UNIT 2 PRECIPITATION MEASUREMENT AND ANALYSIS

Structure

2.1 INTRODUCTION

In the previous unit, you were introduced to the hydrologic cycle and the various hydrometeorological processes responsible for keeping the cycle active. In that unit, the important process of precipitation which denotes all forms of water, viz. rain, snow, hail, frost, dew and so forth reaching the earth's surface from the atmosphere was discussed with regard to its formation mechanism.

This unit intends to apprise you of some simple methods of measuring precipitation and then analysing the collected data, including the required adjustments to be done in the data to obtain homogeneity among measurements by eliminating or reducing the effects of extraneous influences. This exercise is basic to the planning and designing of water resources projects as well as determining the water availability and/or estimating the peak flood for designing various components of a given project.

Objectives

After you have gone through this unit, you should be able to understand the following :

- the commonly used methods of rain and snowfall measurements,
- the determination of missing precipitation data,
- checking consistency of data,
- determination of average areal precipitation,
- depth-area-duration analysis of a storm, and
- intensity-duration-frequency analysis at a point.

2.2 MEASUREMENT OF PRECIPITATION

The total amount of precipitation on a given area, which reaches the ground during a certain time period is expressed as the depth, of water at which it would cover the horizontal projection of this area on (the earth's surface); if any part of this precipitation is falling as snow or ice it is to be accounted for in its melted form. **Precipitation** is thus, the sum of the amounts of liquid precipitation and the **liquid equivalent** of the solid precipitation. Since it is not physically possible to catch all the rainfall or snowfall over a drainage basin, it is only sampled by rain gauges whose **catch** in a perfect exposure represents the precipitation falling on their respective surrounding areas. The measurements are made at several selected points whose location and disposition are representative of the area under consideration; and the equivalent area depth of precipitation is calculated on the basis of this data.

The gauges are located in a manner as to belter represent the spatial variation of rainfall due to physiographic characteristics of the catchmenl. The World Meteorological Organization (WMO) has recommended the following minimum densities of precipitation stations in Table 2.1.

Table 2.1: Minimum Densities of Precipitation Stations

Physiographic Unit	Minimum Densities per Station (Area in km² per Station)	
	Non-recording*	Recording*
Coastal	900	9000
Mountainous	250	2500
Interior plains	575	5750
Hilly/undulating	575	5750
Small islands	25	250
Urban areas	—	10-20
Polar/arid	10000	100000

* **Refer Subsection 2.2.1**

2.2.1 Types of Gauges

The precipitation gauges are based on the simple idea of exposing in an open area a hollow cylindrical vessel with a rigid bottom and no topcover. Rain and/or other forms of precipitation fall into the vessel, and its depth (or volume or weight) is measured, snow or other forms being melted before taking the measurement. The various types of precipitation gauges used are broadly classified as the **non-recording gauges,** and the **recording gauges.**

Non-recording Ganges

The non-recording gauge extensively used in India is the Symons' gauge (Figure 2.1). Recently, the India Meteorological Department has changed over to the use of fibreglass reinforced polyester rain-gauges, which is an improvement over the Symons' gauge. These come in different combinations of collector and bottom. The collector is in two sizes having areas 200 and 100 cm², respectively. Indian Standard (IS : 5225-1969) gives details of these rain-gauges. For uniformity, rainfall is measured every day at 8.30 AM and is recorded as rainfall of that day.

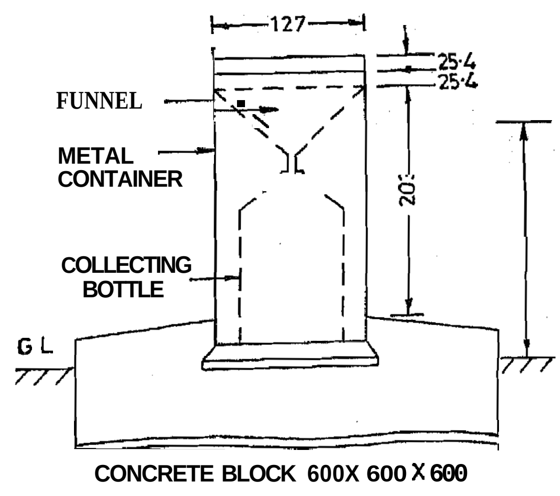


Figure 2.1 : Non-recording Rain-gauge

Recording Gauges

The recording gauges produce a continuous plot of rainfall against time and provide valuable short duration data on intensity and duration of rainfall for hydrological analysis of storms. The commonly used recording gauges are: (i) tipping **bucket type,** (ii) weighing type, and (iii) natural syphon type. The weighing type is suitable for measuring all kinds of precipitation.

Tipping-Bucket **Type**

This is a 30.5 cm-size rain-gauge having a light metal container divided into two compartments (buckets) which is balanced in unstable equilibrium about a horizontal axis. The catch Srom the funnel falls on lo one bucket of the pairs of these small buckets. These buckets are so balanced that when 0.25 mm of rainfall collects in one bucket, it tips over and brings the other one into position. The water from the tipped bucket is collected in a storage can. The tipping actuates an electrically driven pen lo trace a record on clockwork-driven chart. The water collected in the storage can is measured at regular intervals to provide the total rainfall and also serve as a check. For many hydrological purposes, in particular for heavy-rainfall areas and flood warning systems, 0.5 Io 1.0 millimetre buckels are satisfactory. The main advantage of this type of instrument is that it has an electronic pulse output that can be recorded at a distance from the gauge.

