RAINFALL

Topics to be covered:

- Mean Precipitation over an area
- Estimation of Missing Rainfall Data
- Adjustment of Rainfall Records
- Presentation of rainfall data

Mean Precipitation over an area

- Raingages rainfall represent only point sampling of the areal distribution of a storm
- The important rainfall for hydrological analysis is a rainfall over an area, such as over the catchment
- To convert the point rainfall values at various stations to in to average value over a catchment, the following methods are used:
  1. Arithmetic Average Method
  2. Thiessen Polygon Method
  3. Isohyetal Method

- Different methods express equation for mean areal rainfall $\bar{R}$ simply as a weighted average of surrounding station

$$\bar{R} = \sum_{i=1}^{N} a_i r_i$$

Where N = number of stations; a_i = weight assigned to the i^{th} station; and r_i = rainfall observed by the i^{th} station

- Because

$$\sum_{i=1}^{N} a_i = 1$$

it follows that

$0 \leq a_i \leq 1, i = 1, 2, 3, \ldots N$

- The various methods differ in the choice of weights only

For Arithmetic Avg. method (Un weighted mean method)

$a_1 = a_2 = a_3 \ldots\ldots\ldots\ldots\ldots\ldots = a_i = \ldots\ldots\ldots = a_n$

or

$$a_i = \frac{1}{N} \qquad i = 1, 2, 3 \ldots\ldots\ldots\ldots, N$$

Arithmetic Mean Method

Simplest method for determining areal average. When the area is physically and climatically homogenous and the required accuracy is small, the average rainfall ($\overline{R}$) for a basin can be obtained as the arithmetic mean of the values recorded at various stations.

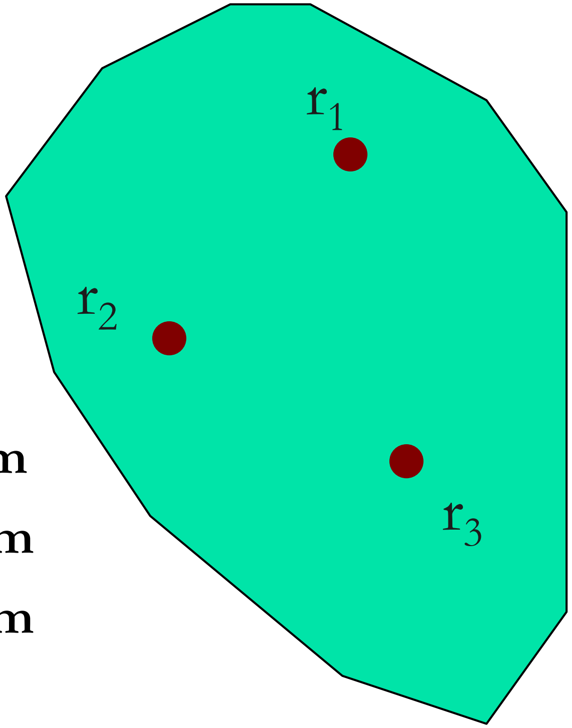
$$\bar{R} = \frac{1}{N}\sum_{i=1}^{N} r_i$$

$$\bar{R} = \frac{10 + 20 + 30}{3} = 20\ mm$$

$r_1 = 10$ mm

$r_2 = 20$ mm

$r_3 = 30$ mm



- Gages must be uniformly distributed
- Gage measurements should not vary greatly about the mean

Thiessen polygon method

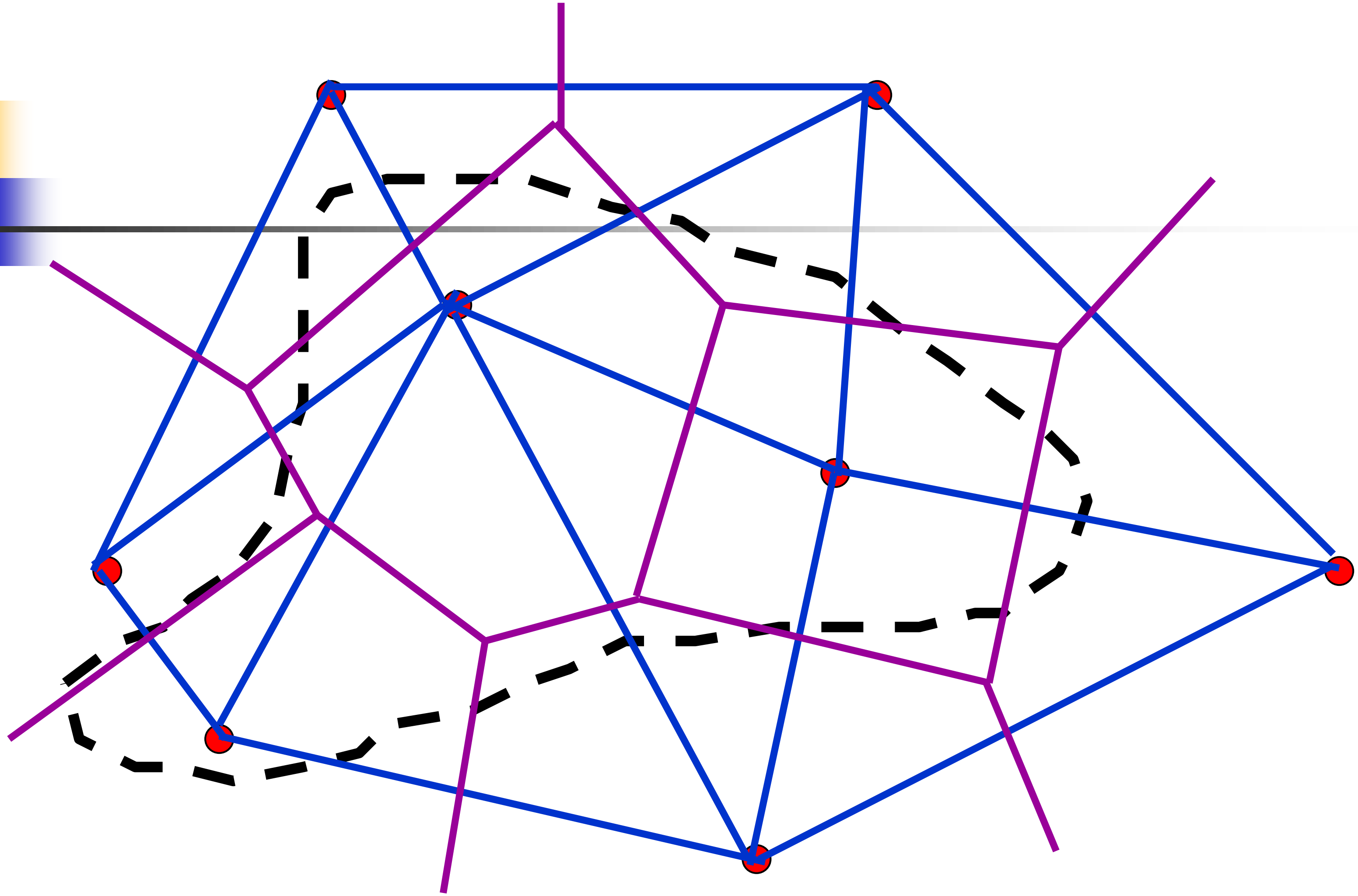
- Any point in the watershed receives the same amount of rainfall as that at the nearest gage.

