Water Resources Engineering -1
Unit 1

Lecture Notes 1

Introduction to Engineering Hydrology and Its Applications

Hydrology: It is the science which deals with the occurrence, distribution and movement of water on the earth's surface including that in the atmosphere and below the earth Surface.

- Water occurs in the atmosphere is in the form of vapour.
- On the ground surface as water or ice.
- Below the earth surface as ground water occupying all the voids with in the geological stratum.

Hydrological Cycle and their Components

Hydrological Cycle:

Except for very deep ground waters, the total water supply of earth is in contact Circulation from earth's surface to the atmospheric and back to the earth's surface.

The earth's water circulatory system is known as hydrological cycle. (Or) hydrological cycle is the process of transfer of moisture from the atmosphere to the earth's surface in the Form of precipitation and evaporation of water back to the atmosphere.

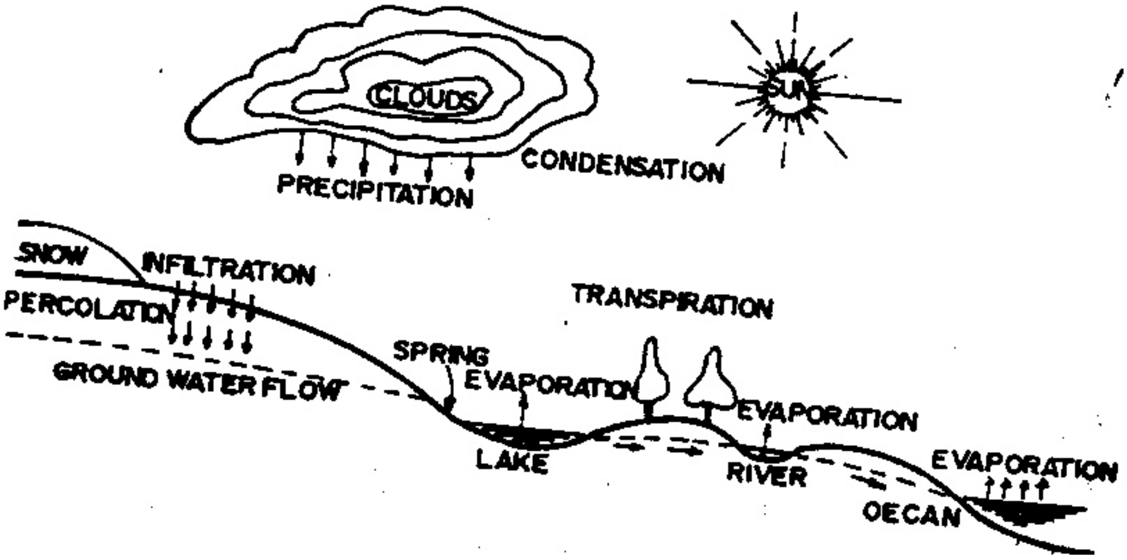


Diagram Showing Hydrological Cycle

Hydrological cycle consists of the following Processes.

1. Evaporation and Transpiration (E)

The water from the surface of the ocean, rivers and also from the moist soil evaporates.

The vapours are carried over the land by air in the form of clouds. Transpiration is the Process of water being lost from the leaves of the plants from their pores.

Total evaporation (E) including transpiration consists of the following:

a. Surface evaporation: Evaporation from moist soil
b. Water surface evaporation: Evaporation from river surface, from oceans
c. Evaporation from plants and leaves (Transpiration)
d. Atmospheric evaporation.

2. Precipitation (P)

Precipitation may be defined as fall of moisture from the atmosphere to the earth's Surface in any form.

Precipitation may be two forms

- Liquid Precipitation - rain
- Frozen form consist of - Snow, Hail, sleet, freezing rain.,

3. Run off (R)

Runoff is that portion of precipitation that is not evaporated. When moisture falls to the ground in the form of precipitation, a part of precipitation will be evaporated by means of soil surface, water surface and plants. The remaining part of precipitation is available as a runoff which ultimately reaches ocean through surface and sub surface streams. The run off may be classified as following:

- Surface Run-off

Water flow over the land surface and first it reaches the streams and rivers ultimately this quantity of water is discharged in oceans.

- Inter flow (or) Sub-surface Run-off

It is the part of precipitation that infiltrates below the earth's surface. Infiltrates Capacity depends on the geology of the basin, runs as a sub surface flow ultimately reaches to oceans through rivers and streams.

- Ground Flow (or) Base flow Run-off

It is also a portion of precipitation, which after infiltration, percolates down and joins the ground water reservoir. This ultimately reaches the oceans.

Precipitation = Evaporation + Run off

Measurement of Rain fall

Rain fall is the main source of water used for various purposes. Knowledge of rain fall quantity, intensity of rain fall & distribution of rain fall is extremely useful for irrigation engineering.

- The amount of rain fall is measured in centimeters (inches).which is falls on a level surface and is measured by rain gauges.
- The intensity of rain fall is the rain fall per unit time. It is expressed as cm/hr.

The following are the main types of rain Gauges used for measurement of rain fall.

- Non-automatic rain gauges

Non automatic rain gauges are non-recording type.

