UNIT –II

PRECIPITATION

CONTENTS

WHAT IS PRECIPITATION?

The term precipitation denotes all forms of water that reach the Earth from the atmosphere.

For precipitation to form:

i) The atmosphere must have moisture
ii) There must be sufficient nuclei present to aid condensation
iii) Weather conditions must be good for condensation of water vapors to take place.
iv) The products of condensation must reach the earth.

FORMS OF PRECIPIATTION

- **Rain:** Water drops that have a diameter of at least 0.5 mm. It can be classified based on intensity as:

Light rain	up to 2.5 mm/h
Moderate rain	2.5 mm/h to 7.5 mm/h
Heavy rain	> 7.5 mm/h

- **Snow:** Precipitation in the form of ice crystals which usually combine to form flakes, with an average density of 0.1 g/cm^3.
- **Drizzle:** Rain-droplets of size less than 0.5 mm and rain intensity of less than 1mm/h is known as drizzle.
- **Glaze:** When rain or drizzle touches ground at 0^oC, glaze or freezing rain is formed.
- **Sleet:** It is frozen raindrops of transparent grains which form when rain falls through air at subfreezing temperature.
- **Hail:** It is a showery precipitation in the form of irregular pellets or lumps of ice of size more than 8 mm.

TYPES OF PRECIPITATION

i) Thermal convention/ conventional precipitation

- It is in the form of local whirling thunderstorms
- It is typical of the tropics.
- When accompanied by destructive winds, it is often called tornados.

ii) Frontal precipitation

- It is the conflict between two air masses due to the contrasting temperatures and densities clash with each other.
- Condensation and precipitation occurs at the surface of contact known as front or frontal surface.
- If a cold air mass drives out a warm air mass, it is called cold front.
- If a warm air mass replaces the retreating cold air mass, it is called a warm front.

iii) Orographic precipitation

- It is the mechanical lifting of moist air over mountain barriers.
- causes heavy precipitation on the windward side.

iv) Cyclonic precipitation

- It is due to lifting of moist air converging into a low pressure belt.
- The wind blows spirally inward counterclockwise in the northern hemisphere and clockwise in the southern hemisphere.
- There are mainly 2 types of cyclones : tropical / hurricane/ typhoon and extra-tropical cyclones.

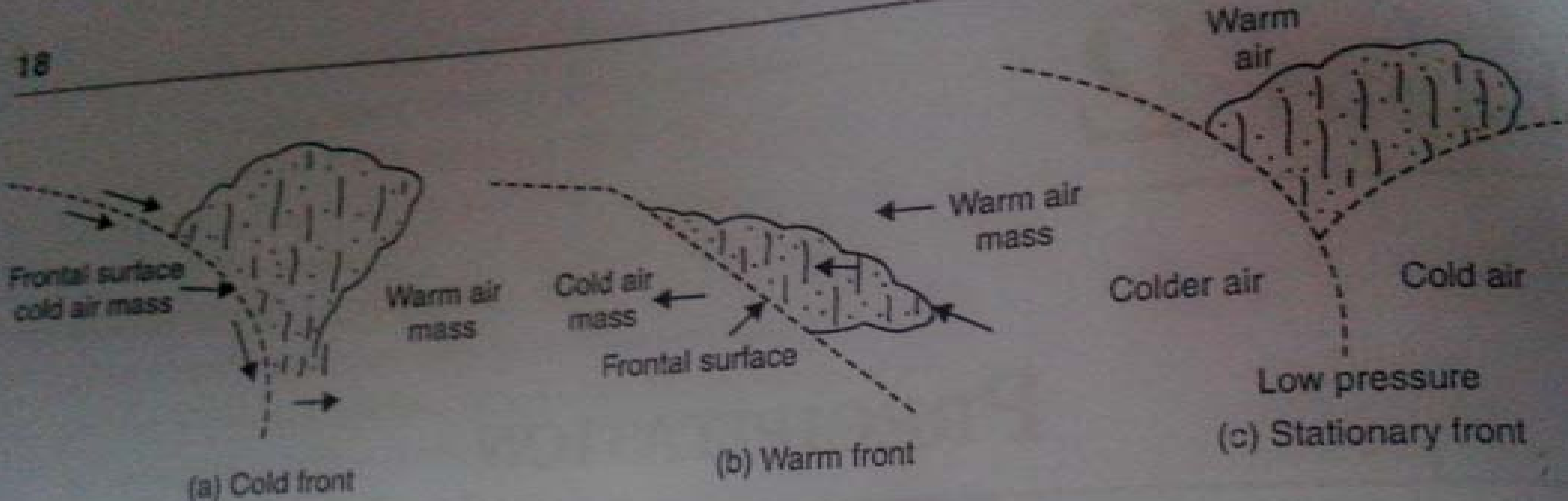


Fig. 2.1 Frontal precipitation

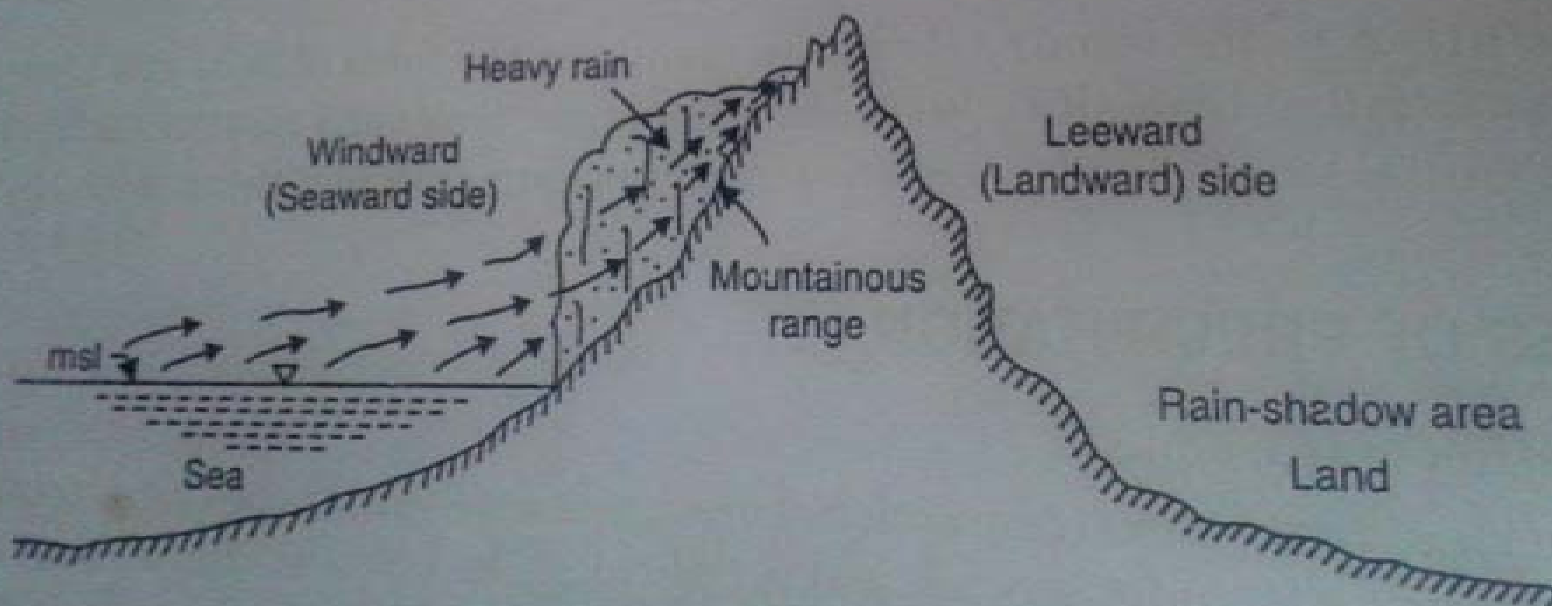


Fig. 2.2 Orographic precipitation

CHARACTERISTICS OF PRECIPITATION IN INDIA

1) South-west monsoon (June-Sept)

- Also known as summer monsoon.
- Principal rainy season of India when over 75% of the annual rainfall is received.
- It originates in Indian ocean and appears in the southern part of Kerala by the end of May.
- The onset is accompanied by high south-westerly winds at speed of 30-70 kmph and low pressure regions in advancing edge.
- It is not a period of continuous rainfall.
- Weather is generally cloudy with frequent spells of rainfall.

2) Post-Monsoon (Oct-Nov)

- As the south-west monsoon retreats low pressure areas form in the Bay of Bengal.
- North-easterly flow of air that picks up moisture in the Bay of Bengal is formed.
- This air mass strikes the east coast of India (Tamil Nadu) and causes rainfall.
- Also in November, severe tropical cyclones form in the Bay of Bengal and Arabian sea.

3) Winter Season (Dec-Feb)

- The western disturbances of extra tropical origin travel eastwards across Afghanistan & Pakistan.
- They cause moderate to heavy rainfall and snowfall in the Himalayas and J&K.
- Some light rainfall occurs in northern plains.
- Low pressure areas in the Bay of Bengal are formed.

4) Summer (Pre-Monsoon) (March-May)

- Very light rainfall in India in this season.
- Convective cells cause some thunderstorms mainly in Kerala, W.B. and Assam.
- Some cyclone activity, dominantly on east coast, also occurs.