Weighing-Bucket Type

In this rain-gauge, the catch from the funnel empties into a bucket mounted on a weighing scale. The weight of the bucket and its accumulating contents are recorded continuously on a clockwork-driven chart. The clockwork mechanism has the capacity to run for as long as one week. This instrument gives a plot of the accumulated rainfall against the elapsed time, i e. the mass curve of the rainfall. This type of gauge normally has no provision for emptying itself, but by a system of levers, it is possible to make the pen traverse the chart any number of times. These gauges have Io be designed lo prevent excessive evaporation losses, which may be reduced further by the addition of sufficient oil or other evaporation suppressing material to form a film over the water surface.

Natural Syphon **Type**

This type of recording rain-gauge is also known as **float type gauge**. Here the 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 Io the float through a lever system records the elevation of the float on a rotating drum driven by a clockwork mechanism. A syphon arrangement empties the float chamber when the float has reached a pre-set maximum level which resets the pen to its zero level. This type of gauge gives a plot of the mass curve of rainfall (Figure 2.2).

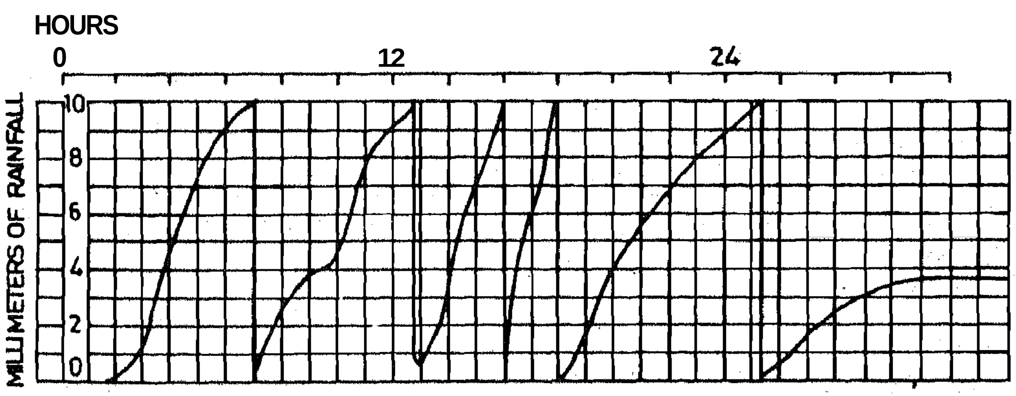


Figure 2.2: Recording from a Natural Syphon-type Gauge

A heating device is installed **inside** the gauge if there is a possibility of freezing. This prevents damage to the float and float chamber due to water freezing, and enables **rain to** be recorded **during that period. A** small **heating** element or **an** electric lamp is suitable where **supply of** electricity is available. The amount of heat supplied is **kept** to the minimum necessary in **order** to prevent **freezing,** because heat affects the accuracy of the observations by stimulating vertical air movements above the **gauge** and **also** by increasing evaporation losses.

Storage Gauges

In sparsely populated or remote regions such as in a desert or a mountainous terrain, storage gauges are used to measure total seasonal precipitation. These gauges are read monthly, seasonally, or whenever it is possible lo inspect the stations. These gauges consist of a collector provided above a funnel, which stores the seasonal catch. A typical gauge consists of a vertical 60 cm-diameter steel pipe of sufficient length to place its 20 cm-catch ring above maximum accumulated snow.

An anti-freeze solution is placed in the receiver to convert the snow which falls into the gauge to a liquid state. A mixture of 37.5 per cent of commercial-grade calcium chloride (78 per cent purity) and 62.5 per cent water by weight makes a satisfactory anti-freeze solution. Alternatively, an ethylene glycol solution is used. Though more expensive, the ethylene glycol solution is less corrosive than calciumchloride and gives protection over a much wider range of dilution caused by ensuing precipitation. The volume of the solution placed in the receiver is not to be more than one-third of the total volume of the gauge. In areas where extremely heavy snowfall occurs, the collector is placed above the maximum expected depth of snow cover. This is accomplished by mounting the entire gauge on a tower or by mounting the collector on a 30 centimetres diameter steel pipe of sufficient length to place its catch ring above the maximum accumulated snow.

SAQ 1

Discuss the important features of different types of rain gauges.

The seasonal precipitation catch is determined by weighing or measuring the volume of the contents of the receiver. The amount of anti-freeze solution placed in the receiver at the beginning of the season is to be taken into account with either method.

2.2.2 Snowfall Water Equivalent and Snow Cover

Snowfall is the amount of fresh snow deposited on the ground over a limited period of time. Measurements of depth of snow are made and its water equivalent is calculated or measured as mentioned below. The **water equivalent** of a given snowfall is the amount of liquid precipitation contained in that snowfall.