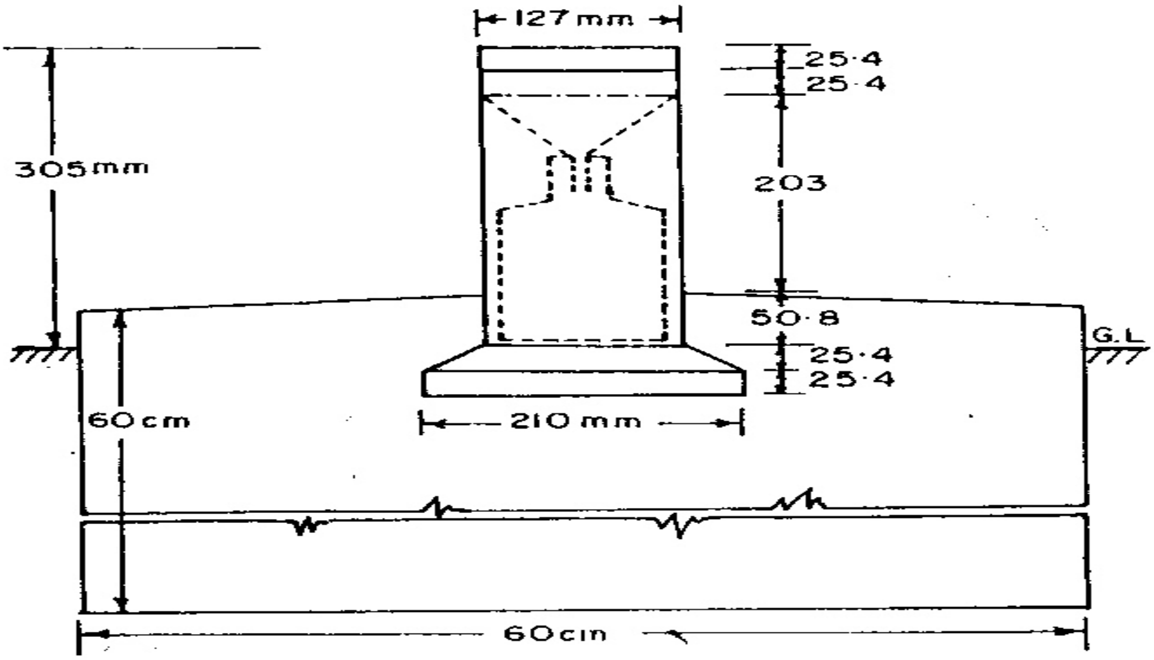
Eg: Symons rain gauge.

- Automatic rain gauges.

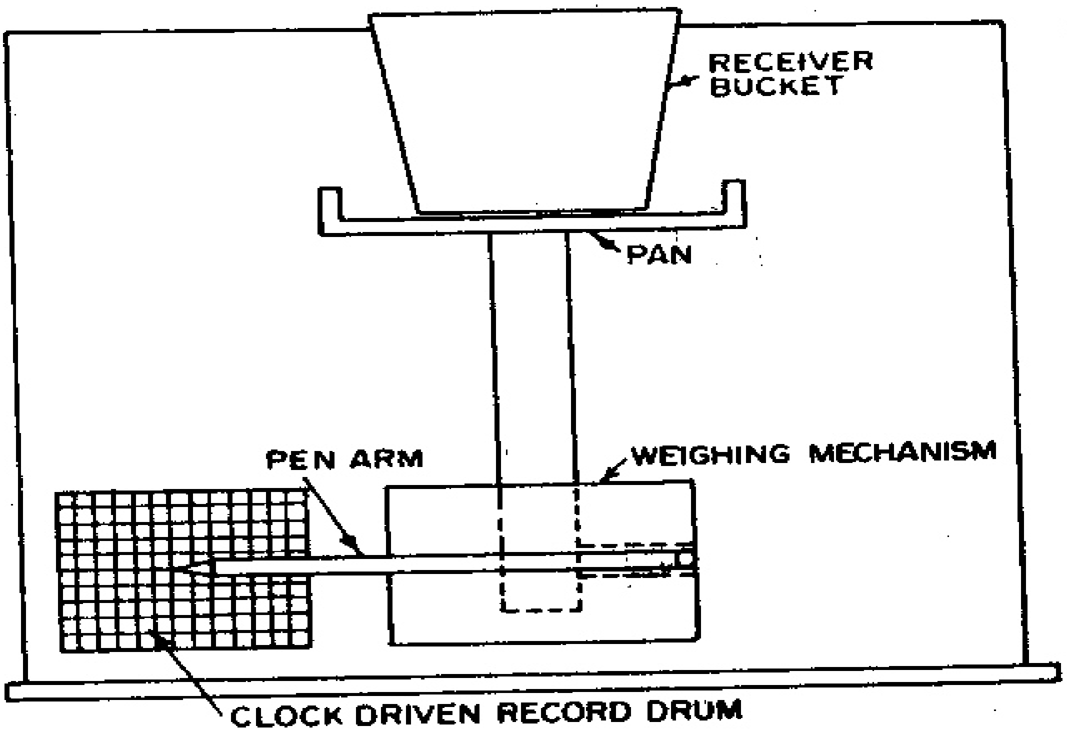
Automatic rain gauges are recording type. They are of three types,

- Weighing bucket type rain gauge.
- Tipping bucket type rain gauge.
- Float type rain gauge.