- Rainfall recorded at a gage can be applied to any point at a distance halfway to the next station in any direction.

- 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.

Thiessen polygons ....



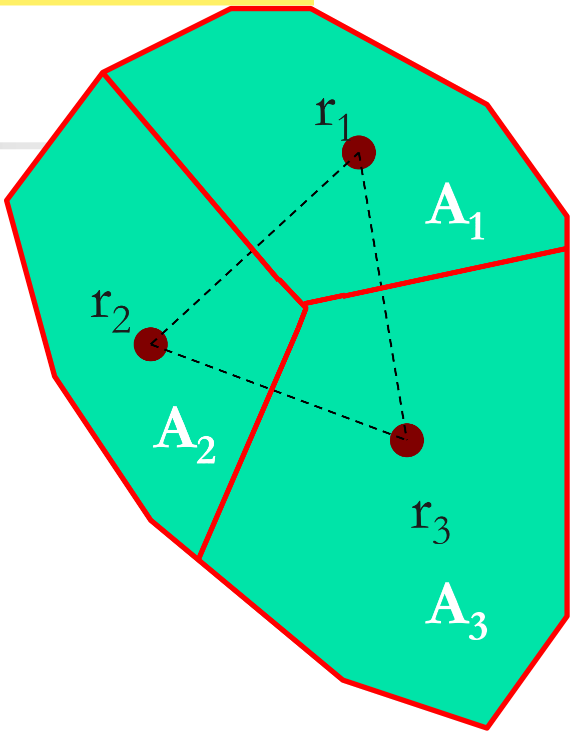
Steps in Thiessen polygon method

1. Draw lines joining adjacent gages
2. Draw perpendicular bisectors to the lines created in step 1
3. Extend the lines created in step 2 in both directions to form representative areas for gages
4. Compute representative area for each gage
5. Compute the areal average using the following formula

$$\bar{R} = \frac{1}{A}\sum_{i=1}^{N} A_i r_i$$

$$\bar{R} = \frac{12 \times 10 + 15 \times 20 + 20 \times 30}{47} = 20.7\ mm$$

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



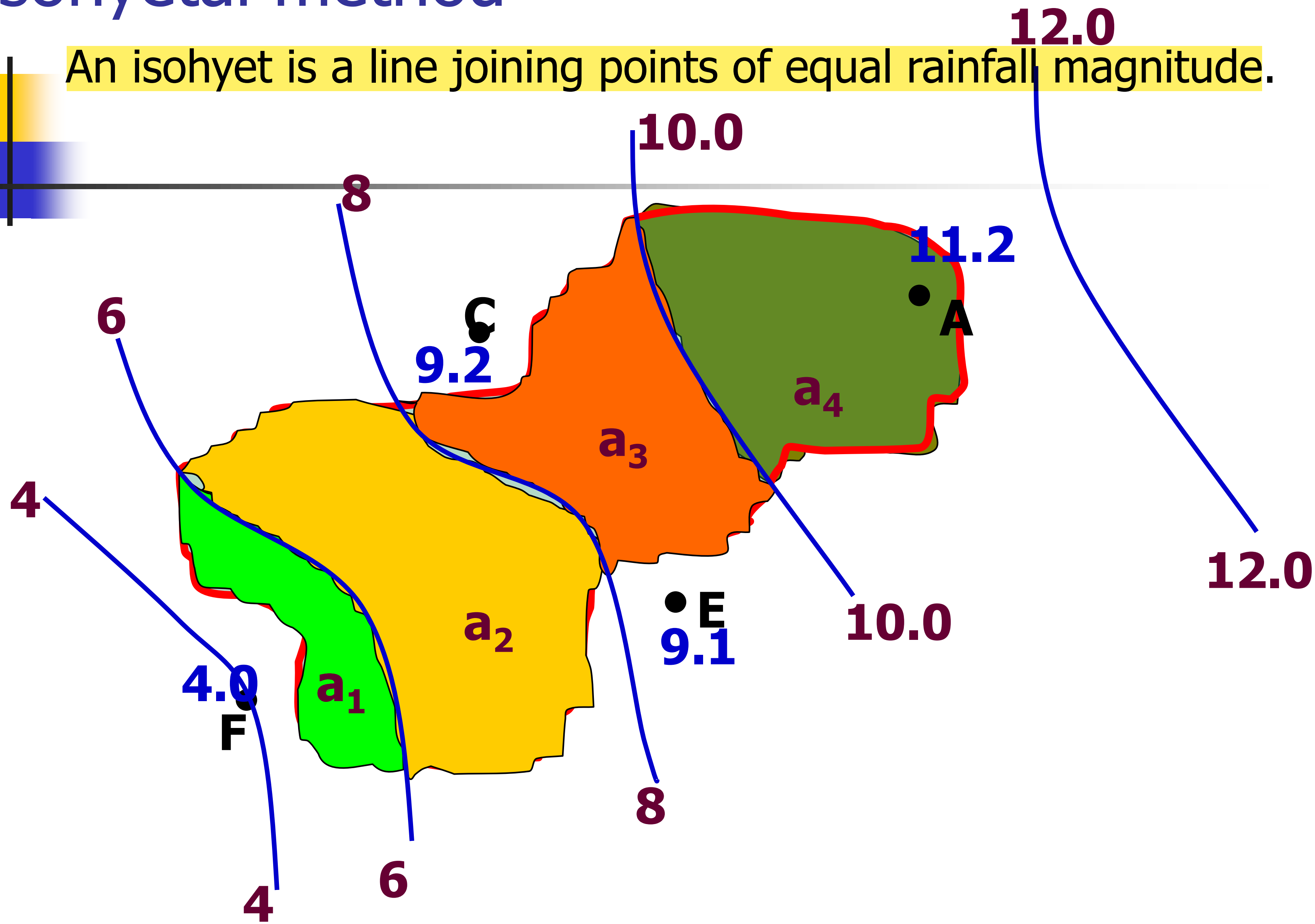
r_1 = 10 mm, A_1 = 12 km^2

r_2 = 20 mm, A_2 = 15 km^2

r_3 = 30 mm, A_3 = 20 km^2

Isohyetal method

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



- $r_1, r_2, r_3, \ldots, r_n$ – 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
- $\overline{R}$ - the mean precipitation over the catchment