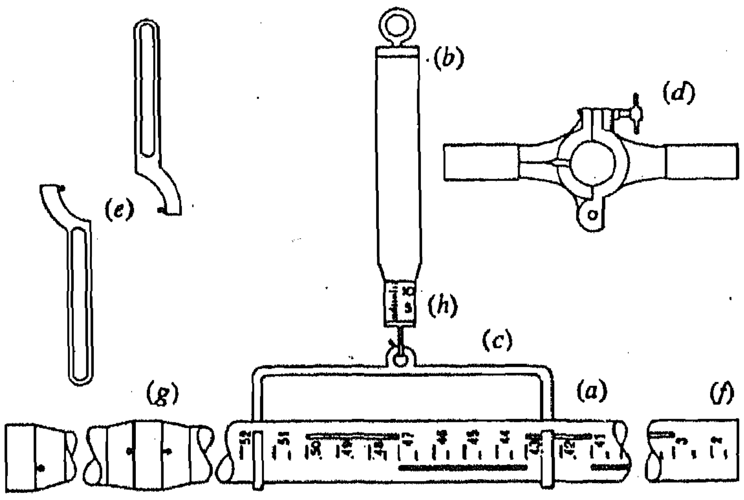
The direct measurements of fresh snow are made with a graduated ruler or scale. A mean of several vertical measurements are made in places which are considered to be free of drifting snow. Special precautions are taken so as not to measure any old snow. This is done by sweeping beforehand a suitable patch clear of grass and debris, or covering the top of the snow surface with a piece of suitable material (such as wood, with a rough surface, or painted white) and measuring the depth down to it. The depth of snow may also be measured in a fixed container of uniform cross-section after the snow has been levelled without compressing.

The water equivalent of the snowfall is determined either by weighing or melting. Snow collected in a non-recording rain-gauge is melted immediately and measured by means of an ordinary measuring cylinder graduated for rainfall measurements. The weighing-type recording gauge is also used to determine the water content of snowfall. During periods of snowfall, the funnels of the gauges are removed so that any precipitation can fall directly into the receiver.

The snow that accumulates over a drainage basin can be considered as a natural storage reservoir from which a major part of the basin's water supply is derived. For reliable forecast of snow-melt runoff, measurements of snow cover are made at snow courses. A **snow course** is defined as a permanently marked line, where snow surveys are taken each year. The snow course locations arc so selected that their average water equivalents represent, as nearly as possible, the avarage water equivalent of the area.

Measurements at a snow course in a mountainous terrain usually consist of samples taken at points spaced 20 to 40 metres apart. In plain regions, the distance between the points of snow density sampling is 100 to 500 metres. Each sampling point is located by measuring its distance from a reference point marked on a map of the snow course. Missing a point by more than a few metres may result in a significant error. Stakes are set high enough to stick out above the deepest snow and offset from the course far enough not to affect the snow cover. They are placed as markers opposite each point where snow samples are to be taken or, at as many points as necessary, to minimize possible error in locating the sampling point.

Snow-sampling equipment commonly consists of a metal or plastic tube (sometimes in sections for achieving portability) with a snow cutter fixed at its lower end and with a length scale stamped on its exterior surface throughout its length, a spring or level balance for determining the weight of the snow cores, a wire cradle for supporting the lube while it is being weighed, and tools for operating the snow sampler. A typical set of equipment for use in deep snow is as shown in Figure 2.3.



(a) Snow-sampling Tube (b) Tubular Spring Balance
(c) Cradle (d) Driving Wrench
(e) Spanner Wrenches (f) Cutter
(g) Screw Couplings (h) Scale

Figure 2.3 : Snow-sampling Equipment

In order to cut the core, the sampler is forced vertically downward through the snow cover until it reaches the ground. If the condition of snow permits, a steady downward thrust, causing an uninterrupted penetration of the core into the lube, is the best procedure. With the cutter at or slightly below ground level and the sampler standing vertically, the reading on the scale that corresponds to the top of the snow cover is observed. After the depth that the sampler has penetrated to beyond the bottom of the snow cover, is ascertained and deducted from this reading, the result is recorded.

Aflerthe sampler is withdrawn, the length of the snow core obtained is observed through the lube slots and read on the scale on the outside of the sampler. After this, reading is corrected for any foreign matter picked up in the cutter, it is recorded. The purpose of this reading is to provide a means for judging quickly if a complete sample of the snow cover has been obtained. The measurement is completed by carefully weighing the snow core in the tube, The weight of the snow core in equivalent centimetres of water is read directly on the scale of the balance. The density of the snow is computed by dividing the water equivalent of the snow by the depth of the snow.

2.2.3 Radar Measurement of Rainfall

Radar permits the observation of the location and movement of areas of precipitation, in the atmosphere; and certain types of radar equipment can yield estimates of rainfall rates over areas within the range of the radar, For hydrological purposes, the effective radar range is usually 40-200 kilometres depending on the radar characteristics, such as antenna beam, power output, and receiver sensitivity, **The hydrological range** of the radar is defined as the maximum range over which the relationship between the radar echo intensity and **rainfall** intensity remains reasonably valid.

The radar emits a regular succession of pulses of electromagnetic radiations within a narrow beam. Precipitation attenuates the radar beam, and this effect is greatest for short 'wave length radar. On other hand, long wave length radiation does not detect light rain and snow as readily as shorter wave length radiation. The selection of a suitable wave length depends on climatic conditions and the purposes to be served. All the three bands of radar wave lengths as given below in Table 2.2 are in use for observation of precipitation.