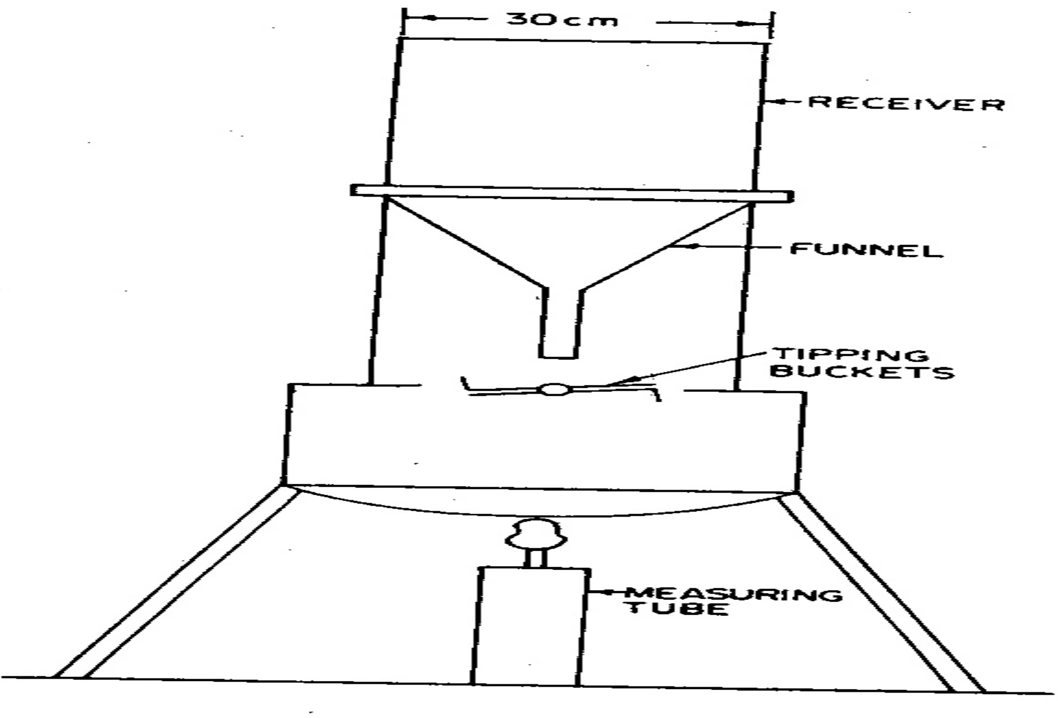
Symons rain gauge: Symons rain gauge is commonly non recording type rain gauge in India and is used in meteorological department of government of India. It consists of cylindrical vessel 127 mm (or 5") in diameter with a base enlarged to 210 mm (or 8") diameter. The top section is a funnel provided with circular brass rim exactly 127 m (5") internal diameter. The funnel shank is inserted. in the neck of a receiving bottle which is 75 to 100 mm (3 to 4") diameter. A receiving bottle of rain-gauge has a capacity of about75 to 100 mm of rainfall and as during a heavy rainfall this quantity is frequently exceeded, the rain should be measured 3 or 4 times in a day on day of heavy rainfall lest the receiver fill should overflow. A cylindrical graduated measuring glass is furnished with each instrument, which reads to 0.2 mm. The rainfall should be estimated to the nearest 0.1 mm.



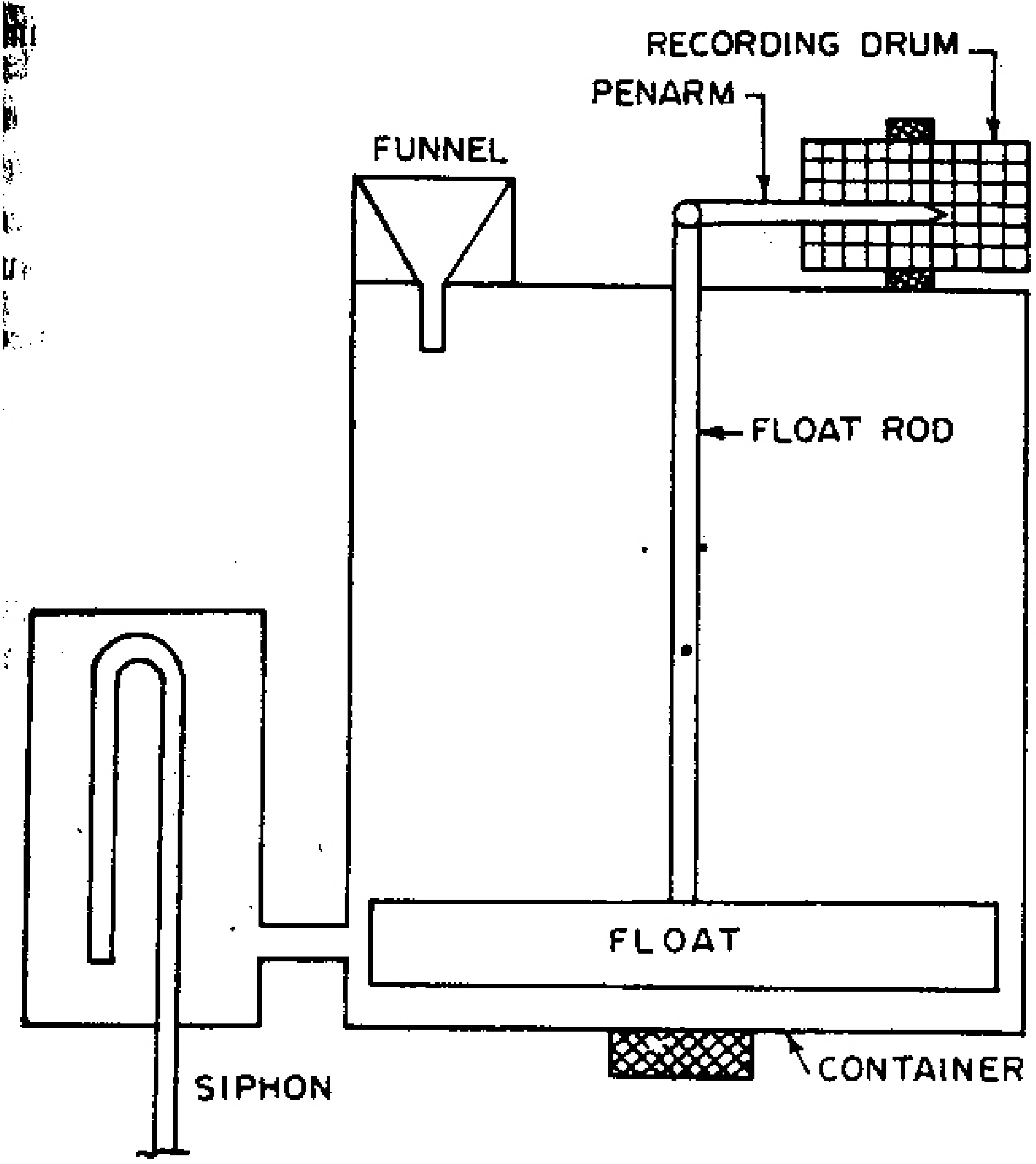
Weighing bucket type rain gauge: it is self recording type rain gauge this is used to determine the rate of rainfall (or) intensity of rain fall over a short period of time. The weighing bucket rain-gauge essentially consists of a receiver bucket supported by aspiring or lever balance or any other weighing mechanism. The movement of the bucket due to its increasing weight is transmitted to a pen which traces the record on a clock driven chart



Tipping bucket type rain gauge: The tipping bucket type rain-gauge consists of 30 eudiometer sharp edge receiver. At the end of the receiver is provided a funnel. A pair of buckets are pivoted under the funnel in such a way that when one bucket receives 0.25mm (0.01 inch) of precipitation it tips, discharging its contents into a reservoir bringing the other bucket under the funnel. Tipping of the bucket completes an electric circuit causing the movement of pen to mark on clock driven revolving drum which carries are cord sheet.