$$\overline{R} = \frac{a_1\left(\frac{r_1 + r_2}{2}\right) + a_2\left(\frac{r_2 + r_3}{2}\right) + \ldots + a_{n-1}\left(\frac{r_{n-1} + r_n}{2}\right)}{A}$$

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

Choice of the Method

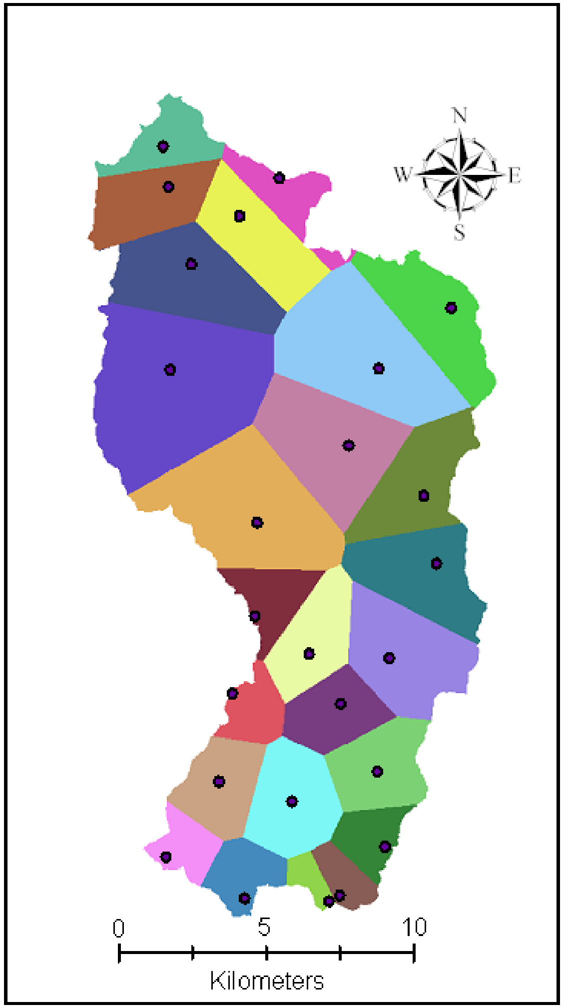
Thiessen polygon may be used when,

- Basin is not rugged, rather plain
- Area is intermediate (upto 5000 km^2)
- Gaging stations are few as compared to the size of the basin

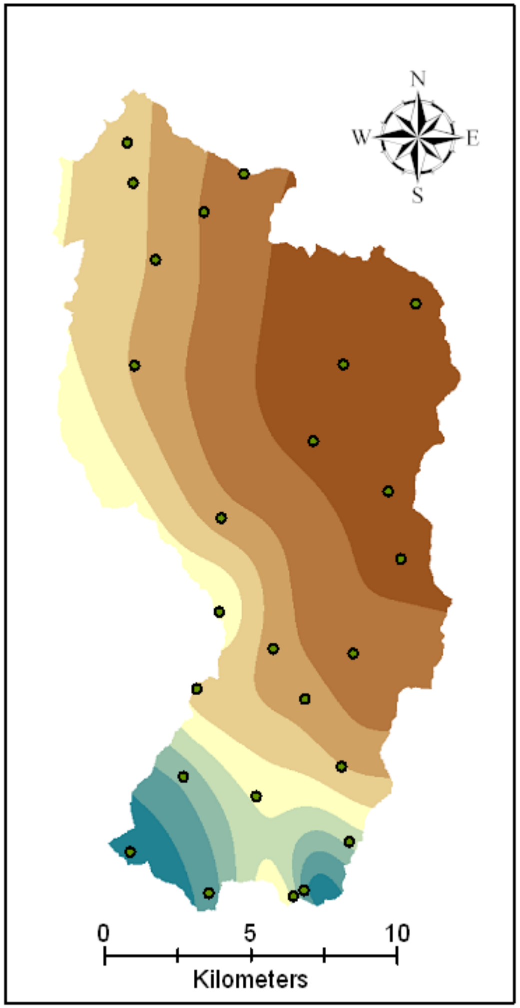
Isohyetal method should be used when,

- Basin is quite rugged and hilly
- Area is large (> 5000 km^2)
- The network of rainfall stations within the storm area is sufficiently dense

Rainfall maps in GIS



Nearest Neighbor “Thiessen” Polygon Interpolation



Spline Interpolation

Estimation of Missing Data

- Many rainfall stations have incomplete records
- Breaks may vary in length from 1 or 2 days to several years
- It is often necessary to estimate the missing data in order to utilize partial records, especially in data-sparse areas

Estimation of Missing Data

- The problem of filling missing data point rainfall estimation at an ungauged location involves transmittal of the rainfall amount observed at nearby index station to a gauge with missing data or an ungaged location and can be formulated as

$$r_x = \sum_{i=1}^{n} a_i r_i$$

Where $a_i > 0$ = weighting factor or factor of contribution for the index station i; r_i = rainfall observed at the station i; n = number of index stations; and r_x = rainfall to be estimated for the station x

Estimation of Missing Data

- Different methods of point rainfall estimation differ in the mechanics of estimating the weighting factors, a_i, $i = 1,2,\ldots\ldots,n$

- Different methods are
  - Arithmetic Average Method
  - Normal Ratio Method
  - Inverse Distance Method

Arithmetic Average Method

- Missing precipitation r_x can be determined using simple arithmetic average, if the normal annual precipitation at various stations are within 10% of the normal precipitation at station, x, as follows:

$$r_x = \frac{1}{n}\left[r_1 + r_2 + \cdots + r_n\right]$$

Normal Precipitation –

- It is the average value of precipitation at a particular date, month or year over a specified 30 year period.
- Thus, the term normal annual precipitation at station A means the average annual precipitation at A based on a specified 30 year of record.