Table 2.2 : Weather Radar Frequency Bands

Band	Frequency (MHz)	Wave Length (m)
S	1500-5200	0.193 - 0.0577
C	3900-6200	0.0769-0.0484
X	5200-10900	0.0577-00275

The Radar-rainfall **equation** (sometimes referred to as the free space maximum range equation (FSMR)) defines the maximum range that can be anticipated from a particular radar system. For precipitation targets, where rainfall is considered to have filled the radar beam, the equation has the following form :

$$P_r = \frac{P_t \, \pi^4 \, A_r \times l \, [K]^2 \, Z}{8 R^2 \lambda^4} \qquad \ldots (2.1)$$

where,

P_r = Average power in watts received from a series of reflected pulses,

P_t = Peak power transmitted in watts,

A_r = Effective area of antenna in m^2,

l = Pulse length in metres,

R = Range in metres,

λ = Wave length in metres,

$[K]^2$ = Refractive index term of rain (0.9313 for a 10 - millimetre radar equipment, assuming a temperature of 10^0C), and

Z = Reflectivity expressed as $\Sigma(d)^6$ per m^3, where d is the drop diameter in millimetres.

The rainfall rate in mm/hr is related to the median drop diameter, as follows :

$$\Sigma(d)^6 = a\left(P_i\right)^b \qquad \ldots (2.2)$$

where,

P_i = Rainfall **intensity** in mm/hr, and

a & b = Constants.

Many determinations have been made of the rain- drop size distribution, as obtaining at the ground, **and** the relationship of the fall speeds of different sized drops to a particular rainfall rate. The most common equation in use is :

$$Z = 200\left(P_i\right)^{1.6} \qquad \ldots (2.3)$$

2.2.4 Observations by Satellites

Precipitation can be estimated by the interpretation of images registered by scanners or by imaging micrometers. Scanners are widely used in operational weather satellites. The amount of data from imaging microwave radiometers is very limited and cannot be used operationally **at** present.

Techniques have been developed for using images of geostationary or polar orbiting satellites for estimating hourly, daily, and monthly precipitation. Images are taken in the visible and/or **infrared** ranges of the electromagnetic spectrum and the estimation is based on the albedo and/or the temperature of the cloud tops as well as, on the shape, texture, and life history of the clouds. Satellite images can be used for estimating precipitation over areas ranging from the global to the very local scale in real or near-real time. This complements the conventional precipitation measurements in areas of sparse rain gauge networks and can improve the accuracy of estimating precipitation for short time periods (several hours).

SAQ 2

i) What do you understand by "water equivalent" of a given depth of snow?

ii) Explain the utility of radar and satellite in the measurement of precipitation.

2.3 ANALYSIS OF POINT PRECIPITATION DATA

The point observations by means of a precipitation gauge are subject to mainly two problems that cause inconsistency in the data. One of these is that a gauge sile has a short break in the record because of instrumental failure, or absence of the observer, and it is often necessary to estimate the missing record. Another problem that arises is that the recording conditions at a gauge site might have changed significantly sometime during the period of record, due to relocation or upgrading of the station in the same vicinity, differencein observational procedure, or any other such reason. Therefore, it is necessary to check, and if necessary eliminate any inconsistency in the recorded data. The problem is resolved, in both the cases, by comparison of the data with the data obtained from the neighbouring gauge sites.

2.3.1 Estimation of Missing Data

The numerical value of precipitation, missing at a site, can he estimated using concurrent observations at three or more neighbouring stations that are located as close as possible to the missing-data station; these neighbouring stations are known as **index stations** and the method is known as the **normal-ratio method.** The method uses the following equation:

$$\frac{P_x}{N_x} = \frac{1}{n}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} + \ldots + \frac{P_n}{N_n}\right] \qquad \ldots (2.4)$$

where,

P_x = Missing precipitation value for station X.

$P_1, P_2, \ldots, P_n$ = Precipitation values at the neighbouring stations for the concurrent period,

N_x = Normal long-term, usually annual, precipitation at station X,

$N_1, N_2, \ldots, N_n$ = Normal long-term precipitation for neighbouring stations, and

n = Number of index (neighbouring) stations.

2.3.2 Checking the Consistency of Data : Double Mass Curve Analysis

The double-mass curve analysis is a consistency check used to detect whether the data pertaining to a given site have been subjected to significant change in magnitude due to external factors such as, tampering of the instrument, change in the recording conditions, or shift in observational practices. The analysis also provides a means of adjusting the data found to be inconsistent. In this analysis, a plot is made of the accumulated (i.e., cumulative) annual or seasonal precipitation values at the site in question (being checked for consistency) against the concurrent accumulated values of several surrounding stations (Figure 2.4). More conveniently, the mean of the surrounding stations is used in the accumulation. If the data are consistent, the plot will be a straight line. On the other hand, the inconsistent data will exhibit a change in slope of its plot, or a break at a point where inconsistency has occurred. This is shown by point *V*, in the Figure, relating to the year 1961. If the slope of the line W is a and of the line VW is b, the adjustment of the inconsistent data is made by the ratio of the slopes of the two line segments. Two ways of adjustment that are possible as stated below :

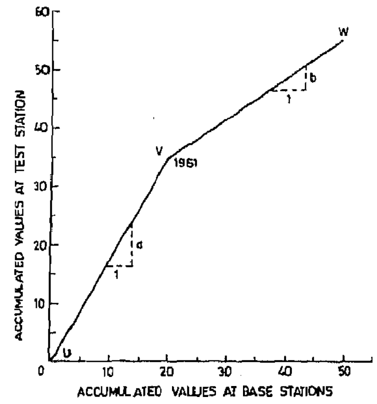


Figure 2.4 : Double Mass-Curve Analysis

1) 'The data are adjusted to reflect the conditions that existed prior to the indicated break. This is done by multiplying each recent precipitation value after the break-point V corresponding to station X (being tested) by the ratio a/b, or/and

2) The data are adjusted to reflect recent conditions following the break. This is achieved by multiplying each value of the precipitation before the break-point by the ratio b/a.