MEASUREMENT OF PRECIPITATION

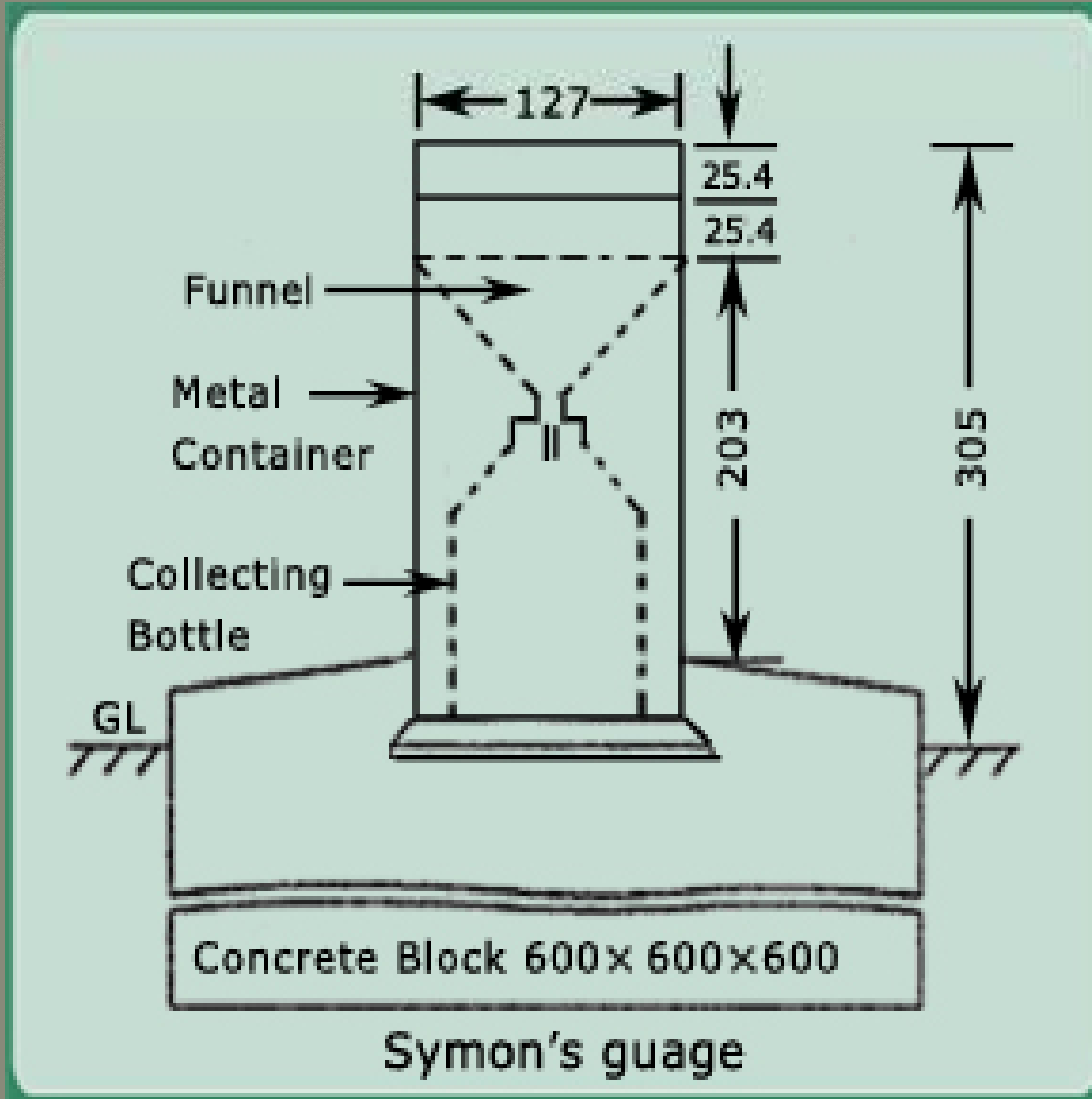
- It is expressed in terms of the depth to which rainfall water would stand on an area if all the rain were collected on it.
- 1cm of rainfall over a catchment area of 1 km^2 represents a volume of water= 10^4 m^3.
- It is collected and measured in a Rain gauge/ pluvimeter/ ombrometer/ hyetometer.
- Types of rain gauges:

1) **Non-Recording**
   - ✓Symon's gauge
2) **Recording**
   - ✓Tipping-bucket type
   - ✓Weighing-bucket type
   - ✓Natural-syphon type

NON-RECORDING RAIN GAUGE

- It is the Symon's rain gauge.
- It consists of a funnel with a circular rim of 2.7 cm dia. And a glass bottle as a receiver.
- The cylindrical metal casing is fixed vertically to the masonry foundation with the level rim 30.5cm above ground surface.
- The funnel and receiving vessel are housed in a metallic container.
- Water contained in the receiving vessel is measured by a suitably graduated measuring glass, with an accuracy up to 0.1 mm.
- When full it can measure 1.25 cm of rain.
- The rainfall is measured everyday at 8:30 hours IST.
- To protect the gauge a barbed wire fence may be erected around it.

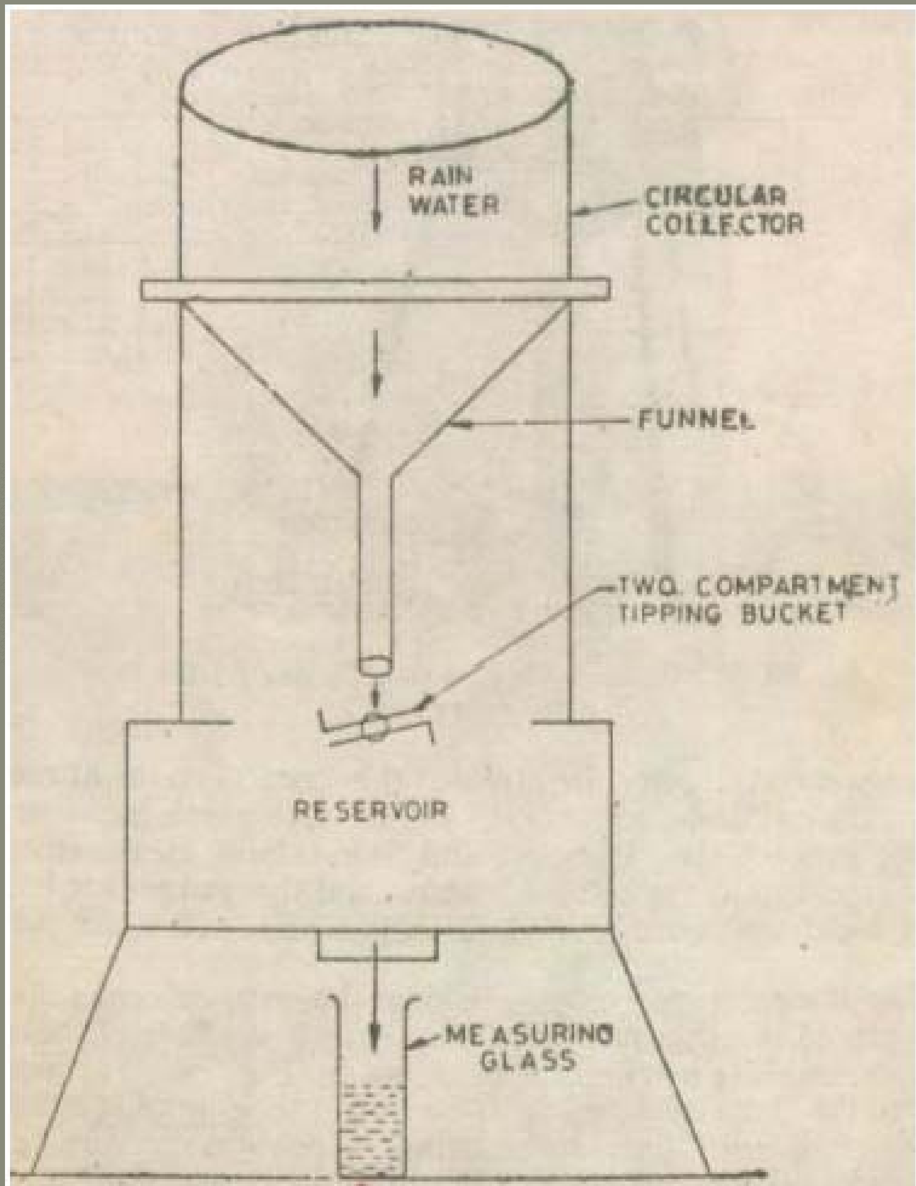
NON-RECORDING RAIN GAUGE



RECORDING RAIN GAUGE

a) Tipping-bucket type

- 30.5 cm size rain gauge adopted for use by US Weather Bureau.
- Catch from the funnel falls onto one pair of small buckets.
- Water from the tipped bucket is collected in a storage can.
- Tipping actuates an electrically driven pen to trace a record on the clock-work driven chart.
- Water collected in storage can is measured at regular intervals to provide total rainfall.
- It gives data on the intensity of rainfall.
- It is ideally suited for digitalizing of the output signal.

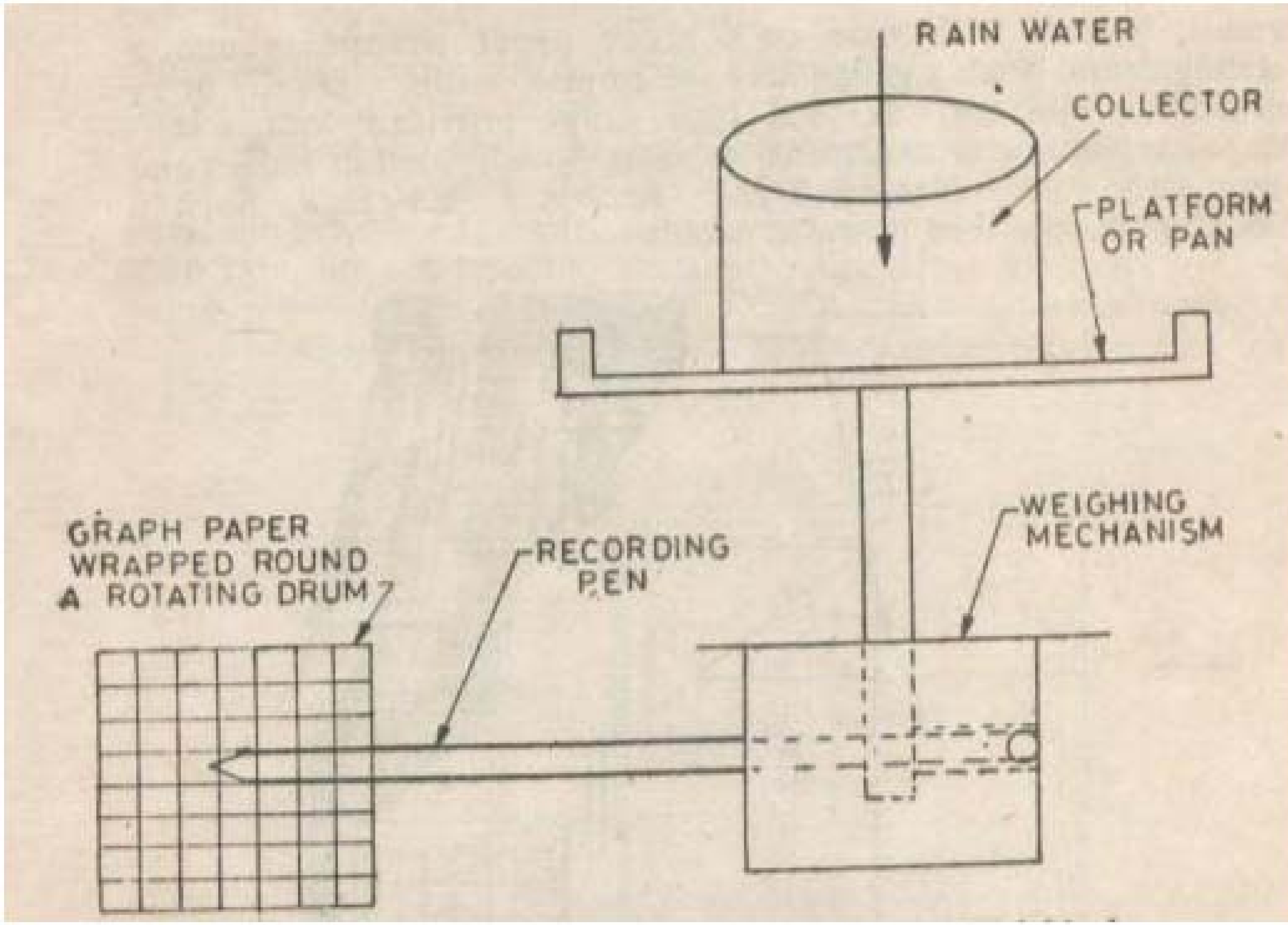


Tipping-bucket rain gauge

b) Weighing-bucket type

- The catch from the funnel empties into a bucket mounted on weighing scale.
- Weight of the bucket and its contents are recorded on a clock-work driven chart.
- Clock-work mechanism has the capacity to run for as long as one week.
- It gives a plot of the accumulated rainfall against the elapsed time (mass curve of rainfall).