Normal Ratio Method

- Rainfall r_x at station x is given by

$$r_x = \frac{1}{N}\left[\frac{\overline{r}_x}{\overline{r}_A} r_A + \frac{\overline{r}_x}{\overline{r}_B} r_B + \frac{\overline{r}_x}{\overline{r}_C} r_C + \cdots + \frac{\overline{r}_x}{\overline{r}_N} r_N\right]$$

where $\overline{r}$ = normal rainfall with A, B, and C as index stations.

- Method is based on selecting N (N is usually 3) stations that are near and approximately evenly spaced around the station with the missing record.

Inverse Distance Method

- The inverse distance method has been advocated to be the most accurate of all

- Amount of rainfall to be estimated at a location is a function of
  - rainfall measured at the surrounding index stations
  - distance to each index station from the ungauged location

Inverse Distance Method

- Algebraically,

$$r_x = \frac{\sum_{i=1}^{n} (r_i / D_i^b)}{\sum_{i=1}^{n} (1 / D_i^b)}$$

b = 2 is commonly used

- The weighting is based strictly on distance

- Therefore, this method may not be entirely satisfactory for hilly regions

Example

- Data for the base station and 5 surrounding stations are tabulated below. Find missing data at A using

  (a) Normal Ratio method

  (b) Inverse Distance method

Station	Rainfall, cm	Normal Rainfall, cm	Distance, km
A (Base)	?	102	
B	2.5	114	1.5
C	3.4	122	1.21
D	1.5	95	0.85
E	2.2	106	1.3
F	1.8	104	2.11

Normal Ratio Method

$$r_A = \frac{1}{5}\left[\frac{\bar{r}_A}{\bar{r}_B} r_B + \frac{\bar{r}_A}{\bar{r}_C} r_C + \frac{\bar{r}_A}{\bar{r}_D} r_D + \frac{\bar{r}_A}{\bar{r}_E} r_E + \frac{\bar{r}_A}{\bar{r}_F} r_F\right]$$

$$r_A = \frac{1}{5}\left[\frac{102}{114} 2.5 + \frac{102}{122} 3.4 + \frac{102}{95} 1.5 + \frac{102}{106} 2.2 + \frac{102}{104} 1.8\right]$$

$$= 2.11\,\text{cm}$$

Inverse Distance Method

- Weight calculation is shown in Table

Station	Distance, D	$1/D^2$	Weights, a
B	1.5	0.44	0.44/3.31= 0.13
C	1.21	0.68	0.21
D	0.85	1.38	0.41
E	1.3	0.59	0.18
F	2.11	0.22	0.07
		SUM=3.31	SUM = 1.0

Hence,

$$r_A = r_B a_B + r_C a_C + r_D a_D + r_E a_E + r_F a_F$$
$$= 2.5(0.13) + 3.4(0.21) + 1.5(0.41) + 2.2(0.18) + 1.8(0.07)$$
$$= 2.18 \text{ cm}$$

Adjustment of Rainfall Records

- Inconsistencies in rainfall records may arise for the following reasons:
  - Locations of stations have changed
  - Observational procedures have changed
  - Instrument exposure has changed

Adjustment of Rainfall Records

- These inconsistencies render the rainfall records heterogeneous

- Hence, the records must be adjusted before use

- Heterogeneity, if there is any, must be quantitatively detected and established in the records

Detection of Heterogeneity in Rainfall Records

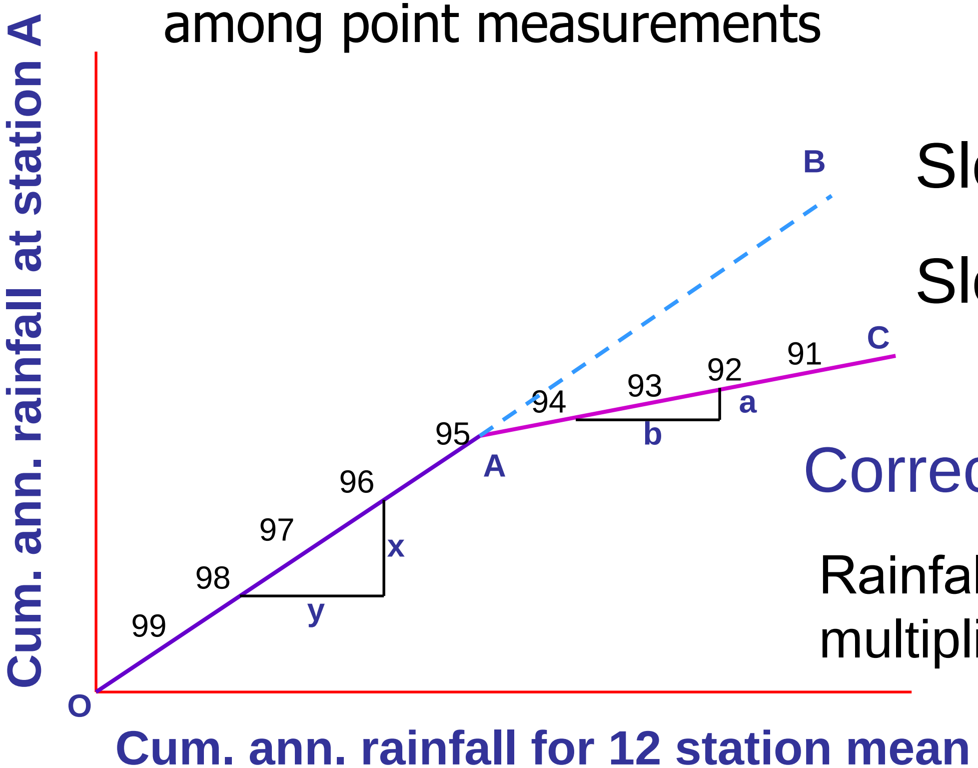
- Heterogeneity in a rainfall record may be identified by
  - Graphical method
    - Double-Mass Analysis (GRAPHICAL)
  - Statistical method
    - The von Neumann Ratio (VNR) Test

Double Mass Analysis

- Graphical method is frequently used for identifying inconsistencies in a station record by comparing it with the records of other stations
- Accumulated annual, seasonal, or monthly values at a station in question are plotted against those of a nearby reliable station or group of stations
- This plotting results in what is called the double-mass curve, which is then examined for trends and changes in slope

Double Mass Curve

- Plot of cumulative annual precipitation for one station versus a group of stations in the same area, for checking for consistency among point measurements



Slope of OA $S_{OA} = x / y$

Slope of AC $S_{AC} = a / b$

Correction Factor = S_{OA} / S_{AC}

Rainfall data prior to '95 has to be multiplied by the Correction Factor

Example

- The average annual precipitation at station X and the average of the annual precipitation at 25 surrounding stations are given for 36 years in the Table.

