1.503	0.2730	0.25	1.0636
	Average for the zone	5.914	0.1623	0.50	1.0127
Central Zone	Bhopal	6.9296	0.1892	0.50	0.8767
	Nagpur	11.45	0.1560	1.25	1.0324
	Raipur	4.683	0. 1389	0.15	0.9284
	Average for the zone	7.4645	0.1712	0.75	0.9599
Western Zone	Aurangabad	6.081	0.1459	0.50	1.0923
	Bhuj	3.823	0.1919	0.25	0.9902
	Veraval	7.787	0.2087	0.50	0.8908
	Average for the zone	3.974	0.1647	0.15	0.7327
Eastern Zone	Agarthala	8.097	0.1177	0.50	0.8191
	Kolkata (Dumdum)	5.940	0.1150	0.15	0.9241
	Gauhati	7.206	0.1157	0.75	0.9401
	Jarsuguda	8.596	0.1392	0.75	0.8740
	Average for the zone	6.933	0.1353	0.50	0.8801
Southern Zone	Bangalore	6.275	0.1262	0.50	1.1280
	Hyderabad	5.250	0.1354	0.50	1.0295
	Chennai	6.126	0.1664	0.50	0.8027
	Trivandrum	6.762	0.1536	0.50	0.8158
	Average for the zone	6.311	0.1523	0.50	0.9465

Extreme-point rainfall values of different durations and for different return periods have been evaluated by *IMD* and the *iso-pluvial* (lines connecting equal depths of rainfall) maps covering the entire country have been prepared. These are available for rainfall durations of 15 min, 30 min, 45 min, 1 h, 3 h, 6 h, 9 h, 15 h and 24 h for return periods of 2, 5, 10, 25, 50 and 100 years. A typical 50 year 24 h maximum rainfall map of the southern peninsula is given in Fig. 2.23. The 50 year 1 h maximum rainfall depths over India and the neighbourhood are shown in Fig. 2.24. Isopluvial maps of the maximum rainfall of various durations and of 50-year return periods covering the entire country are available in Ref. 1.