WEIGHING- BUCKET RAIN GAUGE



c) Natural-syphon type

- Also known as float-type gauge.
- Rainfall collected by a funnel shaped collector is led into a float chamber causing a float to rise.
- As the float rises, a pen attached to the float records the elevation of the float on a rotating drum driven by clock-work mechanism.
- A syphon arrangement empties the float chamber when the float has reached a preset maximum level.
- It is adopted as the standard recording type rain gauge in India.
- Its details are described in IS: 5235- 1969.

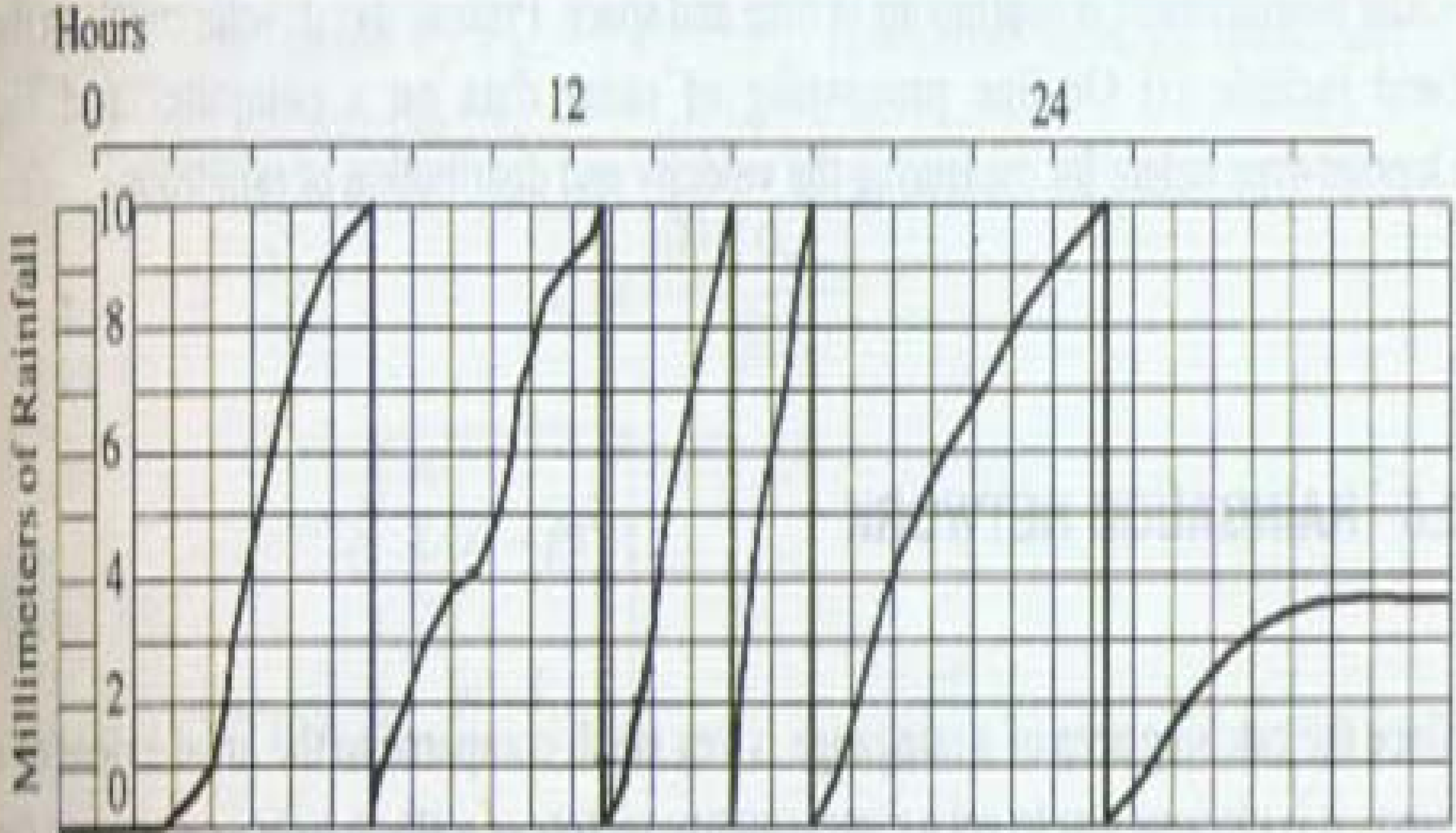


Fig. 2.6 Recording from a natural syphon–type gauge (schematic)

RAIN GAUGE NETWORK

Rainfall data is the most important and fundamental data required for all hydrological investigations.

Catch area of a rain gauge is very small compared to the aerial extent of a storm. Hence to get a representative picture of a storm over the entire drainage basin, the number of rain gauges should be as large as possible (drainage area/rain gauge should be small).

The rain gauge network should consist of adequate number of rain gauges evenly distributed all over the drainage basin.

However the number of rain gauges is many a time restricted by economic considerations as well as topography, accessibility etc.

Desired density would also depend on the purpose.

Aim: Establish a rain gauge network with an optimum density of rain gauges from which a reasonably accurate information about storms can be obtained.

BIS recommendations on rain gauge density

According to IS: 4987-1968

In plains – 1 station for every 520sq.km.

In regions with average elevation 1000m – 1 station per 260-390 sq.km.

In hilly areas with heavy rainfall – 1 station for every 130 sq.km.

Adequacy of Rain gauge Stations

$$C_V = \frac{100\ \sigma_{m-1}}{\overline{P}}$$

$$\sigma_{m-1} = \sqrt{\left[\frac{\sum_{1}^{m} (P_i - \overline{P})^2}{m-1}\right]}$$

$$\overline{P} = \frac{1}{m}\left(\sum_{1}^{m} P_i\right) = mean - precipitat\ \ ion$$

P_i = precipitation magnitude in the i^{th} station.

σ = standard deviation.

Adequacy of Rain gauge Stations

$$N = \left(\frac{C_v}{\varepsilon}\right)^2$$

where *N* = optimal number of stations,

ε = allowable degree of error in the estimate of

the mean rainfall, and

***Cv* = coefficient of variation of the rainfall values**

at the existing *m* stations (in per cent)

EXAMPLE

A catchment has 5 rain gauge stations. In a year,
the annual rainfall recorded by the gauges are as follows:-

Station	A	B	C	D	E
Rainfall (mm)	82.6	102.9	180.3	98.8	136.7

For a 10% error in the estimation of the mean rainfall,
calculate the optimum number of stations (N) in the catchment

Solution:- from first data

$$m = 5$$

$$\overline{P} = 118.6mm$$

$$\sigma_{m-1} = 35.04mm$$

$$\varepsilon = 10\%$$

$$C_v = \frac{100 * 35.04}{118.6} = 29.54\%$$

$$N = \left(\frac{29.54}{10}\right)^2 = 8.7, say 9$$

ANALYSIS OF RAINFALL DATA

Before using rainfall records at a station for any analysis, the data has to be checked for

- Continuity
- Consistency

Missing rainfall data can be estimated using the rainfall data at neighbouring stations.

CAUSES OF MISSING DATA

It is common to find in actual practice that precipitation data may be missing from the set of records. There are several reasons why precipitation data may be missing from the database. Some of them are listed below.

- Malfunctioning of precipitation gage and/or related equipment
- Effect of natural hazards (floods, landslides, hurricanes, etc.)
- Sabotage (terrorism)
- Human related problems (temporary absence of people in charge of reading gages, mistakes in handling data, etc.)
- Others

Estimation of Missing Rainfall Data

- Required to find the missing annual precipitation P_x at station X (not included in the m neighbouring stations), given the annual precipitation values at m neighbouring rain gauge stations p_1, p_2, p_3…… p_m. Let the normal annual precipitation at the m+1 stations be n_1, n_2, n_3………
- If the normal precipitations at the different stations are within 10% of the normal annual precipitation at station X, then

$$P_x = \frac{P_1 + P_2 + P_3 + \dots\dots\dots + P_m}{m}$$

If the normal precipitation at any of the m stations vary by more than 10% from the normal annual precipitation at station X, then is estimated by the normal ratio method as

$$P_x = \frac{N_x}{m}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \dots\dots\dots + \frac{P_m}{N_m}\right]$$

PRESENTATION OF RAINFALL DATA

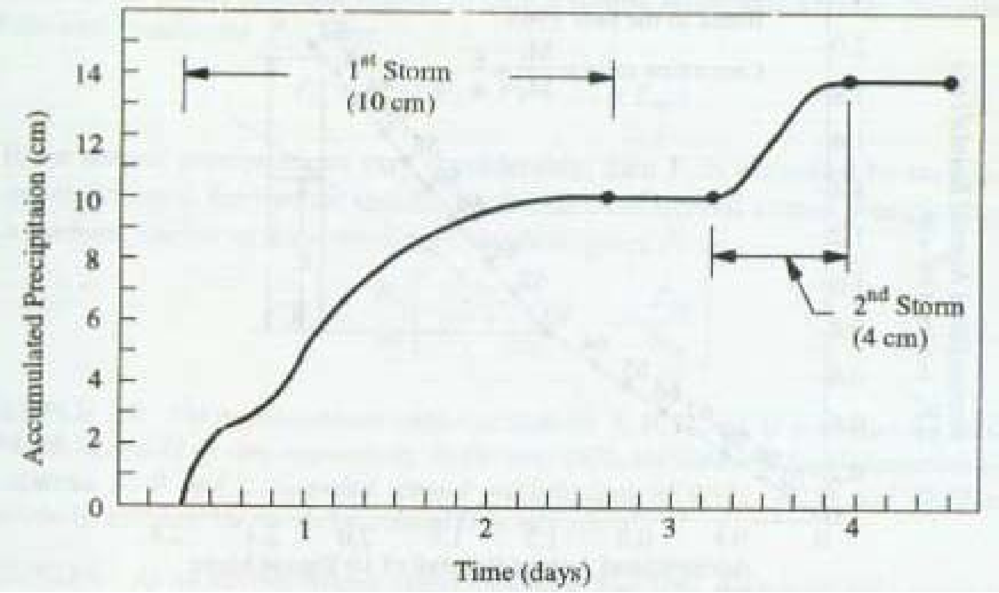
1) Mass Curve of Rainfall

• It is a plot of accumulated precipitation against time, plotted in chronological order.