- Determine the consistency of record at station X using Double mass curve

Example

Sl. No.	Year	Annual Ppt, Stn. X	Annual Ppt, 25-Stn. Avg.
1	1941	41.4	34.3
2	1942	30.2	27.9
3	1943	30.7	31.5
4	1944	32.8	28.2
5	1945	32	31.2
6	1946	30.5	22.9
7	1947	38.9	35.1
8	1948	43.7	30.2
9	1949	32.3	27.43
10	1950	27.4	27.2
11	1951	32	28.2
12	1952	48.3	36.1
13	1953	28.4	28.4
14	1954	24.6	25.1
15	1955	21.8	23.6
16	1956	28.2	33.3
17	1957	17.3	23.4
18	1958	22.4	36.1

Sl. No.	Year	Annual Ppt, Stn. X	Annual Ppt, 25-Stn. Avg.
19	1959	28.5	31.2
20	1960	24.1	23.1
21	1961	27	23.4
22	1962	20.6	23.1
23	1963	29.5	33.3
24	1964	28.5	26.4
25	1965	20.3	24.64
26	1966	22.35	28.2
27	1967	21.6	29
28	1968	22.9	23.4
29	1969	30.5	37.1
30	1970	18.3	23.6
31	1971	28.7	35.1
32	1972	20.8	28.4
33	1973	29.5	29.7
34	1974	31	38.6
35	1975	18.5	22.86
36	1976	18.8	26.4

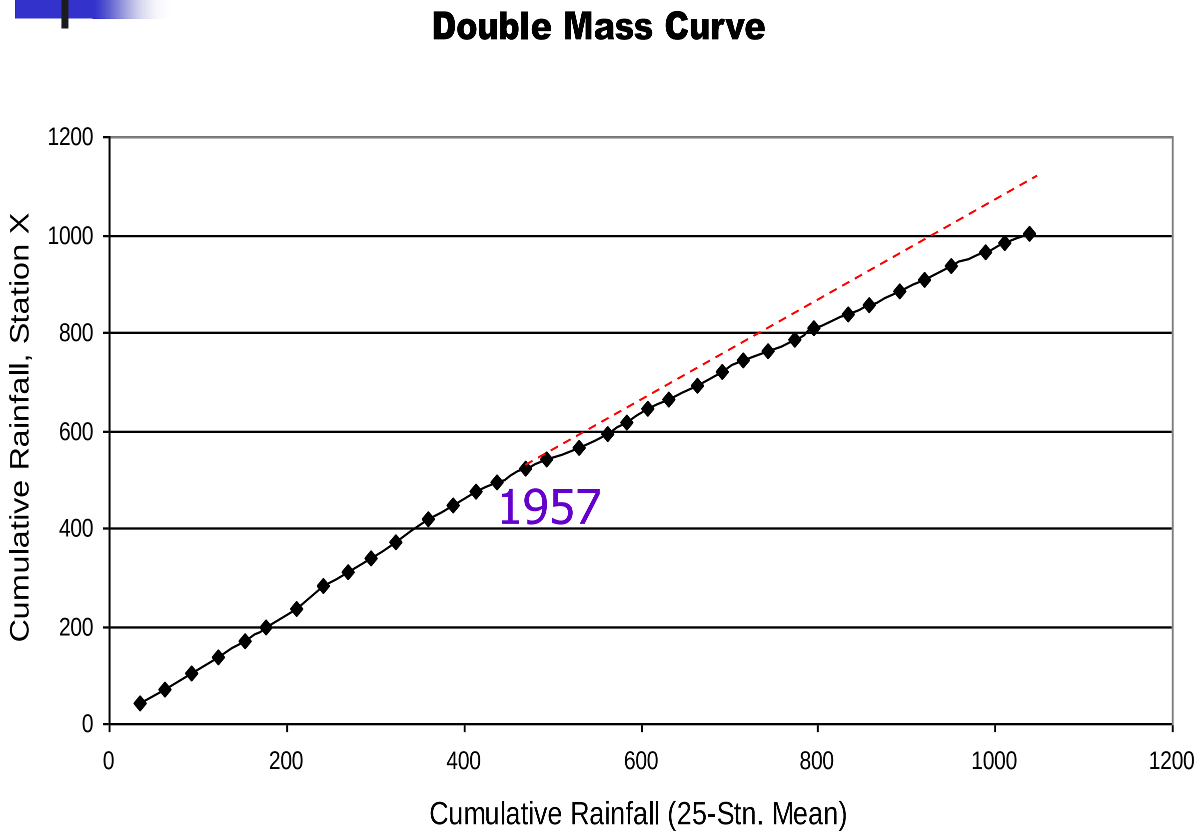
Double-mass Curve

- Compute the cumulative annual precipitation for station X as well as for 25 stations
- Draw a double-mass curve using these cumulative values (Fig.)

Double mass curve

Sl. No.	Year	Annual Ppt, Stn. X	Annual Ppt, 25-Stn. Ave.	Cum. Ppt, X	Cum. Ppt., 25 Stn
1	1941	41.4	34.3	41.4	34.3
2	1942	30.2	27.9	71.6	62.2
3	1943	30.7	31.5	102.3	93.7
4	1944	32.8	28.2	135.1	121.9
5	1945	32	31.2	167.1	153.1
6	1946	30.5	22.9	197.6	176
7	1947	38.9	35.1	236.5	211.1
8	1948	43.7	30.2	280.2	241.3
9	1949	32.3	27.43	312.5	268.73
10	1950	27.4	27.2	339.9	295.93
11	1951	32	28.2	371.9	324.13
12	1952	48.3	36.1	420.2	360.23
13	1953	28.4	28.4	448.6	388.63
14	1954	24.6	25.1	473.2	413.73
15	1955	21.8	23.6	495	437.33
16	1956	28.2	33.3	523.2	470.63
17	1957	17.3	23.4	540.5	494.03
18	1958	22.4	36.1	562.9	530.13
19	1959	28.5	31.2	591.4	561.33
20	1960	24.1	23.1	615.5	584.43
21	1961	27	23.4	642.5	607.83
22	1962	20.6	23.1	663.1	630.93
23	1963	29.5	33.3	692.6	664.23
24	1964	28.5	26.4	721.1	690.63
25	1965	20.3	24.64	741.4	715.27
26	1966	22.35	28.2	763.75	743.47
27	1967	21.6	29	785.35	772.47
28	1968	22.9	23.4	808.25	795.87
29	1969	30.5	37.1	838.75	832.97
30	1970	18.3	23.6	857.05	856.57
31	1971	28.7	35.1	885.75	891.67
32	1972	20.8	28.4	906.55	920.07
33	1973	29.5	29.7	936.05	949.77
34	1974	31	38.6	967.05	988.37
35	1975	18.5	22.86	985.55	1011.23
36	1976	18.8	26.4	1004.35	1037.63