An adjustment of the second type, as mentioned above, is usually made. If fewer than 10 stations are grouped together to check the consistency of a station, the record of each station is to be tested by double-mass analysis for consistency by plotting it against the group of all other remaining stations of the group, and those records that are inconsistent are to be eliminated from the group.

2.3.3 Average Depth of Precipitation over a Catchment

The precipitation over a catchment is measured as point values at a finite number of precipitation stations within and around the catchment area of the stream. The measurements are made under the assumption that the value obtained at each station is representative of the precipitation of the area surrounding the station. The precipitation and the area represented by each station are different from that associated with the other stations of the group, and are required to be determined for estimating the average depth of precipitation over the catchment, for our hydrological analysis. To convert the point rainfall values at various stations into an average value over a catchment, several methods are available. The choice of the method requires judgement regarding the quality and nature of the data, and the importance, use, and required precision of the result. The methods most commonly used for estimating average precipitation over an area are described as follows:

Arithmetic Average Method

It is the simplest of all methods, and consists of computing the arithmetic average of precipitation values for all stations lying within the area under consideration. If $P_1, P_2, P_3, \ldots, P_n$ are the precipitation values at stations 1, 2, 3, . . ., n, respectively, then the average precipitation $\bar{P}$ over the area would be :

$$\bar{P} = \frac{P_1 + P_2 + P_3 + \ldots + P_n}{n} \quad .. (2.5)$$

This method assigns equal weightage to all the stations irrespective of their relative spacings and other influencing factors. It is suitable for basins with a large number of precipitation stations which are spaced uniformly or can be considered to adequately sample the precipitation distribution over the basin.

Thiessen Polygon Method

This method is used with non-uniform station spacing, and it assigns weightages to each station in proportion to the area represented by a polygon that surrounds the station. It assumes that the amount of precipitation at any station can be applied halfway to the next station in any direction. It is applied by constructing a **Thiessen** Polygon around each station marked on a map of the area, drawn lo scale. The polygons are formed by first drawing dashed lines between the adjacent stations in the form of a triangular network, and then drawing solid lines perpendicular bisectors of these dashed lines to form a pattern of polygons with one station falling within each polygon (Figure 2.5). For stations close to the boundary, the boundary line forms closing limit of the polygons.

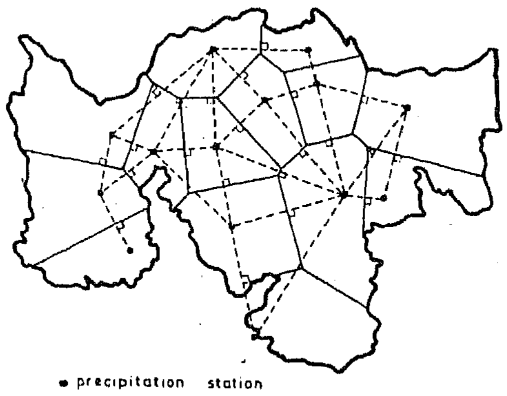


Figure 2.5 : Thiessen Polygons

That is, around the edge of the catchment where parts of polygons extend beyond the basin boundary, only the portion of the polygon falling inside the drainage area is considered. The area of each polygon is taken as 'the area represented by the station within that polygon, and is used as a factor for weighting the station precipitation. The sum of the producls of each station area and the value of precipitation is divided by the total basin area to gel lhe average precipitation for the catchment.

In case, the data of any one or more stations are considered, or are left out while estimating the average precipitation, the network gets changed and it requires recomputation of the station weightages. If $P_1, P_2, P_3, \ldots, P_n$ are the precipitations recorded at stations 1, 2, 3, . . ., n within a total basin area (A), where $A_1, A_2, A_3, \ldots, A_n$ are the respective polygon areas, then the average precipitation would be given by :

$$\left.\begin{aligned} P &= \frac{P_1 A_1 + P_2 A_2 + P_3 A_3 + \ldots + P_n A_n}{A_1 + A_2 + A_3 + \ldots + A_n} \\ &= \frac{P_1 A_1 + P_2 A_2 + P_3 A_3 + \ldots + P_n A_n}{A} \\ &= P_1 \frac{A_1}{A} + P_2 \frac{A_2}{A} + P_3 \frac{A_3}{A} + \ldots + P_n \frac{A_n}{A} \\ &= P_1 w_1 + P_2 w_2 + P_3 w_3 D + \ldots + P_n w_n \end{aligned}\right\} \quad \ldots (2.6)$$

where, $w_1, w_2, w_3, \ldots, w_n$ denote the respective weightages.