• Records of float type, weighing bucket type etc rain gauges are of this form.

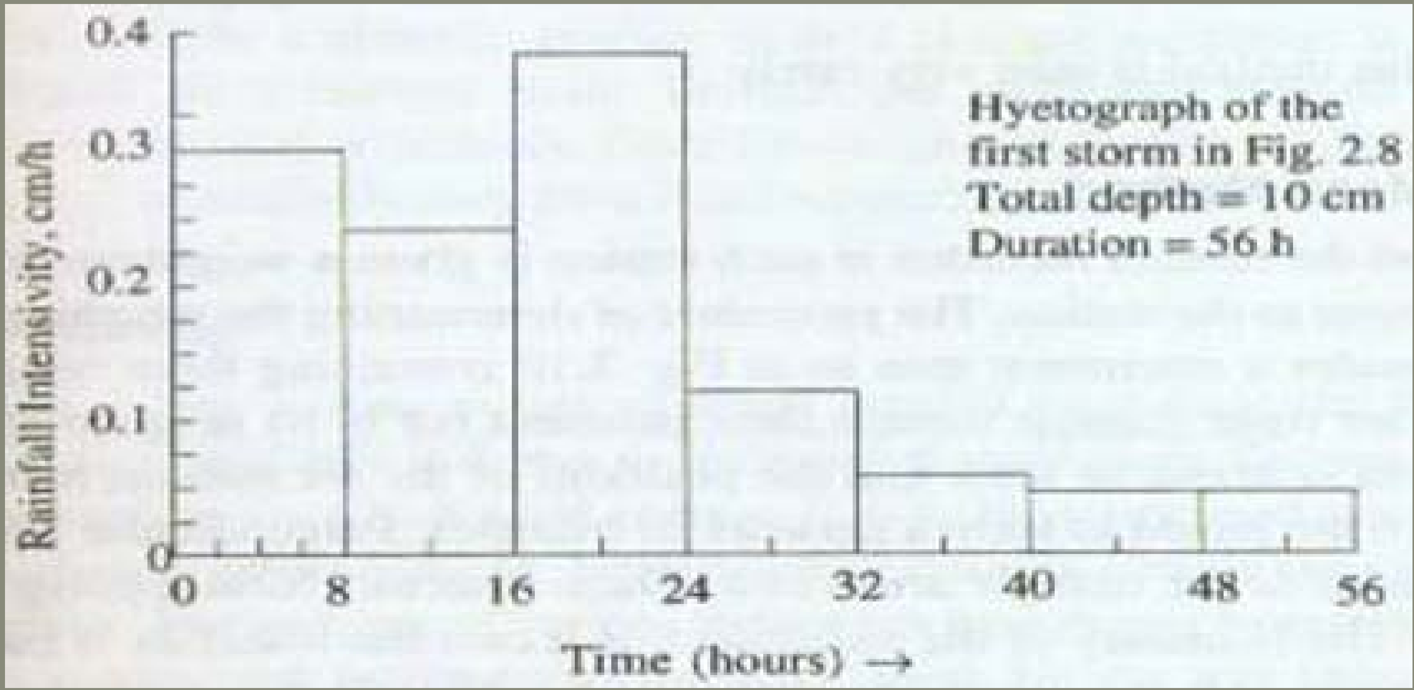
• It gives information on duration and magnitude of a storm. Intensity at various time intervals in a storm = slope of the curve.

• It can be prepared for non-recording rain gauges also if the approximate start and end of a storm are known.



2) Hyetograph

- It is a plot of rainfall intensity against time interval.
- Time interval depends on the purpose (urban drainage problems – small durations, flood flow computations from large catchments~ 6h).
- It can be derived from the mass curve of rainfall.
- It is represented as a bar chart.
- It is useful in developing design storms to predict extreme floods.
- Area under a hyetograph = total precipitation received in that time period.



3) Point rainfall

- Also known as station rainfall.
- It refers to the rainfall data of a station.
- Depending upon the need the data can be listed as daily, weekly, monthly, seasonal or annual values for various periods.
- Graphically these data are represented as plots of magnitude vs chronological time in the form of a bar diagram.
- It has become obsolete these days.

4) Moving average

- It is technique for smoothening out the high frequency fluctuations of a time series.
- The basic principle is that a window of time range m years is selected.
- Larger the size of range m , the greater is the smoothening.

MEAN PRECIPITATION OVER AN AREA

Rain gauge – does point sampling of the areal distribution of a storm
Hydrological Analysis – requires information on rainfall over an area, say, over a catchment

Methods used to convert point rainfall values at different rain gauge stations into an average value over a catchment include:

- **Arithmetical Mean Method**
- **Thiessen Polygon Method**
- **Isohyetal Method**

Arithmetic Mean Method

- When the area is physically and climatically homogenous and the required accuracy is small, the average rainfall ($\overline{P}$) for a basin can be obtained as the arithmetic mean of the P_i values recorded at various stations.
- Applicable rarely for practical purpose

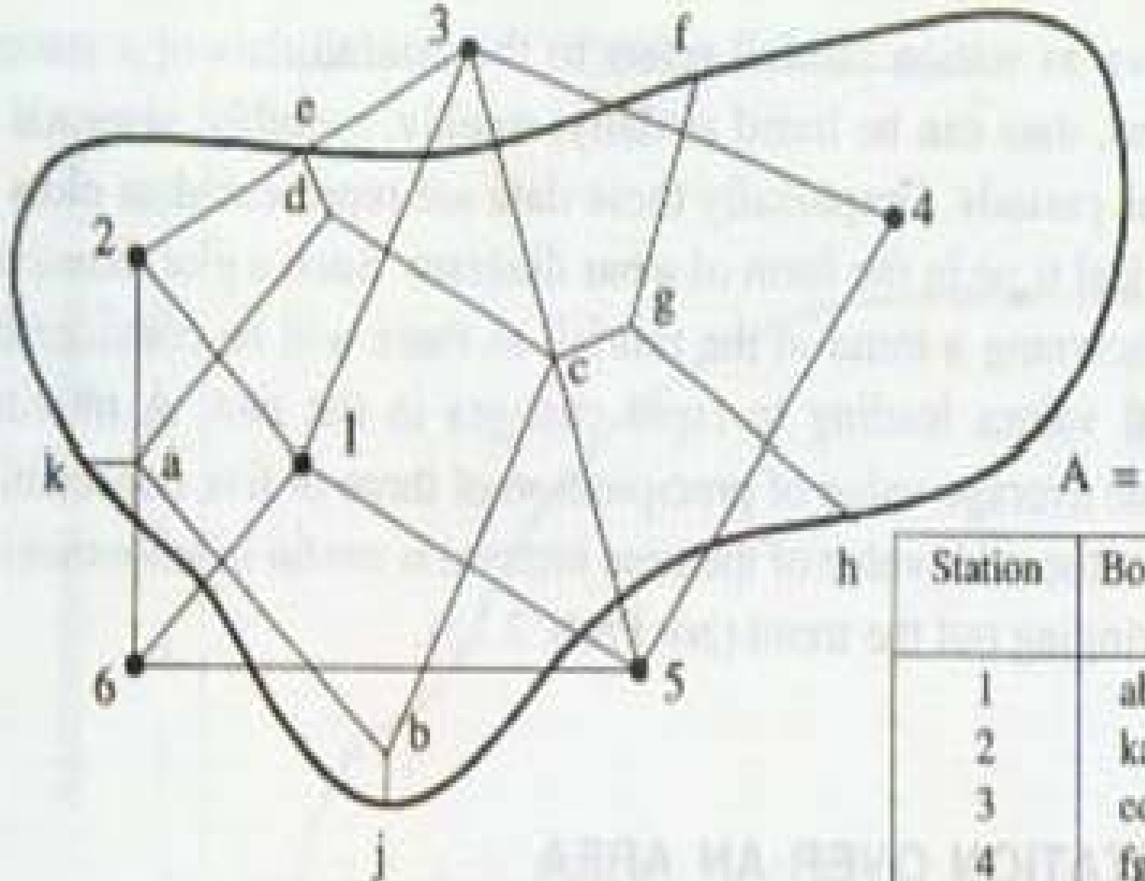
$$\overline{P} = \frac{P_1 + P_2 + \ldots.. + P_i + \ldots..P_n}{N} = \frac{1}{N}\sum_{i=1}^{N} P_i$$

$\overline{P}$ = average precipitation over the catchment area (for a given time period)

$P_1, P_2, P_3, \ldots\ldots\ldots\ldots, P_n$ are the precipitations in a given time period at stations $1, 2, 3, \ldots.., n$ respectively within the catchment