Float Type Automatic Rain-gauge: The working of a float type rain-gauge is similar to the weighing bucket type gauge. A funnel receives the rain water which is collected in rectangular container. A float is provided at the bottom of the container. The float is raised as the water level rises in the container, its movement being recorded by a pen moving on a recording drum actuated by a clock work. When the water level in the contain erases so that the float touches the top, the siphon comes into operation, and releases the water; thus all the water in the box is drained out.



Site Selection for Rain Gauge:

- The rain gauge should be installed on a plain surface.
- The distance between rain gauge and nearest objective should be at least twice the height of the objective
- The rain gauges should not be provided side and top of the hill.

Advantages of recording type rain fall over none recording type rain Gauge:

- Rain fall is recorded automatically and hence no attender is necessary.
- By using automatic rain gauge records the intensity of rain fall, where as in the Case of non automatic rain fall rain gauges, only rain fall depth is measured.
- Rain fall is recorded automatically, that's why it can be placed even inaccessible points also.
- Human errors are avoided.

Disadvantages

- It is costly.
- Fault may be developed in electric &mechanical mechanism for recording the readings.

Optimum number of rain Gauges:

The optimum number of rain gauges depending up on the coefficient of variation (CV) of the mean annual rain fall values at the existing stations and available gauge error (e). Optimum numbers of rain gauge stations are equal to $(Cv/e)^2$.

Cv = coefficient of variation

e = error expressed in (%)

$Cv = \sigma / \bar{p}$

Where, σ = standard deviation= $\sqrt{\Sigma (p-\bar{p})/n-1}$.

$\bar{p}$ =average annual rainfall over the catchment area= $\Sigma p/n$.

n = number of existing rain gauge stations

Σp = sum of annual rain fall of total rain gauge stations

The additional rain gauges required = m - n

m = Optimum numbers of rain gauge stations

n = existing numbers of rain gauge stations

1) Determine the optimum number of rain gauges in a catchment area from the following data:

a) Number of existing rain gauges = 8

b) Mean annual rain fall at the gauges=1000, 950, 900, 850, 800, 700, 600, & 400 mm.

c) Permissible error =6%.

Sol:

Optimum numbers of rain gauge stations = $(Cv/e)^2$.

$Cv = (\sigma / \bar{p}) \times 100$

$$\bar{p} = \Sigma p/n. = \frac{1000+950+900+850+800+700+600+400}{8}$$

$$\frac{6200}{8} = 775mm$$

Standard deviation $\sigma = \sqrt{[\Sigma(p-\bar{p})/(n-1)]}$

$\Sigma (p-\bar{p})^2 = (1000-775)^2+(950-775)^2+(900-775)^2+(850-775)^2+(800-775)^2+(700-775)^2+(600-775)^2+(400-775)^2$

Standard deviation $\sigma = 200$

$C_v = (200/\ 775) \times 100 = 25.8\%$
Optimum numbers of rain gauge stations = $(C_v/e)^2$. = 25.8/6 =18.4 say 19
Additional rain gauges = m – n = 19 -8 = 11numbers.

Estimation of missing rainfall data

Missing rainfall data of the rain gauge stations can be calculated from the mean annual rainfall of the existing rain gauge stations called index stations. From the determination of missing rainfall data we know the mean annual rainfall of all the rain gauge stations, including the station with missing rainfall data.

- The normal annual rainfall of a station is the average value of the annual rainfall over a i

specific period 30years.

- The normal annual rainfall is updated every 10 years.

The missing rainfall data can be calculated by using the following methods:-
1. Comparison method
2. Normal ratio method
3. Isohyetal method

Comparison method: The missing data can be estimated by comparing the mean annual rainfalls of missing rainfall station X with that of an adjacent rain gauge station A.

$P_X = N_X$

$P_A \; N_A$

Where P_X and P_A precipitation of stations X and A
N_X and N_A mean annual rainfall of stations X and A

Normal ratio method: X is the missing rainfall of rain gauge station A.B; C is the adjoining rain gauge stations

(a) When the mean annual rainfall at each of the Index station A, B, and C is with in 10% of the mean annual rainfall of the station X is Simple Average value of three.

$P_X = 1/3(P_{A+} P_{B+} P_{C)}$

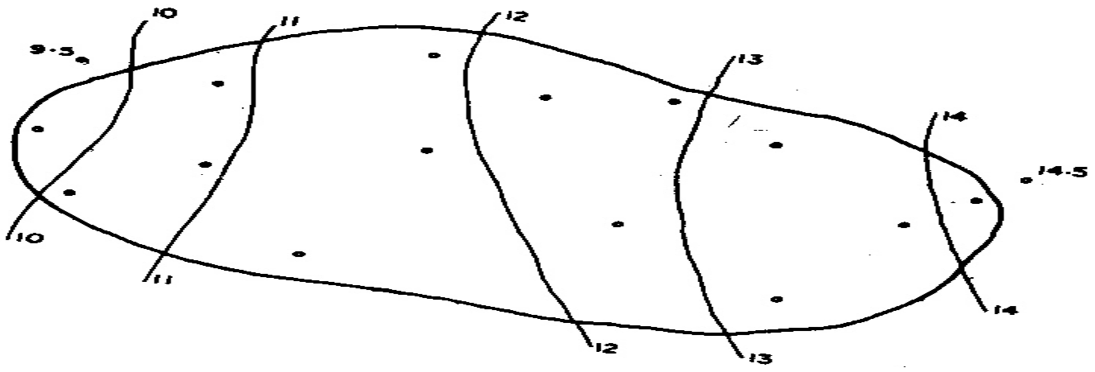
(b) When the mean annual rainfall at each of the Index station differs from the station X by more then 10%, the normal ratio method is used.