Isohyetal Method

It is more accurate of the two previous methods as discussed above, and provides a means of considering the orographic (mountains) effect on precipitation. In this method, the stations and rainfall values are plotted on a map to a suitable scale. Then the contours of equal precipitation (isohyets) are drawn (Figure 2.6). and the areas between successive

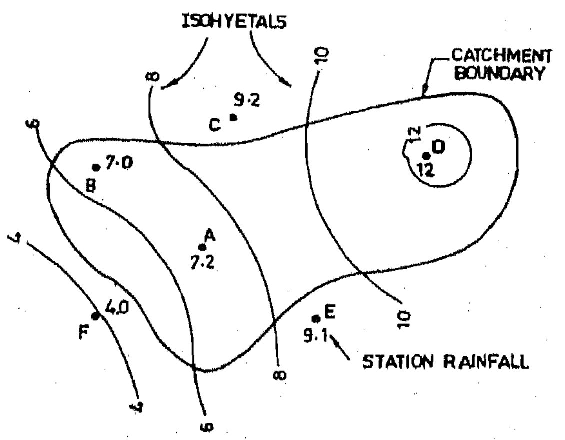


Figure 2.6 : Isohyetals of a Storm

isohyets are determined and multiplied by the numerical average of the two contour (isohyet) values. The sum of the products is divided by the tdtal drainage area to get the weighted average precipitation.

Per Cent Normal **Method**

This method is most successful in regions of pronounced physiographic influence where individual storms tend to have a similar isohyetal pattern. In this method, storm precipitation is expressed as a percentage of mean annual or mean seasonal precipitation, and **isopercental** maps are used for preparing isohyetal maps. That is the ratio of the precipitation during a storm to the mean seasonal or annual precipitation and is worked out for each observation station, and **isolines** of these ratios are plotted. The mean of the ratios is determined for any incremental area, and is multiplicd by the mean annual precipitation to give storm depth for the incremental area. Then the multiplication of this depth by the size of the corresponding incremental area, and the addition of all these incremental volumes for the basin, and lastly, division by the total of the basin area gives the required average depth of precipitation over the basin.

Hypsometric Method

The hypsometric method **(area-elevation method)** is particularly useful in mountainous regions (Figure 2.7). The area-elevation curve in quadrant (a) is constructed by plotting the respective areas of the basin lying below the various elevation contours (A, on the x-axis) against the corresponding elevations (z on the y-axis).

The locations of the station-identifiers on the x-axis can always be determined by "back-tracking" from the station elevation on the y-axis to the area-elevation curve, and then upward to the x-axis. The locations of the station-identifierson the x-axis are then projected, as indicated, in quadrants, (a) and (b) with the lines in quadrant (*b*) projected at an angle of 60° from the y-axis.

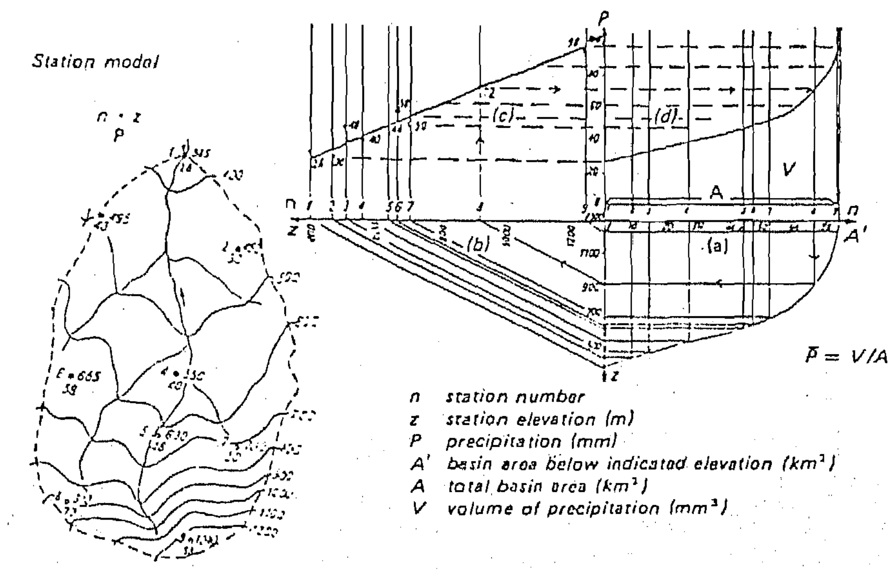


Figure 2.7 : Hypsometric Method

The curve of quadrant (c) is constructed by plotting station precipitation against the corresponding stations. From this quadrant, the values are projected to quadrant (d) and plotted against their respective station-identifiers to derive the precipitation curve. The area in quadrant (*d*) lying below this curve represents the volume of precipitation. Dividing by the total area of the basin yields the average depth of precipitation.

The quadrants (a) and (b) are fixed for a particular basin and that only the curves of the two top quadrants have to be re-determined for each storm. The method may also be used for averaging monthly or annual precipilation.

2.3.4 Design Application of Rainfall Data

The design of various structures, that need be constructed in water resources engineering, require inputs, such as, likely maximum rainfall and floods over a given basin, Various methods regarding the analysis of the above mentioned hydrologic data are available . Each method is best suited for specific objectives as discussed below:

Depth-area Duration Analysis of Storm

A storm-rainfall analysis expresses the depth-area duration characteristics of the rainfall occurring from a particular storm. The depth is defined for pertinent combinations of enveloping area and duration, and is usually portrayed by tables or curves. Such analyses provide useful records for the design of spillwnys.