Method of Thiessen polygons

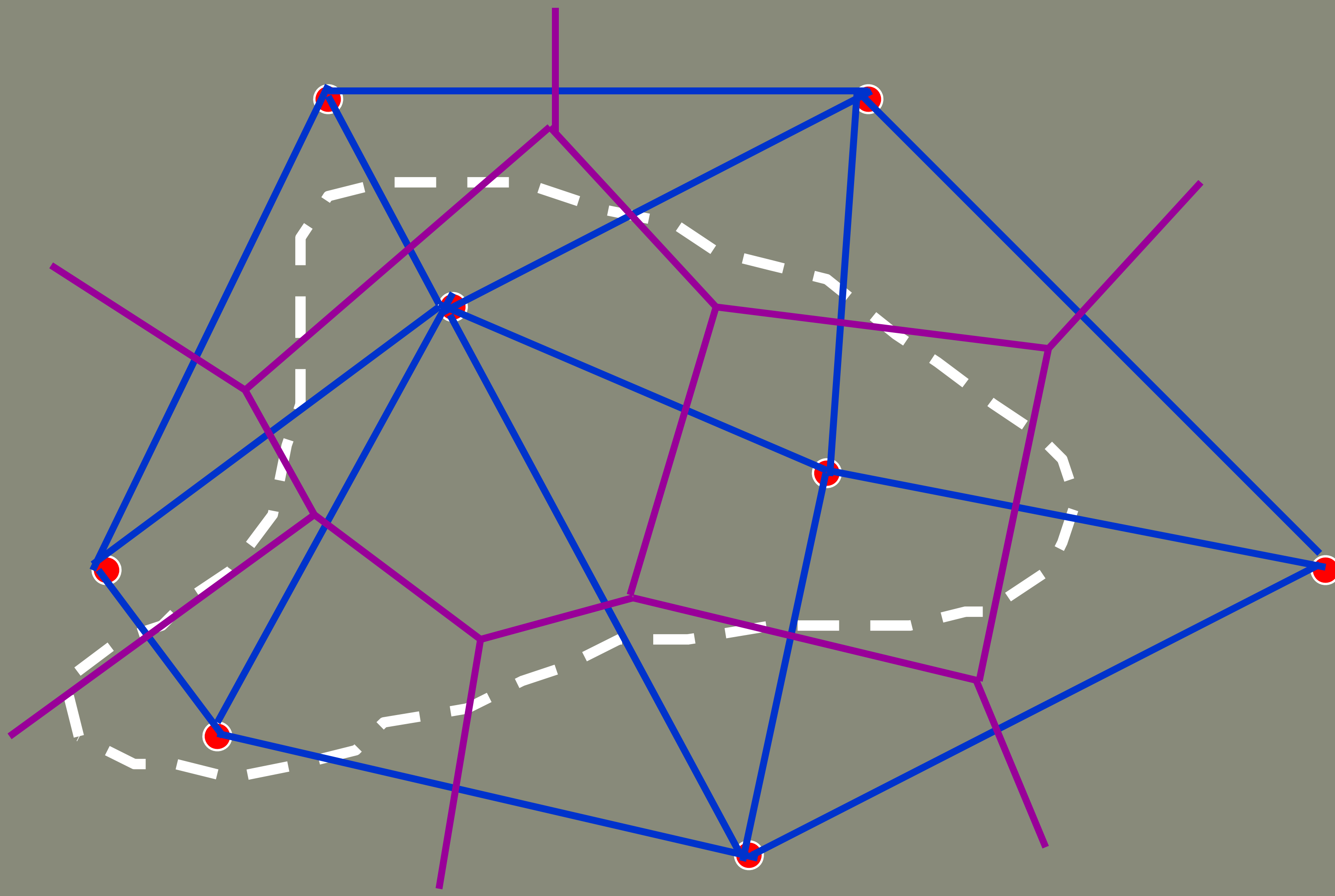
- The method of Thiessen polygons consists of attributing to each station an influence zone in which it is considered that the rainfall is equivalent to that of the station.
- The influence zones are represented by convex polygons.
- These polygons are obtained using the mediators of the segments which link each station to the closest neighbouring stations .
- This method is considered superior to the arithmetical averaging method since some weightage is assigned to each rain gauge station.
- Even rain gauge stations located outside the catchment are used in computing mean precipitation



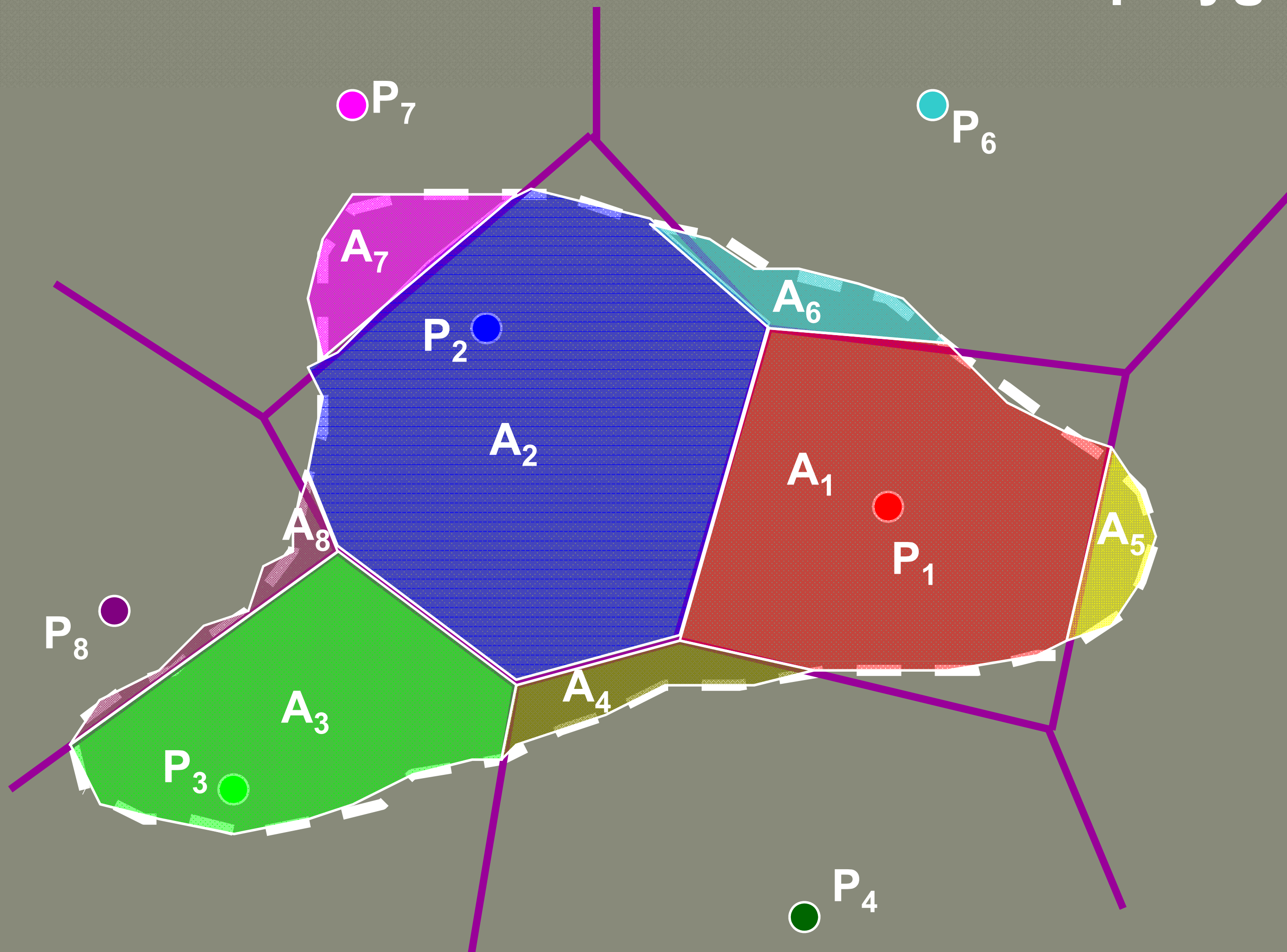
A = total catchment area

Station	Bounded by	Area	Weightage
1	abcd	A_1	A_1/A
2	kade	A_2	A_2/A
3	edcgf	A_3	A_3/A
4	fgh	A_4	A_4/A
5	hgcbj	A_5	A_5/A
6	jbak	A_6	A_6/A

Thiessen polygons ……….



Thiessen polygons ....



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

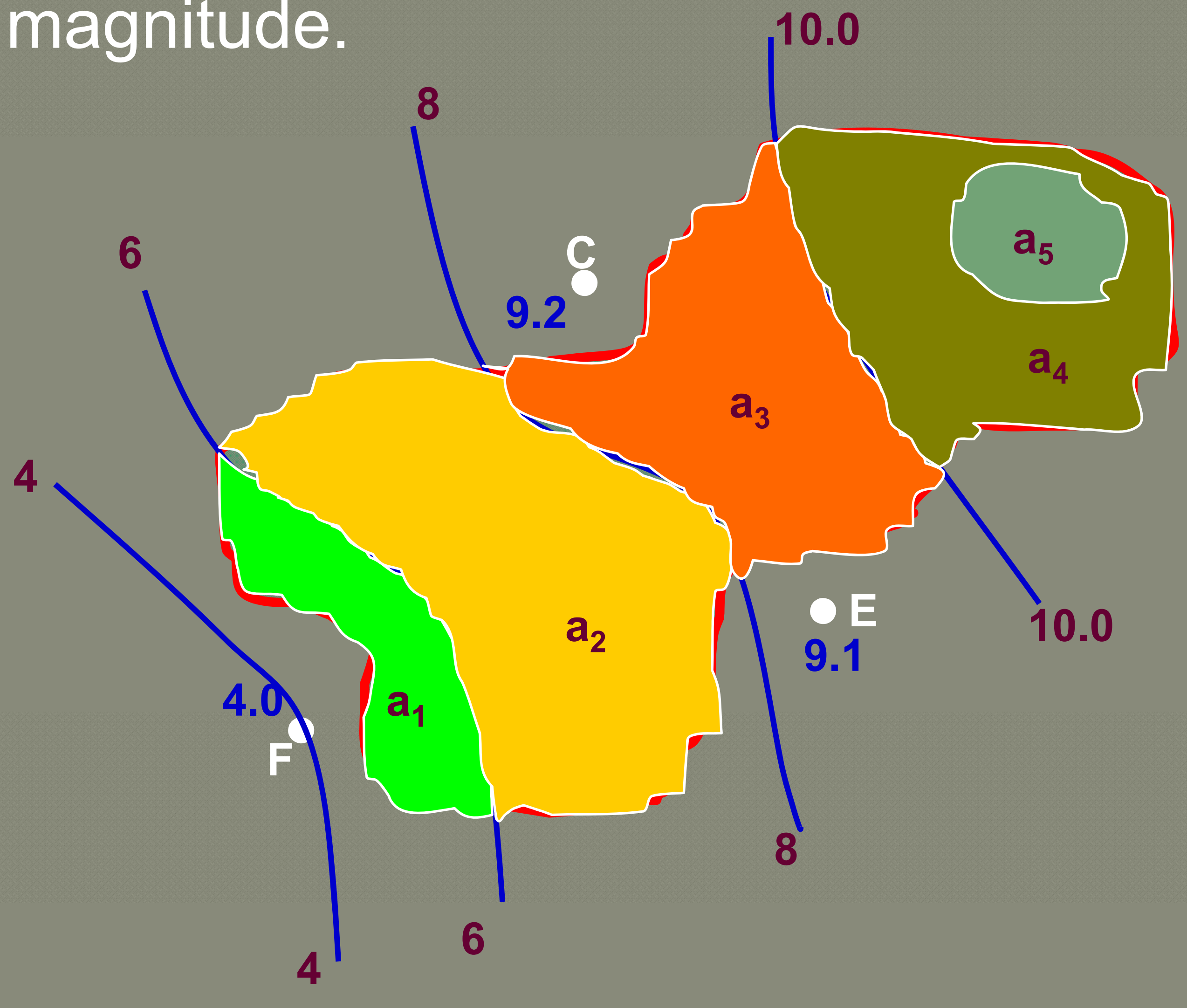
Generally for M station

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

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.