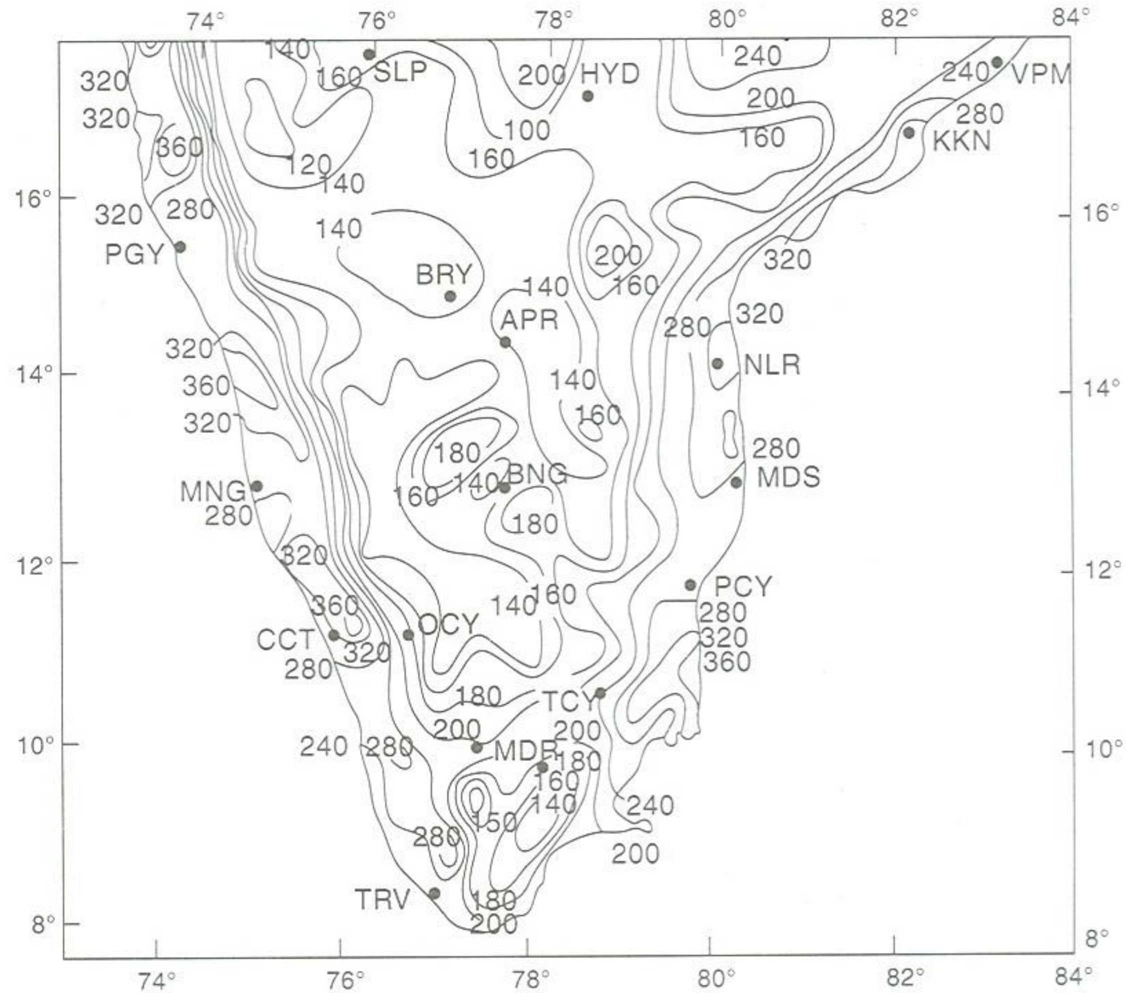


Fig. 2.23 ***Isopluvial Map of 50 yr 24 h Maximum Rainfall (mm)***

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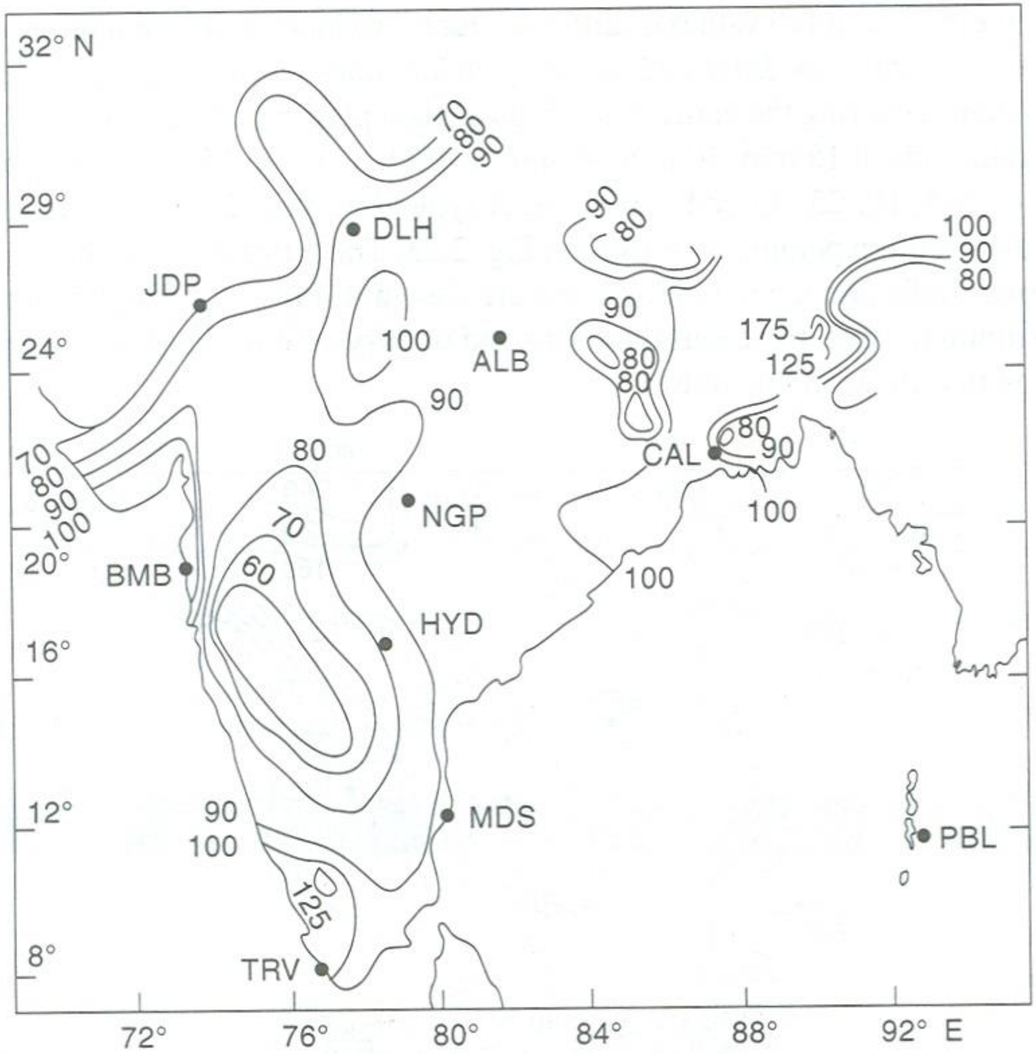

Fig. 2.24 ***Isopluvial Map of 50 yr–l h Maximum Rainfall (mm)***

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The territorial waters of India extend into the sea to a distance of 12 nautical miles measured from the appropriate baseline

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