$P_X = N_X/3\ (P_A/N_A + P_B/N_B + P_C/N_C)$

Symbol N is used for mean annual rainfall, when there are m Index stations

$P_X = N_X/m\ (P_A/N_A + P_B/N_B + P_C/N_C + \text{----}\ P_M/N_M)$

Isohyetal method: Isohyets are the Counters of equal rain fall depth. An Isohyets map is prepared from the record of various rain gauge stations by interpolation.



(1)The rain gauge station X was inoperative for apart of a month during which a storm occurred .The storm rain fall recorded at the three surrounding stations A,B and C was 75mm,59mm and 85mm respectively. if the average annual rainfall of the station A,B,C and X are 750,650,850 and 700mm respectively estimate the storm rain fall of station X.

Sol: Given data, $P_A = 75mm$ $N_A = 750mm$

$P_B = 59mm$ $N_B = 650mm$

$P_C = 85mm$ $N_C = 850mm$

$N_X = 700mm$

Because the difference in average annual rainfall is more then 10%

$P_X = N_X/3\ (P_A/N_A + P_B/N_B + P_C/N_C)$

$= 700/3(75/750 + 59/650 + 85/850) = 67.8mm$

Computation of average rainfall over a basin

If a basin or catchment area contains more than one rain-gauge station, the computation of average precipitation or rainfall may be done by the following methods

1. Arithmatic average method.
2. Thiessen polygon method.
3. Isohyetal method.

Arithmatic Average Method

If the rainfall is uniformly distributed on its areal pattern, the simplest method of estimating average rainfall. is to compute the arithmatic average of the recorded *rainfall* values at various stations. Thus, if P_1, P_2, P_3,......... P_n etc., are the precipitation or rainfall values measured at n gauge stations, we have

$$P_{av} = \frac{P_1 + P_2 + P_3 \ldots\ldots P_n}{n} = \Sigma P/n$$

Arithmatic Average Method

Station No.	Precipitation(mm)	Average Precipitation
1	12.6	$P_{av} = 72.8/5 = 14.6$
2	18.8	
3	14.8	
4	10.4	
5	16.2	
	ΣP = 72.8mm	

Thiessen Polygon Method

The arithmetic average method is most approximate method since rainfall varies in intensity and duration from place to place. Hence rainfall recorded by each rain-gauge station should be weighed according to the area.. Thiessen polygon method is a more common method of weighing the rain-gauge observations according to the area. Thiessen polygon method is also called weighted mean method and is more accurate than the arithmetic average method.

Procedure

1 Join the adjacent rain-gauge stations, *A, B,* C, *D,* etc., by straight lines.

2 Construct the perpendicular bisectors of each of these lines

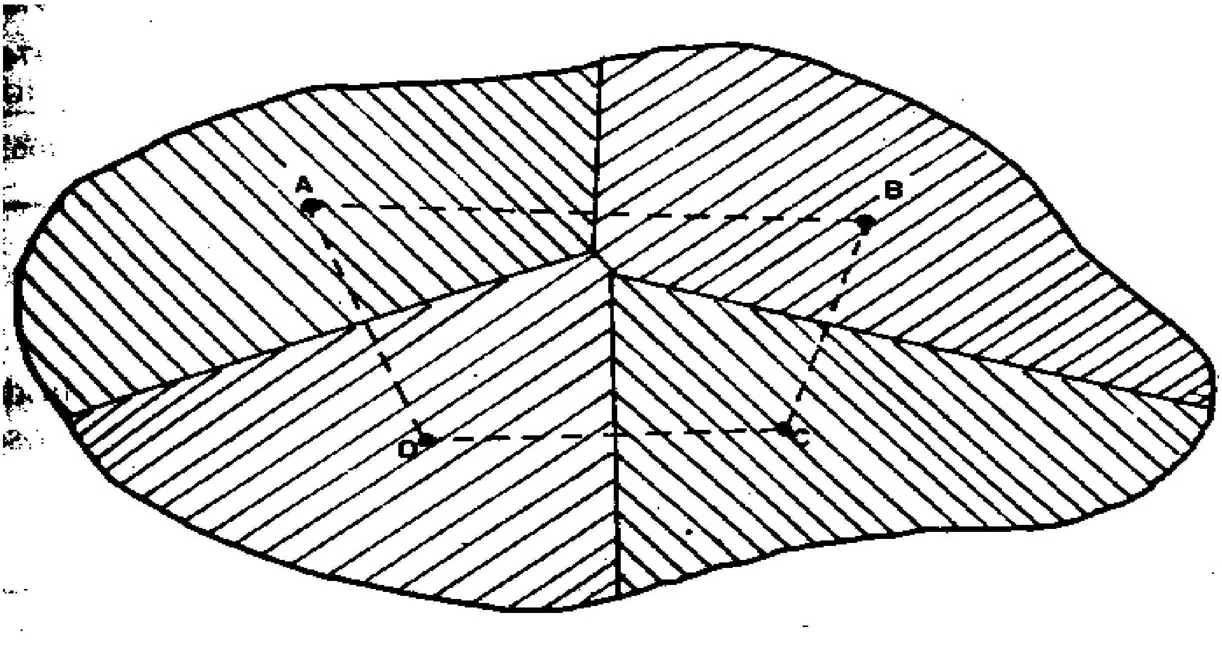
3 A Thiessen network is thus constructed. The polygon formed by the perpendicular bisectors around a station encloses an area which is everywhere closer to that station than to any other station. Find the area of each of these polygons. as shown in figure below.