- The recorded rainfall values for which areal average is to determined are marked at the respective stations
- Neighbouring stations outside the catchment are also considered
- Taking point rainfall values as the guide, isohyets of different rainfall values are drawn (similar to drawing contours based on spot levels).

The area between adjacent isohyets is measured using a planimeter.

- If isohyets go out of the catchment, the catchment boundary is used as the bounding line. It is assumed that the average value of rainfall indicated by two isohyets acts over the inter isohyetal area
- This method is considered superior to the previous methods when the number of rain gauge stations are large

Isohyetal Method

- P_1, P_2, P_3, …. , P_n – the values of the isohytes
- a_1, a_2, a_3, …., 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.

DEPTH AREA DURATION RELATIONSHIP

- The areal distribution characteristics of a storm of given duration is reflected in its depth-area relationship.
- A Depth-Area-Duration (DAD) analysis is carried out based on records of several storms on an area and, the maximum areal precipitation for different durations corresponding to different areal extents.
- The result of a DAD analysis is the DAD curves.

Depth-Area Relation: For a rainfall of a given duration, the avg. depth decreases with the area in an exponential fashion.

$$\overline{P} = P_o \exp\left(-kA^n\right)$$

where

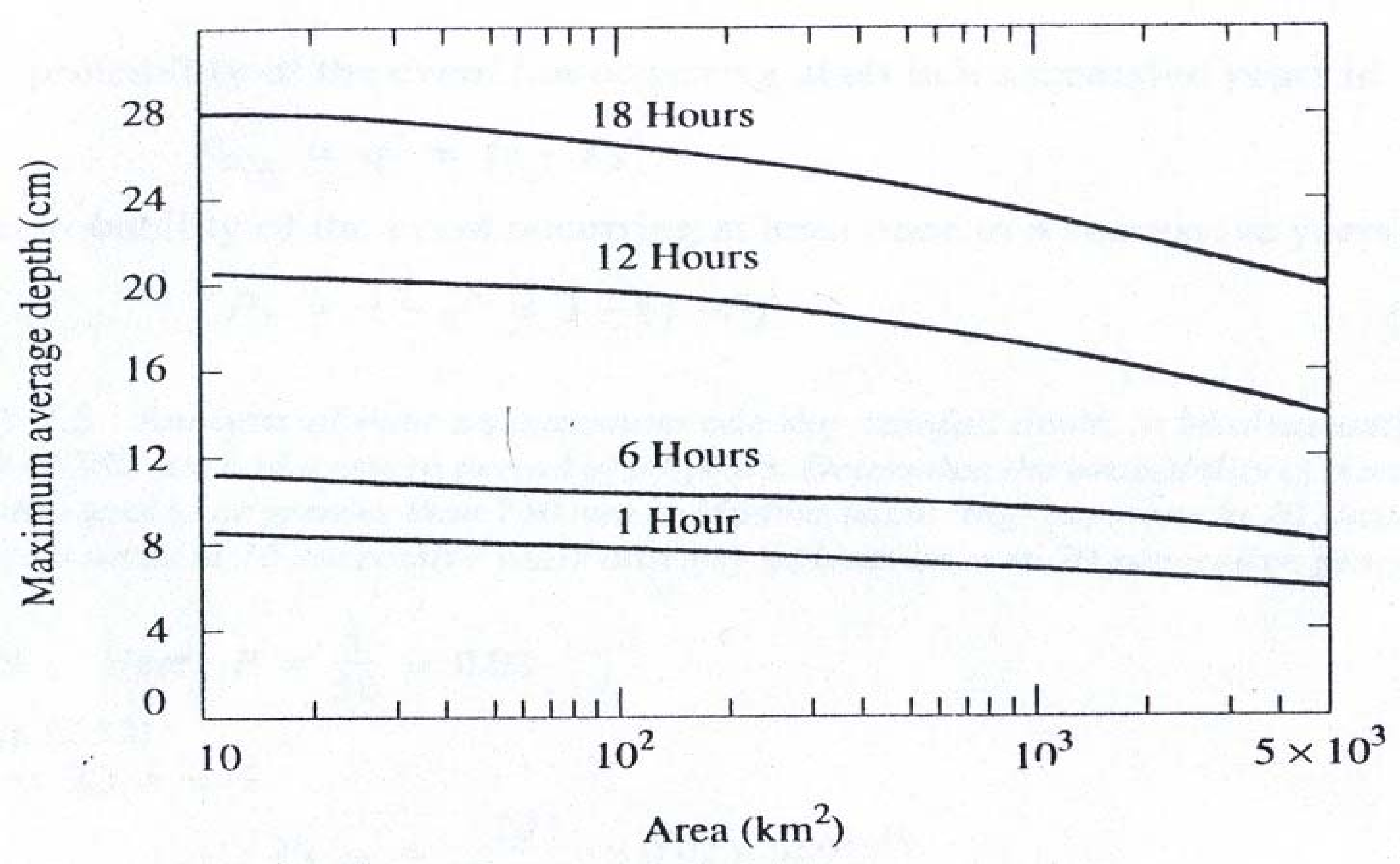
$\overline{P}$ = average depth in (cm.) over an area (*A in* km^2),

P_o = highest amount of rainfall in (cm.) at the storm center , and

K and n are constants for a given region

DEPTH-AREA—DURATION RELATIONSHIPS

Maximum Depth-Area-Duration Curves



FREQUENCY OF POINT RAINFALL

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

If the probability of an event occurring is *P,* the probability of the event *not occurring* in a given year is q = (1 - P)