Double mass Curve



Slope till 1957
1.127

Slope after 1957
0.863

*Slope obtained using **LINEST** in Excel

Double-mass Curve

- The difference in the two slopes is 0.264, which equals to (0.264/1.127)x100 = 20.8 %

- Since the difference is greater than 10 %, the data are inconsistent and require correction

- We can use $P_a = \frac{0.863}{1.127} P_0$ for correction to bring the entire record in tune with the current trend

Limitations of Double Mass Curve Method

- It is possible that an apparent change in slope is noticed because of a natural variation in the data which is not associated with changes in gage location, gage environment or observation procedure. In the case of doubt, a test of hypothesis should be performed by the Fisher distribution on two data sets (before and after the break) to check whether the data are homogeneous and the break is purely by chance.
- If fewer than 10 stations are grouped together to check the consistency of a station, the record of each station should be tested by double mass analysis for consistency by plotting it against the group of all other stations, and those records that are inconsistent should be eliminated from the group.
- This method should seldom be used in mountainous areas.
- It is also not suitable for adjusting daily or storm precipitation.

Presentation of rainfall data

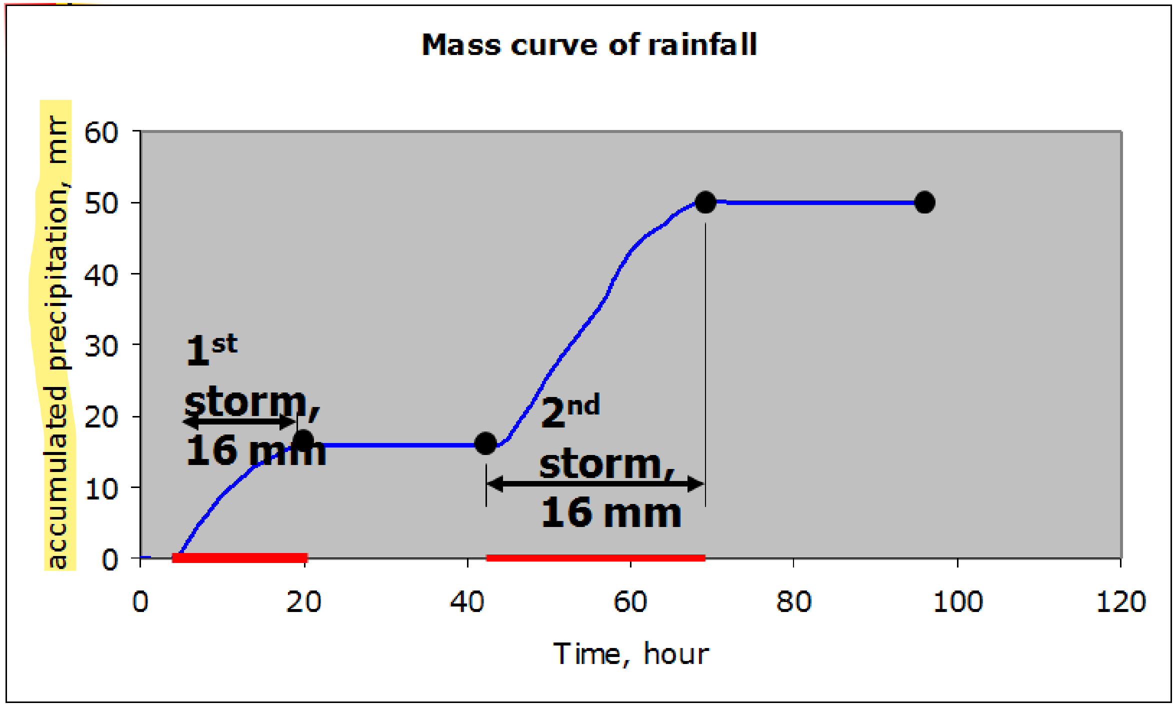
Commonly used methods are

- Mass curve of rainfall
- Hyetograph
- Depth-Area-Duration (DAD) curve

Mass Curve

Double Mass Curve is for checking inconsistency
Mass Curve is for presentation of rainfall data
Both have cummulative rainfall in common