4 Multiply the area of each Thiessen polygon by the rain gauge value of the enclosed station.

5 Find the total area ΣA of the basin.

6 Compute the average precipitation or rainfall from the equation:

$$P_{av} = \frac{A_1 P_1 + A_2 P_2 + A_3 P_3 \ldots\ldots A_n P_n}{A_1 + A_1 + A_1 \ldots\ldots A_n}$$



Thiessen Polygon Method

Rain-gauge Station	Area of Thiessen Polygon(A)	Precipitation(P)	AxP

A	45 sq. kin		
B	38 sq. kin	30.8 mm	1386
C	30 sq. kin	34.6 mm	1315
D	40 sq. km	32.6 mm	978
		24.6 mm	974

Sum 153 sq-km 4663

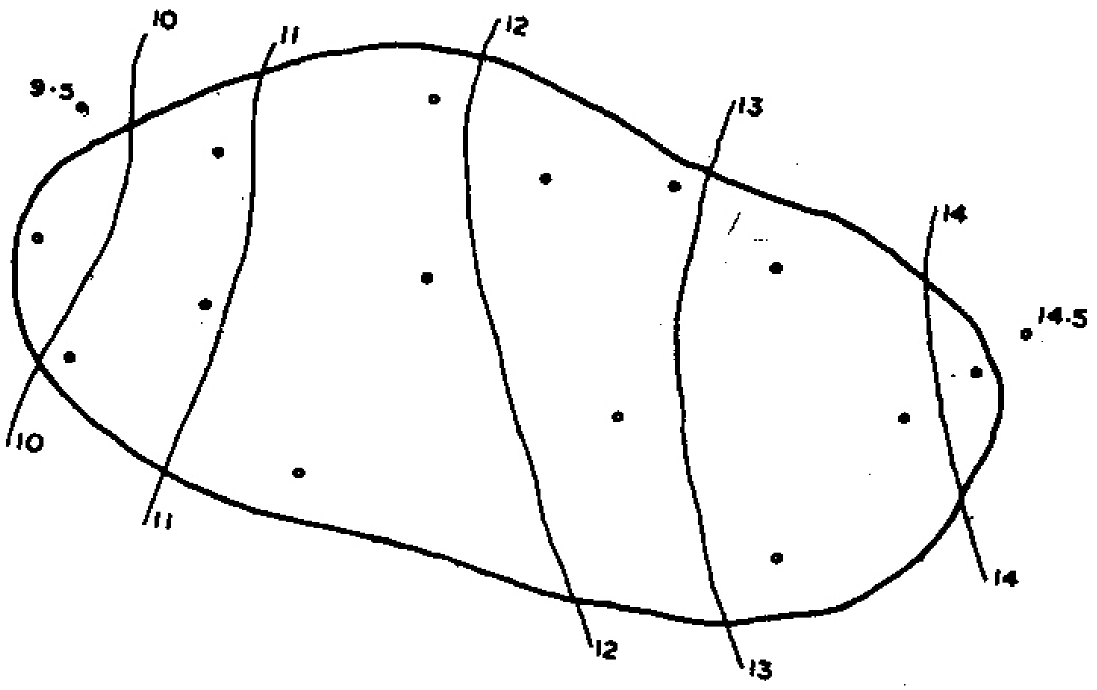
$P_{av} = \Sigma A x P / \Sigma A = 4663/153 = 30.5$

Isohyetal Method

The basic assumption in the Thiessen Polygon method is that a rain-gauge station best represents the area which is close to it. However, this may not always be valid, specially when the rainfall is controlled by topography or results from intense convection. The Isohyetal method is the most elaborate and accurate in such conditions. An Isohyet is a line, on a rainfall map of the basin, joining places of equal rainfall readings. An isohyetal map showing contours of equal rainfall presents a more accurate picture of the rainfall distribution over the basin.

Procedure

1. From the rainfall values recorded at various rain-gauge stations, prepare the isohyetal map for the storm causing the rainfall over the area.
2. Measure the areas enclosed between successive isohyets with the help of planimeter.



3. Multiply each of these areas by the average rainfall between the isohyets;
4. The average rainfall is then computed from the expression

$P_{av} = \underline{\Sigma A x\ [P_1 + P_2/2]}$

ΣA

Isohyetal Method

Isohyets(cm)	Area between Isohyets(A) (sq-.km)	Average precipitation ½($P_1 + P_2$)	Product =Ax(P_1 +P_2)/2
9			
10	22	9.5	209
11	80	10.5	840
12	105	11.5	1208
13	98	12.5	1225
14	78	13.5	1053
15	16	14.5	232
Sum	399		4767

$$P_{av} = \frac{\Sigma Ax\ [P_1 + P_2/2]}{\Sigma A}$$

= 4767/399 = 11.92cm

2.1.5 Average rainfall depth The time of rainfall record can vary and may typically range from 1 minute to 1 day for non – recording gauges, Recording gauges, on the other hand, continuously record the rainfall and may do so from 1 day 1 week, depending on the make of instrument. For any time duration, the average depth of rainfall falling over a catchment can be found by the following three methods. • The Arithmetic Mean Method • The Thiessen Polygon Method • The Isohyetal Method Arithmetic Mean Method The simplest of all is the Arithmetic Mean Method, which taken an average of all the rainfall depths as shown in Figure .

FIGURE 1. A hypothetical catchment showing four raing gauge stations

In Figure 1, a catchment of a river is shown with four rain gauges, for which an assumed recorded value of rainfall depth have been shown in the table.

assumed recorded value of rainfall depth have been shown in the table. Time (in hours)		Total Rainfall				
First		Second		Third	Fourth	
Rain(mm)	A	15	10	3	2	30
	B	12	15	8	5	40
	C	8	10	6	4	28
	D	5	8	2	2	17

It is on the basis of these discrete measurements of rainfall that an estimation of the average amount of rainfall that has probably fallen over a catchment has to be made. Three methods are commonly used, which are discussed in the following section.