$$P_{r,n} = {}^{n}C_{r} P^{r} q^{n-r} = \frac{n!}{(n-r)!\,r!} P^{r} q^{n-r}$$

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

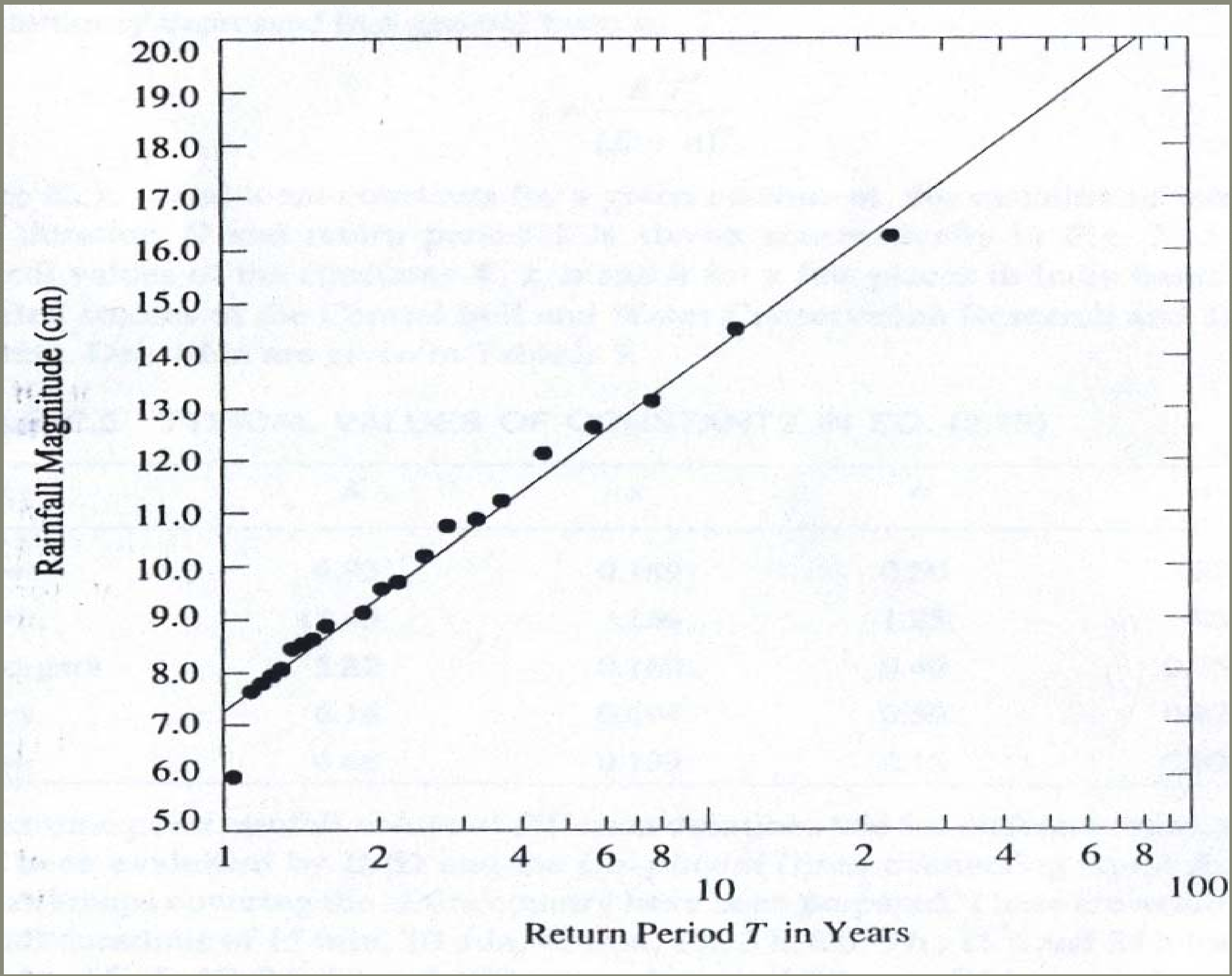
FREQUENCY OF POINT RAINFALL

Plotting Position

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

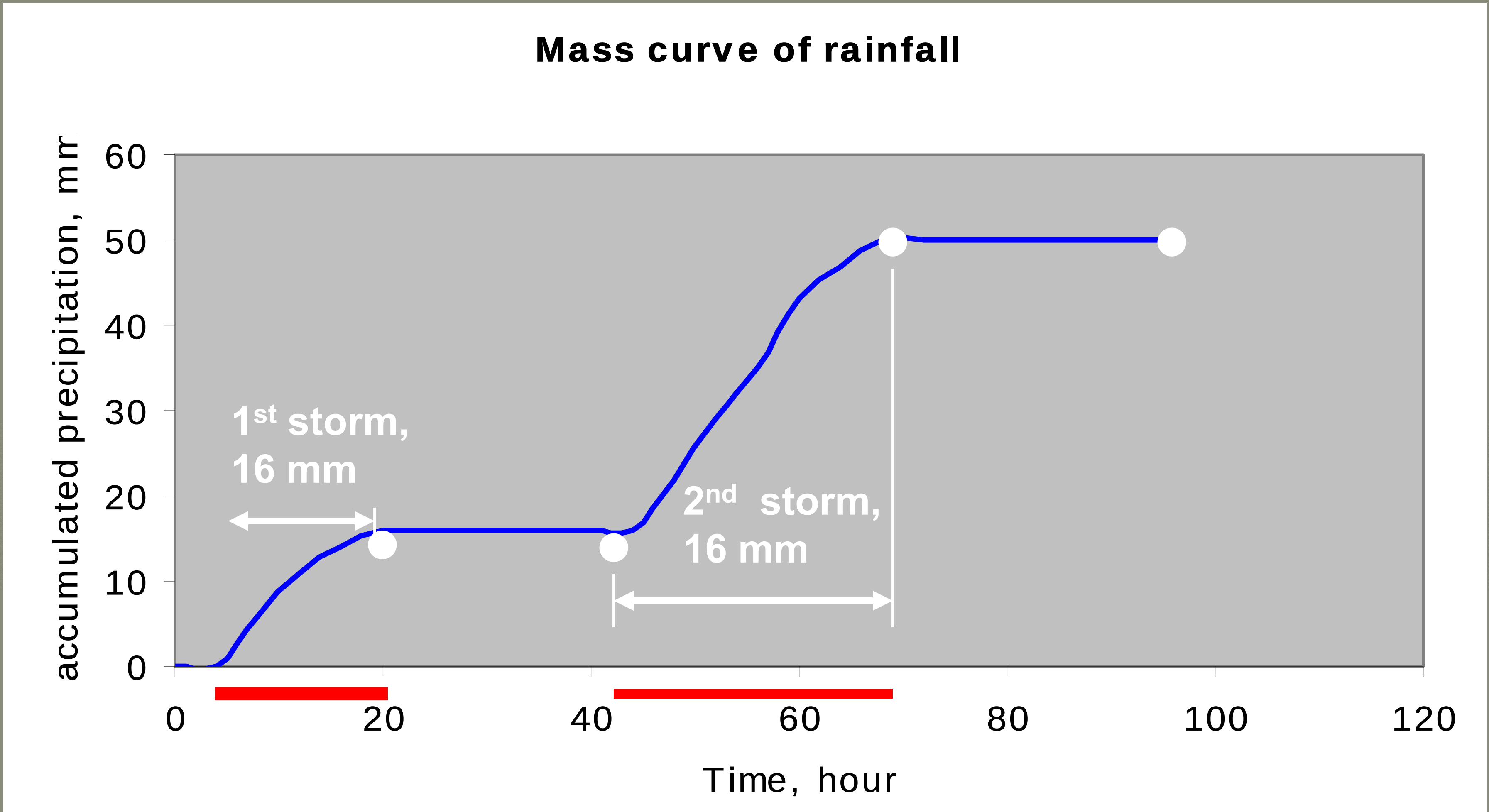
Method	P
California	m/N
Hazen	(m-0.5)/N
Weibull	m/(N+1)
Chegodayev	(m-0.3)/(N+0.4)
Blom	(m-0.44)/(N+0.12)
Gringorten	(m-3/8)/(N+1/4)

FREQUENCY OF POINT RAINFALL



- **a) Rainfall Intensity:** The amount of precipitation accumulated over a unit time.
- **b) Duration:** A continuous period of rainfall.
- **c) Frequency/Return Period/Recurrence Interval :** This gives the average number of years within which a given event will be expected to occur at least once.

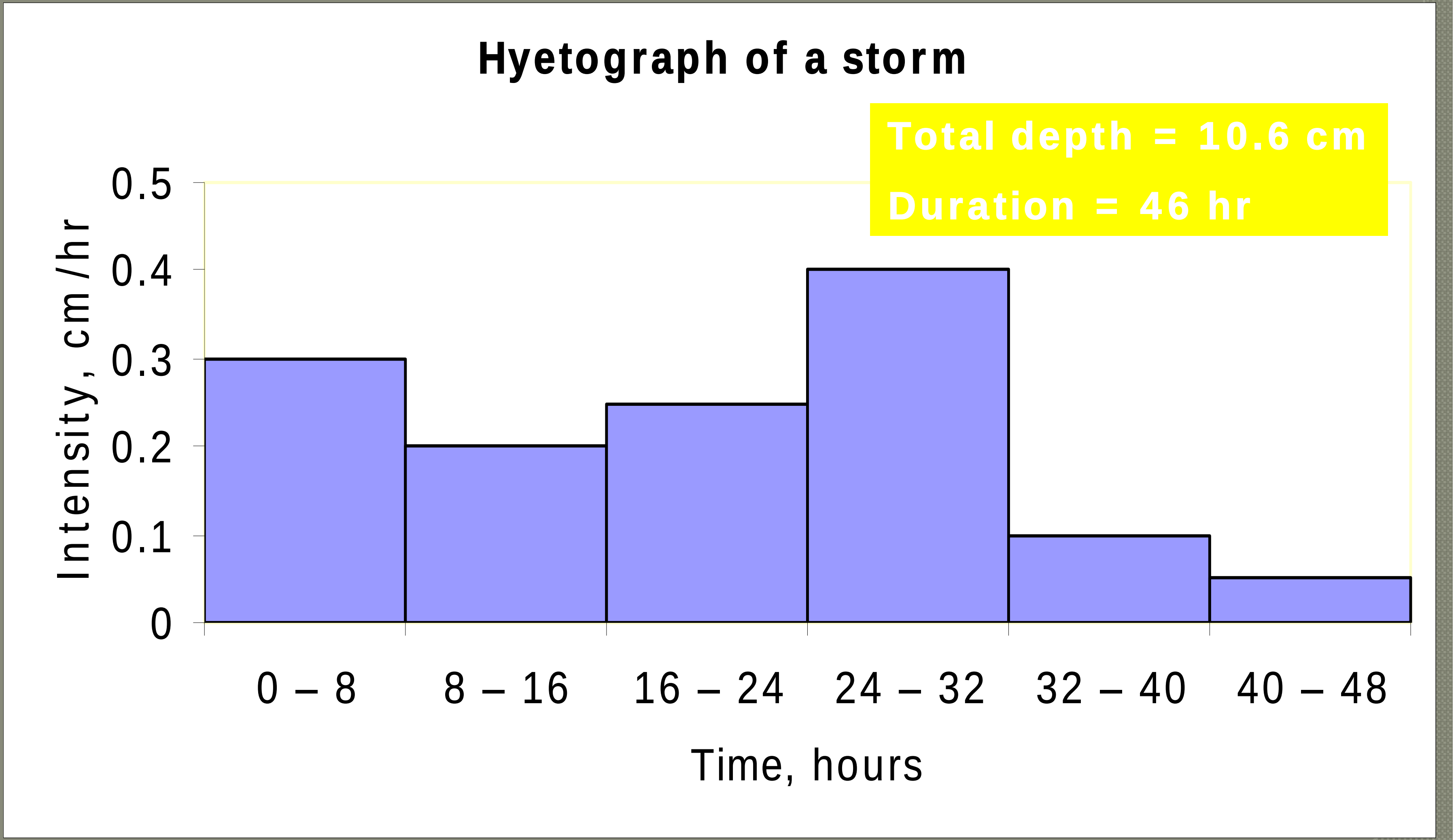
INTENSITY – DURATION – FREQUENCY (IDF) RELATIONSHIP



Mass Curve of Rainfall

Hyetograph

- is a plot of the accumulated precipitation against time, plotted in chronological order



- 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:

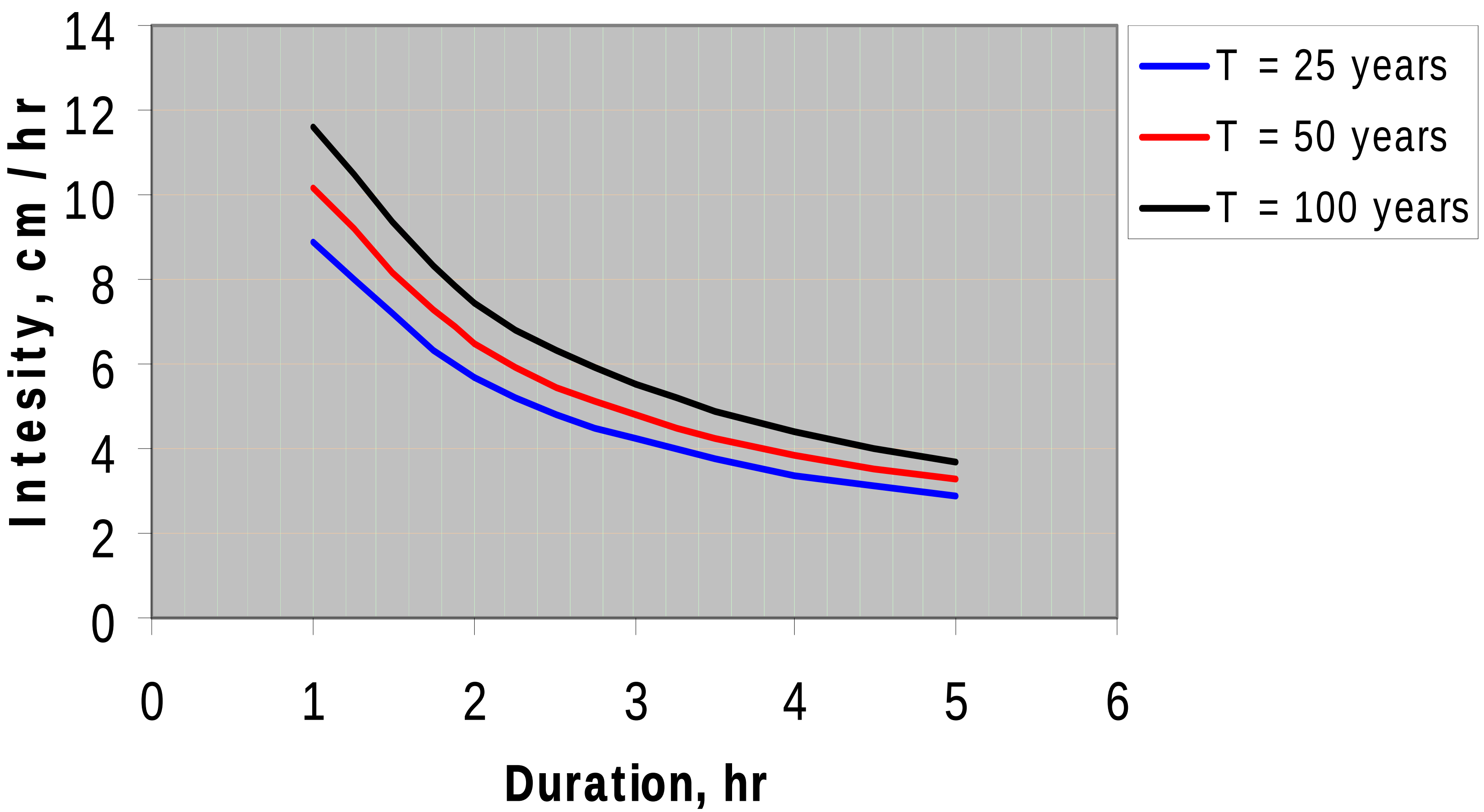
$$i = \frac{k\,T^{x}}{(D+a)^{n}}$$

i – Intensity (cm/hr)