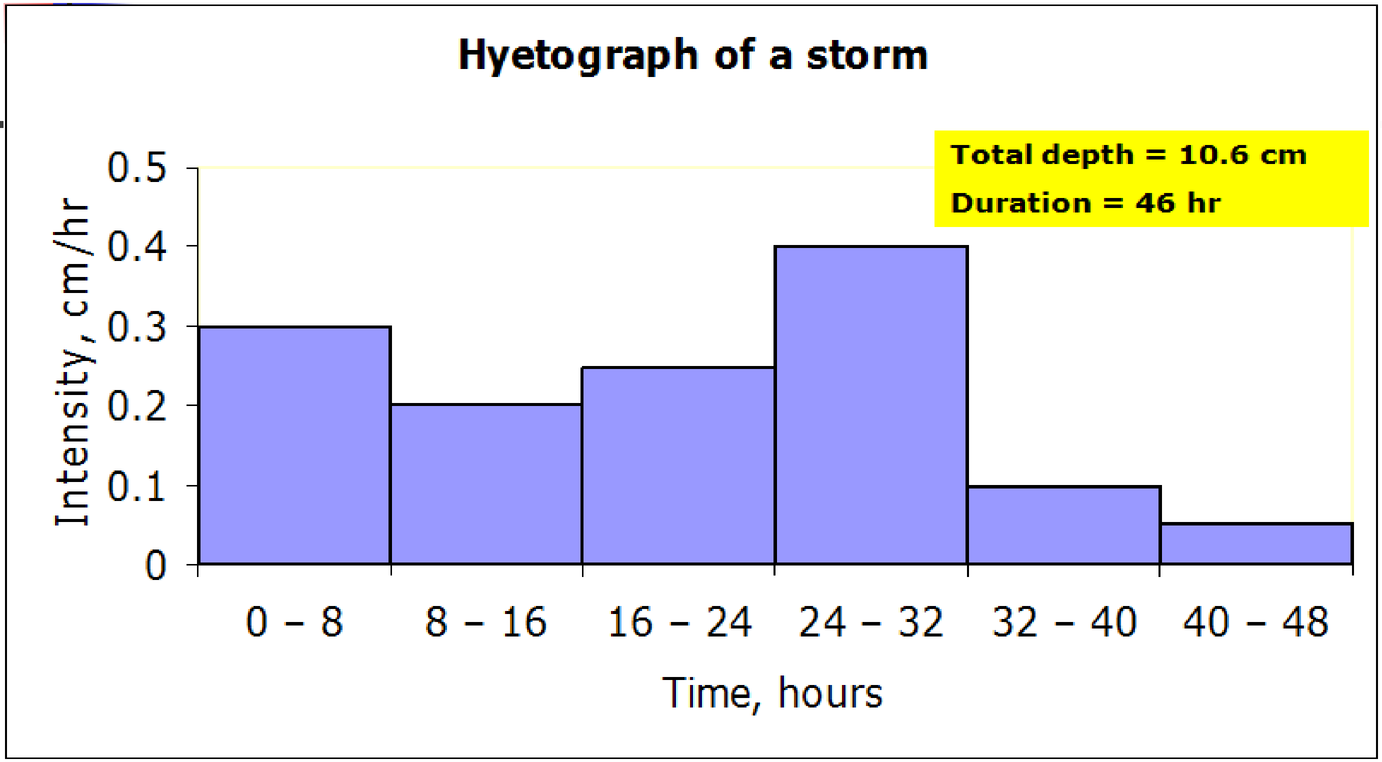
It is a plot of accumulated rainfall against time (records of weighing bucket type and siphon type)



It gives Information of,

- ✓ Duration and magnitude of the storm
- ✓ Intensities at various time interval (using slope of the curve)

Hyetograph



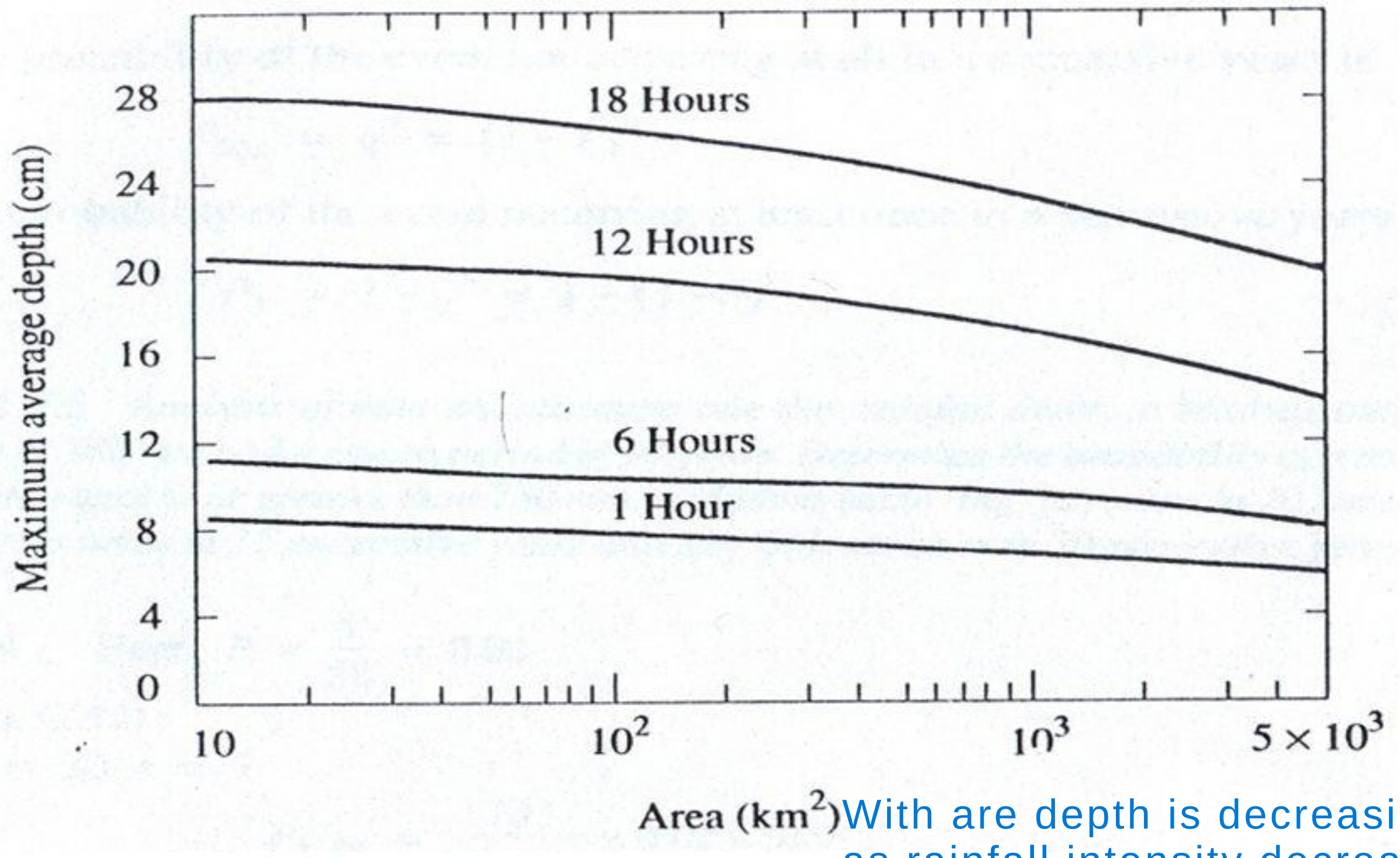
✓It is a plot of rainfall intensity against time interval

✓It is derived form the mass curve & is usually represented as a bar chart

✓It is important in the development of a design storm to predict extreme flood

DEPTH-AREA—DURATION RELATIONSHIPS

Maximum Depth-Area-Duration Curves



With are depth is decreasing as rainfall intensity decreases with distance.