The depth-area duration is an areal precipitation analysis of a single storm (Figure 2.8). The analysis is performed to determine the maximum amount of precipitafionof various durations over areas of various sizes. For this purpose, information from a recording gauge is needed.

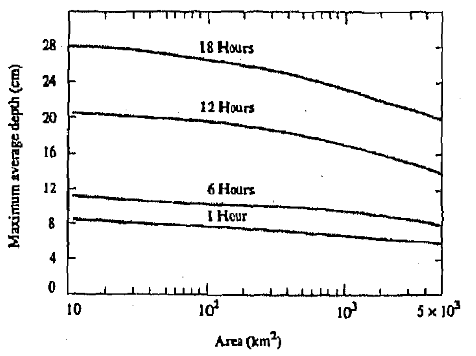


Figure 2.8 : Depth-area Duration Curves

The procedure, as sucli, is applied to a storm that produces an excessive depth of precipitation. In a study of the probable maximum precipitation (PMP), which is defined as a rational upper limit of precipitation of a given duration over a particular basin (refer next subsection), several severe slorms arc analysed and the maximum values for various durations are selected for each size of area. From the tabulation of maximum rainfall increments, isohyetal maps are prepared for each duration (e.g., 6hours, 12-hours etc.). Areas enclosed by each isohyet arc then measured by using a planimeter or by tallying grid points, and the resulting values are plotted on a graph of area *versus* depth, with a smooth curve drawn for each co-relation. A linear scale is commonly used for plotting the depth, and a logarithmic scale for area. The enveloping or maximum depth-area duration data for each increment of area and duration may also be tabulated as in Table 2.3 below from curves such as those in Figure 2.8.

Table 2.3 : Maximum Average Depth of Rainfall (mm)

Area km^2	Duration (hours)					+
	1	6	12	18	24	–
25	0	90	165	205	–	–
100	0	85	155	190	–	–
1000	0	70	130	165	–	–
10000	0-	50	90	115	–	–
–	–	–	–	–	–	–

Intensity-Duration-Frequency(IDF) Analysis

The point precipitation data of various storms are analysed in an IDF study. Since the precipitation data are used for the purposes of estimating the streamflows in many instances, not only the total precipitation but its rate, known as the intensity, and the duration are important while making a peak-flow study of the stream, ***The IDF data is required in the rational formula for estimating design flood for a system having small catchment,*** say, 25 km^2. This analysis is carried out as given below;

A specific duration of rainfall, such as 5 min, is selected. From the record of the rain gauge, which indicates the accumulated amount of precipitation with respect to time, the maximum rainfall of this duration in each year is noted. **This** is the **maximum** Incremental precipitation (difference between accumulated precipitation values) for the selected duration (*5* min) obtained from the gauge record. For a partial duration series, all values in the record that exceed a level given by the excessive precipitation for the selected duration are noted. The precipitation values are arranged in descending order and the return period (T) for each value is obtained using the formula:

$$T = \frac{(n+1)}{m}$$

where,

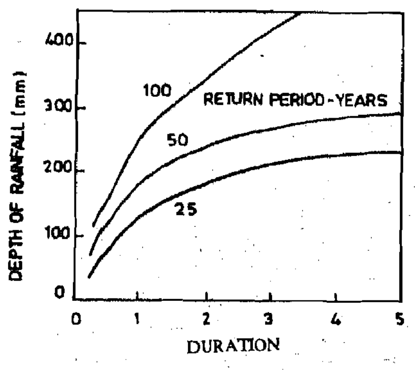
m = Rank of the particular rain-fall data in order of magnitude, and

n = Total number of years of data in the record.

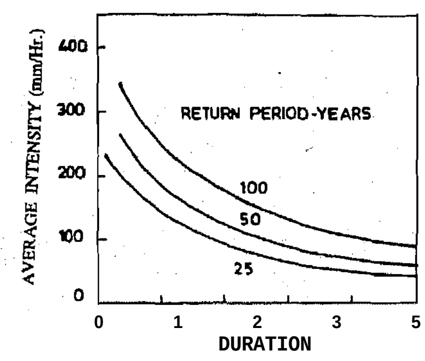
For partial duration series, some adjustment in the precipitation values is made by applying some empirical multiplying factors. Similar analyses are carried out for other selected durations (10, 15, 20, . . . min).

For each frequency level computed, the precipitation amounts (depths) are plotted for different durations. These are the depth-duration-frequency curves (Figure 2.9). The precipitation depth can be converted to intensities. These values are plotted as intensity-duration-frequency curves. Interpolation between the return periods can be done from the curves of the lower and higher return periods.