Depth-Area-Duration curves

In designing structures for water resources, one has to know the areal spread of rainfall within watershed. However, it is often required to know the amount of high rainfall that may be expected over the catchment. It may be observed that usually a storm event would start with a heavy downpour and may gradually reduce as time passes. Hence, the rainfall depth is not proportional to the time duration of rainfall observation. Similarly, rainfall over a small area may be more or less uniform. But if the area is large, then due to the variation of rain falling in different parts, the average rainfall would be less than that recorded over a small portion below the high rain fall occurring within the area. Due to these facts, 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 which would look as shown in Figure

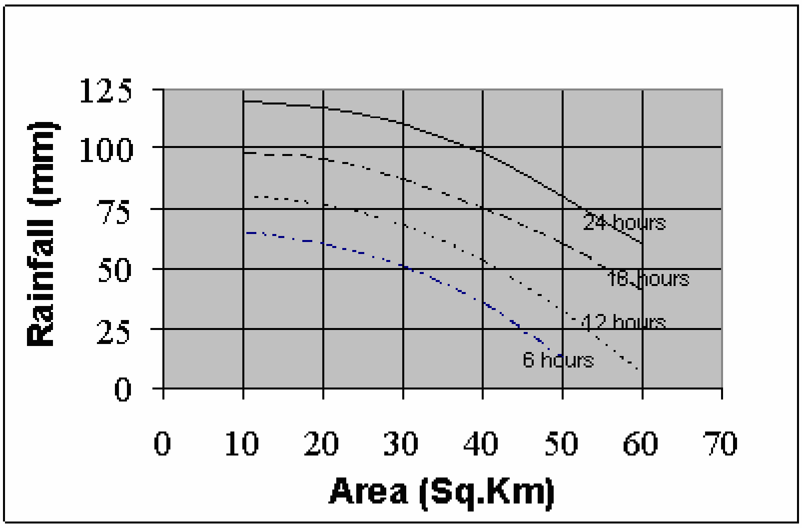


FIGURE 5. A typical Depth-Area-Duration (DAD) curve

Intensity-Duration-Frequency curves

The analysis of continuous rainfall events, usually lasting for periods of less than a day, requires the evaluation of rainfall intensities. The assessment of such values may be made from records of several part storms over the area and presented in a graphical form as shown in Figure .

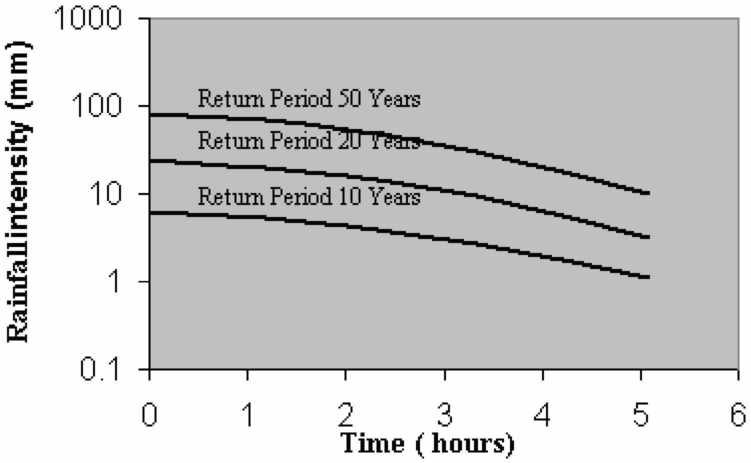


FIGURE 6. A typical rainfall intensity-duration-frequency (IDF) curve

Two new concepts are introduced here, which are:

- **Rainfall intensity**

  This is the amount of rainfall for a given rainfall event recorded at a station divided by the time of record, counted from the beginning of the event.
- **Return period**

  This is the time interval after which a storm of given magnitude is likely to recur. This is determined by analyzing past rainfalls from several events recorded at a station. A related term, the frequency of the rainfall event (also called the storm event) is the inverse of the return period. Often this amount is multiplied by 100 and expressed as a percentage. Frequency (expressed as percentage) of a rainfall of a given magnitude means the number of times the given event may be expected to be equaled or exceeded in 100 years.

Analysis for anomalous rainfall records

Rainfall recorded at various rain gauges within a catchment should be monitored regularly for any anomalies. For example of a number of recording rain gauges located nearby, one may have stopped functioning at a certain point of time, thus breaking the record of the gauge from that time onwards. Sometimes, a perfectly working recording rain gauge might have been shifted to a neighbourhood location, causing a different trend in the recorded rainfall compared to the past data. Such difference in trend of recorded rainfall can also be brought about by a change in the neighbourhood or a change in the ecosystem, etc. These two major types of anomalies in rainfall are categorized as

- Missing rainfall record
- Inconsistency in rainfall record

Missing rainfall record

The rainfall record at a certain station may become discontinued due to operational reasons. One way of approximating the missing rainfall record would be using the records of the three rain gauge stations closet to the affected station by the "Normal Ratio Method" as given below:

Where P_4 is the precipitation at the missing location, N_1, N_2, N_3 and N_4 are the normal annual precipitation of the four stations and P_1, P_2 and P_3 are the rainfalls recorded at the three stations 1, 2 and 3 respectively.

Inconsistency in rainfall record

This may arise due to change in location of rain gauge, its degree of exposure to rainfall or change in instrument, etc. The consistency check for a rainfall record is done by comparing the accumulated annual (or seasonal) precipitation of the suspected station with that of a standard or reference station using a double mass curve as shown in Figure

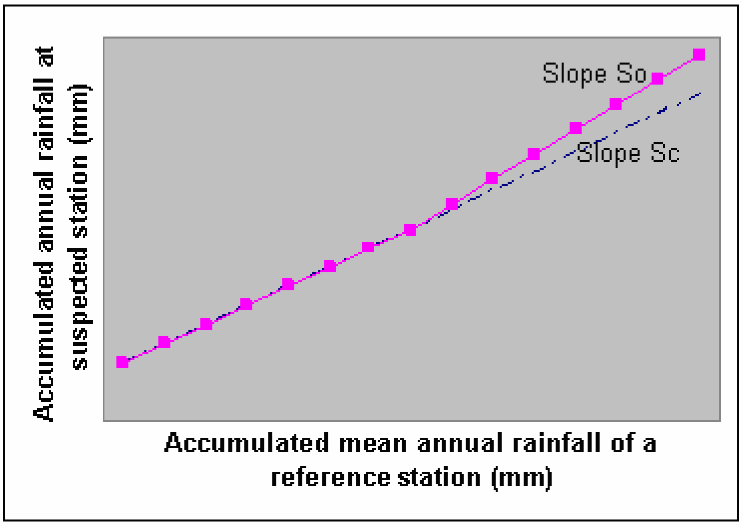


FIGURE 7. A typical example of inconsistent rainfall record

From the calculated slopes S_0 and S_c from the plotted graph, we may write

Where P_c and P_0 are the corrected and original rainfalls at suspected station at any time. S_c and S_0 are the corrected and original slopes of the double mass-curve.