Rainfall Intensity and Duration

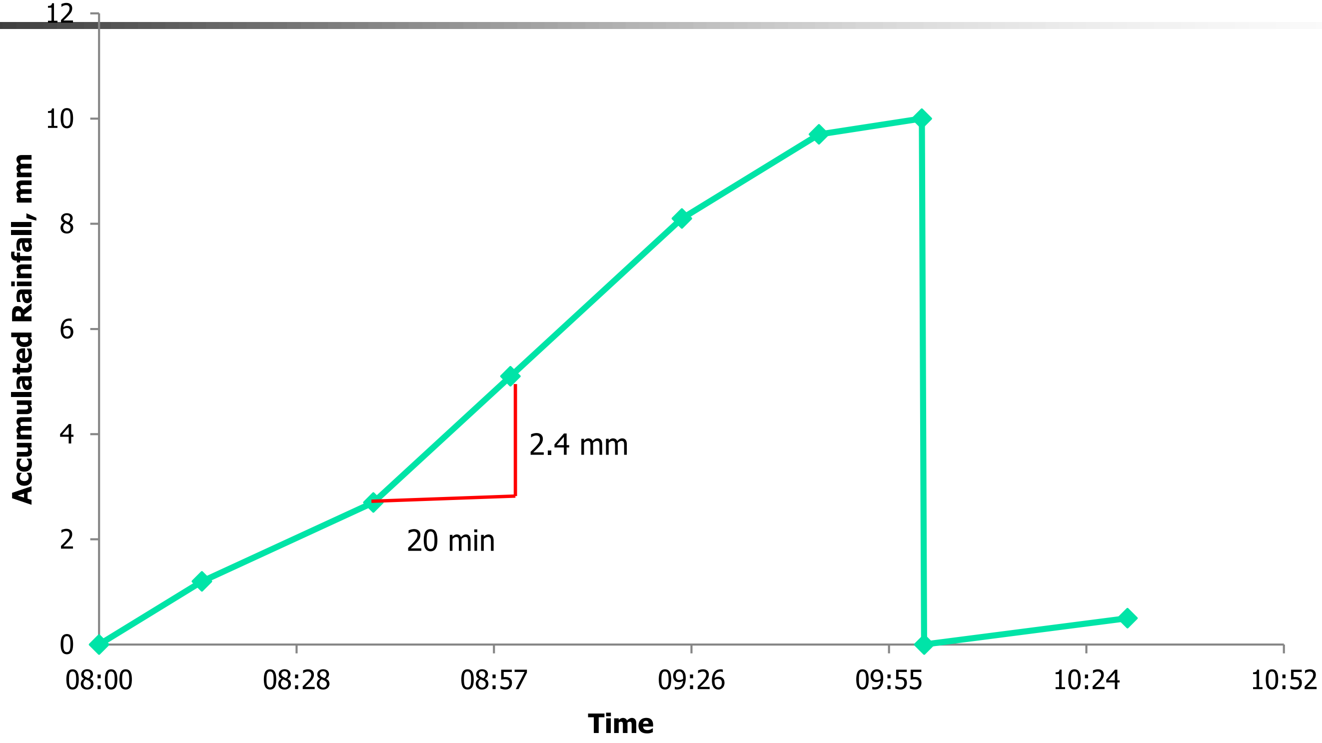
- One of the most important rainfall characteristics is rainfall intensity expressed as mm/hr
- Very intense storms are not necessarily more frequent in areas having a high total annual rainfall.
- High intensity storms generally last for fairly short periods and cover small areas.
- Storms covering large areas are seldom of high intensity and may last for several days.
- The infrequent combination of relatively high intensity and long duration gives large total amounts of rainfall. These storms do much erosion damage and may cause devastating flood.

Cont..

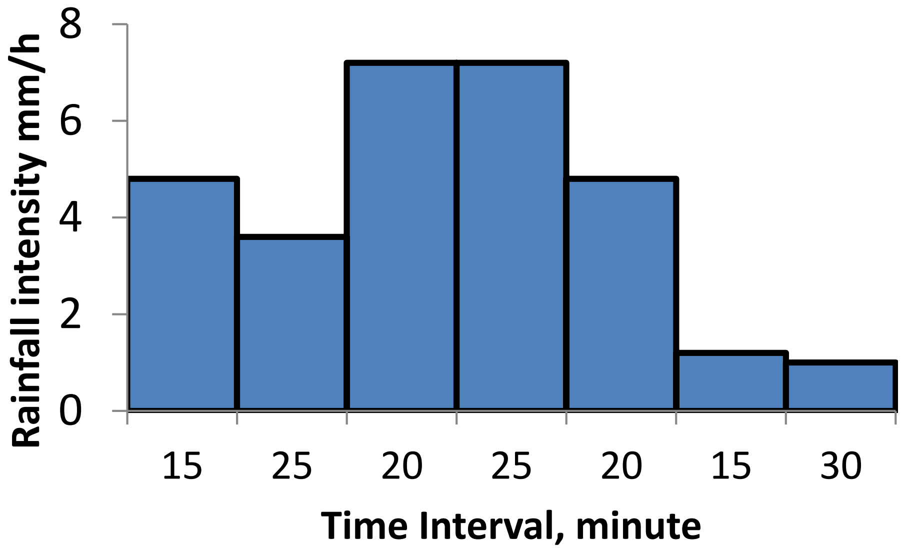
- A typical recording chart from a Siphon type raingage is shown.
- The line on the chart is cumulative rainfall curve, the slope of the line being proportional to the intensity of the rainfall.
- The peak is the point of siphoning of the water.
- The time and amount of rain should be selected from representative points when the rainfall rate changes so that the data will represent the curve on the chart. These points are tabulated and intensity is calculated.

Time	Time interval (min)	Time Since beginning (min.)	Rainfall during the interval (mm)	Cumulative rainfall (mm)	Rainfall intensity (mm/hr)
8			0	-	-
8.15	15	15	1.2	1.2	4.8
8.4	25	40	1.5	2.7	3.6
9	20	60	2.4	5.1	7.2
9.25	25	85	3	8.1	7.2
9.45	20	105	1.6	9.7	4.8
10	15	120	0.3	10	1.2
10.3	30	150	0.5	10.5	1

A plot between time and cumulative rainfall is called mass curve, whereas a plot between time and rainfall intensity is called rainfall hyetograph



cumulative rainfall vs. time



Rainfall hyetograph