D – Duration (hours)

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

Typical IDF Curve



INTENSITY-DURATION-FREQUENCY RELATIONSHIP

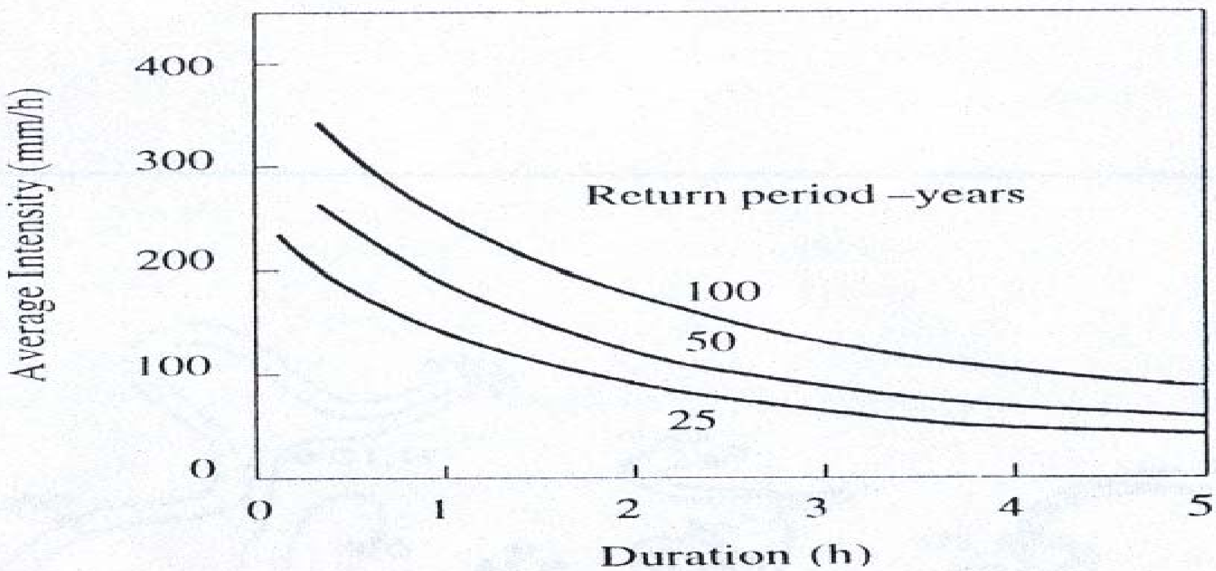
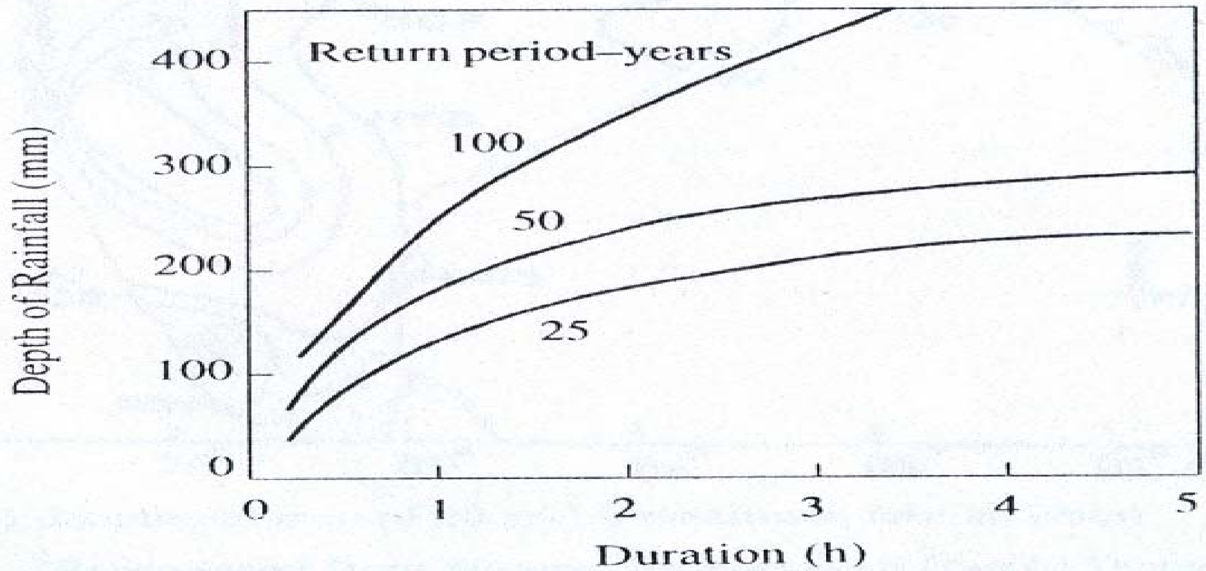
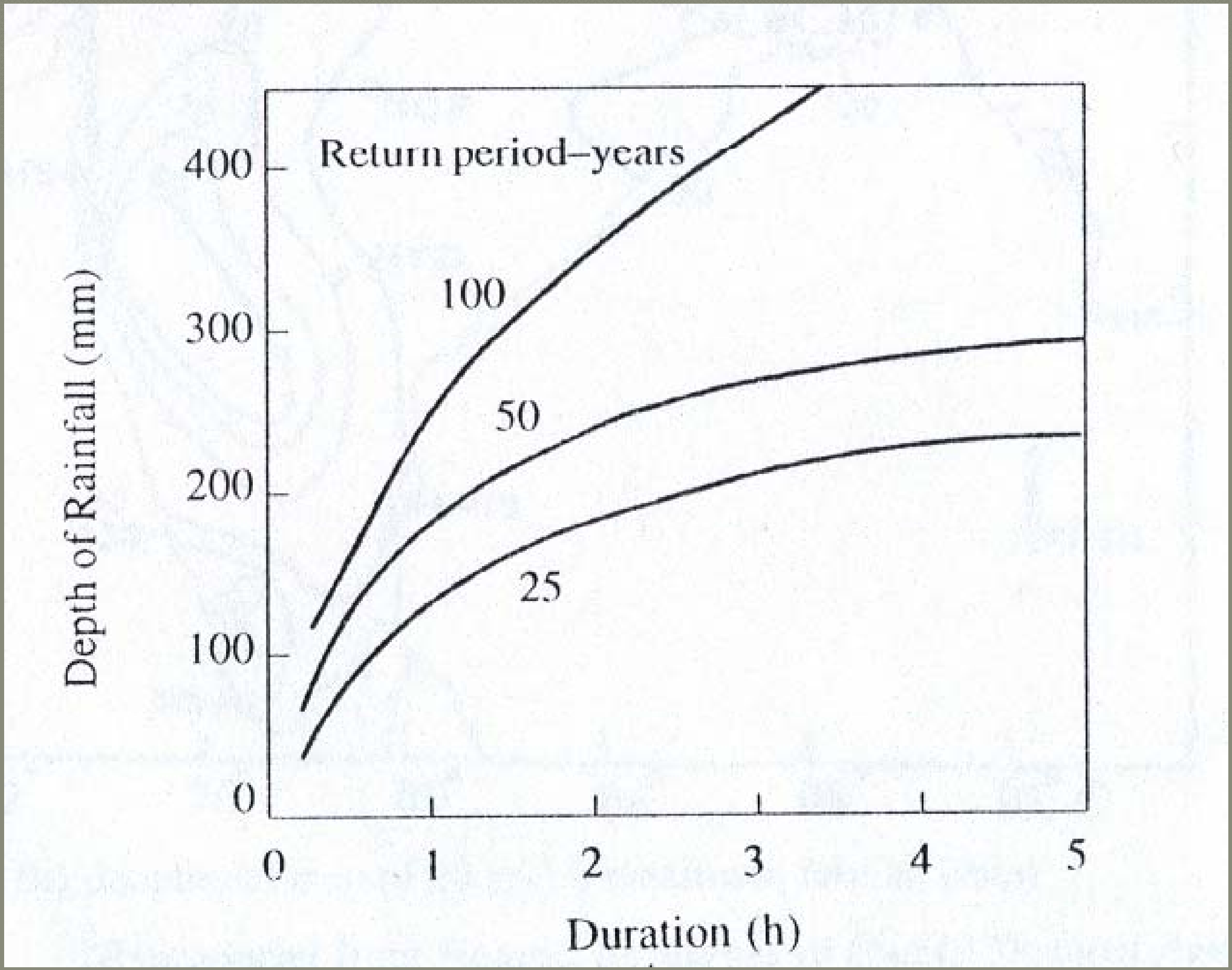


Fig. 2.15 (a) Intensity–duration–frequency curves



INTENSITY-DURATION-FREQUENCY RELATIONSHIP



PROBABLE MAXIMUM PRECIPITATION (PMP)

$$PMP = \overline{P} + K\sigma$$

where $\overline{P}$ = mean of annual maximum rainfall series,

σ = standard deviation it the series and ,

K = a frequency factor

•PMP is defined as the greatest or extreme rainfall for a given duration that is physically possible over a station or basin.

•It can also be defined as that rainfall over a basin which would produce a flood flow with virtually no risk of being exceeded.