Probable **Maximum Precipitation** (PMP)



Depth-duration-frequency Curves



Intensity-duration-frequency Curves

Figure 2.9 : Depth-duration-frequency and Intensity-duration-frequency Curves

The term, probable maximum precipitation (PMP) is widely used to refer to the quantity of precipitation that approximates the physical upper limit for a given duration over a particular basin. PMP for a river basin, is usually derived by : taking the results of depth-area-duration analyses of precipitation in major storms that have or could have occurred in the area of interest; adjusting them for maximum moisture charge and rate of moisture inflow; and, enveloping the adjusted values for all storms to obtain the depth-area -duration curves of PMP. Use of other storm models i.e., storm **transposition** (i.e., the use of storms outside the area of interest) and **maximization** (i.e., maximising the precipitation values to their upper limits consistent with meteorological knowledge; and then reassemble them suitably) involves modification for differences in factors affecting rainfall, e.g., elevation, latitude, and distance from moisture source. Changes in shape and orientation of isohyetal patterns are also considered. The limitations imposed by shortness of rainfall records for a project basin are minimized by the transposition of large storms that have occurred within the surrounding meteorologically homogeneous region. The transposition of storms in mountainous areas is limited to regions of similar orographic influences, since orographic influences have an important effect on rainfall distribution in mountainous areas. The maximization of observed storm precipitation for determining PMP involves moisture adjustment with the basic assumption that a storm would have produced maximum precipitation had the maximum moisture supply been available. Determination of probable maximum flood (PMF) begins with the determination of PMP.

It may be mentioned that storm models have been used to estimate PMP; it can also be estimated by statistical procedures.

Design Storm

Because of difficulties in estimating flood frequency for ungauged catchments or where records are short, the concept *of the* ***design storm*** has *developed.* **A** rainfall time-intensity pattern is selected and the runoff hydrograph or peak flow is calculated by standard procedures used in the analysis of a hydrograph or using relations belween precipitation runoff (in many cases by an empirical formula), as the case may bc. The technique is sometimes extended to large areas, and **an** areal pattern of rainfall is specified for the design storm. It is commonly assutned that the probability of the derived flow is the same as that of the design rainfall. This assumplion is rarely right and often grossly in error. **A** storm includes a time-intensity pattern, an areal pattern and the total rainfall. It is impossible to assign a frequency to such a complex event. Usually, only the total rainfall is considered. Since the time-intensity and areal patterns affect runoff volume and flood peak, storms with the same rainfall volume seldom produce the same flood peak. In addition, a storm occurs in a sequence of events which fix antecedent conditions and, in turn, runoff volume and hydrograph shape.

A single design storm, even if the frequency is known accurately, is inadequate for the economic analysis which should be made for *flood mitigation, storm drainage,* culvert *design, etc.* The preferred procedure is to synthesize the longest possible flood series and derive a frequency relation from the synthetic data. The design-storm approach is seldom warranted except when there has been a policy decision that the structure should be designed for the probable maximum event (Refer the subsection discussing PMP).

Standard Project Storm (SPS)

The probable maximum flood (PMF), to be expecled in case of hundred per cent coincidence of all the contributing factors, that would cause the heaviest rainfall and maximum runoff. This event is derived from a probable *maximum precipitation* (PMP), and hence its frequency cannot be determined. It is obvious that from the economic point of view, it is usually prohibitive to design a structure for PMF, except in the case of large hydraulic structures, like spillways, because their failure would lead to lot of avoidable damage and loss of life. Therefore, in practice, the flood event actually considered for purposes of design is often the grcalest flood (a scaled down version) that may reasonably be expected, which would be much less than the above mentioned *estimated limiting value* (ELV).

In practice, the design flood is commonly called the *standard project flood* (SPF). The SPF is estimated using rainfall-runoff modelling by applying the unit hydrograph method to the standardproject *storm* (SPS) which is the greatest storm that may reasonably bc expected. The SPS can be derived from a detailed analysis of storm patterns and transposition of storms to a position that would give maximum runoff. For a given basin, and the season of the year in which snow melt is not a major factor, the SPS estimate should represent the most severe flood-producing depth-mca-duration relationship and the isohyetal pattern of any storm that is considered reasonably characteristic of the area, Similar considerations should be given to various relevant facts of the basin.

Generally, an SPF estimate is relevant for major and intermediate structures because a **lot** of effort goes into their construction.

Problem Maximum Flood (PMF)

PMF is estimated by transforming the PMP using hydrologic methods. Thus conversion may be accomplished with rainfall-runoff *relations and unit hydrographs* or by similar techniques. The PMF is normally several times larger than the largest flood in the record concerning a catchment.

SAQ 3

i) How will you estimate missing precipitation data at a given rain-gauge station?

ii) What is Double Mass Curve analysis as applied to rainfall data ?

iii) What is the usefulness of various methods of computing the average depth of rainfall over a given area ?

iv) Discuss any two methods of analysis of rainfall data.

2.4 SUMMARY

This unit discussed various methods of measurement of precipitation (rainfall as well as snow). Analysis of precipitation data; estimation of missing data, double-mass analysis; and computation of average depth of precipitation was explained in some detail.

Lastly, various methods of processing the precipitation data (for a given catchment) with a view to using it for design purposes were discussed.

2.5 KEY WORDS

Basin (Catchment) : A given area hounded by a ridge, so that all the rain that falls within the bounds (respresented by the ridge line) ultimately drains off the area through a single stream.

Water Equivalent (of a snow **deposit**) : It is the amount of liquid precipitation (i.e. water) contained in that snowfall.

Hypsometric **Method** : This method of rainfall analysis uses a curve between the area of the basin (lying below the various elevation contours) and the elevation of the corresponding contour.

2.6 ANSWERS TO SAQs

Refer for answers the respective text for each SAQ.