2.1.10 Probable extreme rainfall events

Two values of extreme rainfall events are important from the point of view of water resources engineering. These are:

Probable Maximum Precipitation (PMP)

This is the amount of rainfall over a region which cannot be exceeded over at that place. The PMP is obtained by studying all the storms that have occurred over the region and maximizing them for the most critical atmospheric conditions. The PMP will of course vary over the Earth's surface according to the local climatic factors. Naturally, it would be expected to be much higher in the hot humid equatorial regions than in the colder regions of the mid-latitudes when the atmospheric is not able to hold as much moisture. PMP also varies within India, between the extremes of the dry deserts of Rajasthan to the ever humid regions of South Meghalaya plateau.

Standard Project Storm (SPS)

This is the storm which is reasonably capable of occurring over the basin under consideration, and is generally the heaviest rainstorm, which has occurred in the region of the basin during the period of rainfall records. It is not maximized for the most critical atmospheric conditions but it may be transposed from an adjacent region to the catchment under considerations.

The methods to obtain ***PMP*** and ***SPS*** are involved and the interested reader mayfind help in text books on hydrology, such as the following:

- Mutreja, K N (1995) Applied Hydrology, Tata McGraw Hill
- Subramanya, K (2002) Engineering Hydrology, Tata McGraw Hill

2.1.11 Evapotranspiration

As discussed earlier, evapotranspiration consists of evaporation from soil and water bodies and loss of water from plant leaves, which is called transpiration. It is a major component of the hydrologic cycle and its information is needed to design irrigation projects and for managing water quality and other environmental concerns. In urban development, evapotranspiration

flood control. The term consumptive use is also sometimes used to denote the loss of water molecules to atmosphere by evapotranspiration. For a given set of atmospheric conditions, evapotranspiration depends on the availability of water. If sufficient moisture is always available to completely meet the needs of vegetation fully covering the area, the resulting evapotranspiration is called potential evapotranspiration (PET). The real evapotranspiration occurring in a specific situation is called actual evapotranspiration (AET).

2.1.12 Measurement of evapotranspiration

There are several methods available for measuring evaporation or evapotranspiration, some of which are given in the following sub-sections.

Potential Evapotranspiration (PET)

- **Pan evaporation**

The evaporation rate from pans filled with water is easily obtained. In the absence of rain, the amount of water evaporated during a period (mm/day) corresponds with the decrease in water depth in that period. Pans provide a measurement of the integrated effect of radiation, wind, temperature and humidity on the evaporation from an open water surface. Although the pan responds in a similar fashion to the same climatic factors affecting crop transpiration, several factors produce significant differences in loss of water from a water surface and from a cropped surface. Reflection of solar radiation from water in the shallow pan might be different from the assumed 23% for the grass reference surface. Storage of heat within the pan can be appreciable and may cause significant evaporation during the night while most crops transpire only during the daytime. There are also differences in turbulence, temperature and humidity of the air immediately above the respective surfaces. Heat transfer through the sides of the pan occurs and affects the energy balance.

Notwithstanding the difference between pan-evaporation and the evapotranspiration of cropped surfaces, the use of pans to predict ET_o for periods of 10 days or longer may be warranted. The pan evaporation is related to the reference evapotranspiration by an empirically derived pan coefficient:

$$ET_o = K_p E_{pan}$$

Where

ET_o reference evapotranspiration [mm/day],

K_p pan coefficient [-],

E_{pan} pan evaporation [mm/day].

- **Evapotranspiration gauges** The modified Bellani plate atmometer has been offered as an alternative and simpler technique to combination-based equations to estimate evapotranspiration (ET) rate from green grass surface.

Actual Evapotranspiration (AET)

- **Simple methods**
  - Soil water depletion method

Evapotranspiration can be measured by using soil water depletion method. This method is usually suitable for areas where soil is fairly uniform. Soil moisture measured at various time intervals. Evapotranspiration can be measured from the difference of soil moisture at various time levels.

  - Water balance method

The method is essentially a book-keeping procedure which estimates the balance between the inflow and outflow of water. In a standard soil water balance calculation, the volume of water required to saturate the soil is expressed as an equivalent depth of water and is called the soil water deficit. The soil water balance can be represented by:

$$Ea = P - Gr + \Delta S - Ro$$

Where, Gr = recharge;
P = precipitation;
Ea = actual evapotranspiration;
ΔS = change in soil water storage; and
Ro = run-off.

- **Complex methods**
  - Lysimeters

A lysimeter is a special watertight tank containing a block of soil and set in a field of growing plants. The plants grown in the lysimeter are the same as in the surrounding field. Evapotranspiration is estimated in terms of the amount of water required to maintain constant moisture conditions within the tank measured either volumetrically or gravimetrically through an arrangement made in the lysimeter. Lysimeters should be designed to accurately reproduce the soil conditions, moisture content, type and size of the vegetation of the surrounding area. They should be so hurried that the soil is at the same level inside and outside the container. Lysimeter studies are time-consuming and expensive.

  - Energy balance method

The energy balance consists of four major components: net radiation input, energy exchange with soil, energy exchange to heat the air (sensible heat) and energy exchange to evaporate water (latent energy). Latent energy is thus the budget involved in the process of evapotranspiration: Net Radiation -Ground Heat Flux = Sensible Heat + Latent Energy

The energy balance method of determining Evapotranspiration can be used for hourly values during daylight hours but accurate night time values are difficult to obtain. Eddy diffusion equations can be used and combinations of these procedures can be used also to calculate evapotranspiration. The method used is governed often by the data available, the accuracy needed, and the computational capability.

  - Mass transfer method :

This is one of the analytical methods for the determination of lake evaporation. This method is based on theories of turbulent mass transfer in boundary layer to calculate the mass water vapour transfer from the surface to the surrounding atmosphere.

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