JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY ANANTAPUR

B.Tech (CE)– III-I Sem

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(19A01502) WATER RESOURCE ENGINEERING

Course Objectives:

- To Illustrate hydrologic cycle and its relevance to Civil engineering
- To teach students understand physical processes in hydrology & components of the
- hydrologic cycle
- To demonstrate concepts and theory of physical processes and interactions
- To impart on measurement and estimation of the components hydrologic cycle.
- To provide an overview and understanding of Unit Hydrograph theory, flood frequency and its analysis

UNIT -I

Introduction:
Engineering hydrology and its applications, Hydrologic cycle, hydrological data-sources of data. **Precipitation**: Types and forms, measurement, rain gauge network, presentation of rainfall data, average rainfall, continuity and consistency of rainfall data, frequency of rainfall, Intensity-Duration-Frequency (IDF) curves, Depth-Area-Duration (DAD) curves, Probable Maximum Precipitation (PMP), design storm

Learning Outcomes:

At the end of this unit, the student will be able to

- Understand basics of engineering hydrology and its applications.
- Demonstrate measurement techniques of precipitation.
- Learn curves related to frequency of rainfall..

UNIT-II

Abstractions from Precipitation:
Initial abstractions. Evaporation: factors affecting, measurement, reduction Evapo-transpiration: factors affecting, measurement, control - Infiltration: factors affecting, Infiltration capacity curve, measurement, infiltration indices.

Learning Outcomes:

At the end of this unit, the student will be able to

- Attain knowledge on factors influencing evaporation.

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- Analyze factors influencing infiltration.

UNIT-III

Runoff and Hydrograph analysis:
Catchment characteristics, Factors affecting runoff, components, computation- empirical formulae, tables and curves, stream gauging, rating curve, flow mass curve and flow duration curve. Components of hydrograph, separation of base flow, effective rainfall hyetograph and direct runoff hydrograph, unit hydrograph, assumptions, derivation of unit hydrograph, unit hydrographs of different durations, principle of superposition and S-hydrograph methods, limitations and applications of unit hydrograph, synthetic unit hydrograph – Floods: Causes and effects .

Learning Outcomes:

At the end of this unit, the student will be able to

- Determine runoff characteristics and factors influencing runoff.
- Examine components of hydro graph.
- Develop knowledge on floods and its effects.

UNIT-IV

Groundwater: Occurrence, types of aquifers, aquifer parameters, porosity, specific yield, permeability, transmissivity and storage coefficient, types of wells, Darcy's law, Dupuit's equation- steady radial flow to wells in confined and unconfined aquifers, yield of a open well-recuperation test.

Learning Outcomes:

At the end of this unit, the student will be able to

- Understand basics about ground water.
- Learn and implement Darcy's law and Dupuit's equation.

UNIT-V

IRRIGATION:
Introduction-necessity and impotence of irrigation-advantages and ill-effects of irrigation; types of irrigation; methods of application of water; quality for irrigation water; duty and delta; duty at various places; relation between duty and delta; factors affecting duty; methods of improving duty; soil-water-plant relationship; limiting soil moisture conditions, depth and frequency of irrigation.

LIST OF DRAWINGS:

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Draw the following irrigation structures.

1. Sloping glacis weir
2. Surplus weir.
3. Tank sluice with tower head
4. Type III Syphon aqueduct.
5. Canal regulator.

Course Outcomes

At the end of the course the students are able to

- Understand of the theories and principles governing the hydrologic processes.
- Identify major hydrologic components and apply key concepts to several practical areas of engineering hydrology and related design aspects.
- Develop Intensity-Duration-Frequency and Depth-Area Duration curves to design hydraulic structures.
- Determine aquifer parameters, yield of wells and model hydrologic processes.
- Understand duty and delta.
- Understand soil, water, plant relationships.
- Design the Hydraulic structures.

TEXT BOOKS:

1. Jayarami Reddy P., "Engineering Hydrology", Laxmi Publications Pvt. Ltd., (2013). New Delhi
2. B.C. Punmia, Pande B. B. Lal, Ashok Kumar Jain and Arun Kumar Jain, "Irrigation and Water Power Engineering", Lakshmi Publications (P) Ltd.
3. C.Satyanarayana Murthy, "Design of minor irrigation and canal structures", Wiley eastern Ltd

REFERENCES:

1. Subramanya K., "Engineering Hydrology", Tata McGraw-Hill Education Pvt Ltd, (2013). New Delhi.
2. Santosh Kumar Garg," Irrigation Engineering and Hydraulic Structure", Khanna Publishers.
3. Chow V.T., D.R Maidment and L.W. Mays, "Applied hydrology", Tata McGraw Hill Education Pvt Ltd, (2011), New Delhi.
4. Mays L.W, "Water Resources Engineering", Wiley India Pvt. Ltd, (2013).

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Introduction - Precipitation

Engineering Hydrology:-

An irrigation engineer is not only concerned with the collection and distribution of water for irrigation, but it is also essential for him to know about the occurance, distribution and movement of water on the earth.

Hydrology is the science which deals with the occurance, distribution and movement of water on the earth. including that the atmosphere and below the surface of the earth is known as "Hydrology".

Applications of Engineering Hydrology:-

Hydrology is applied to major civil engineering projects such as,

→ Irrigation schemes
→ Dams and Hydroelectric power projects and
→ water supply projects.
→ Determining agricultural water balance
→ Designing urban drinking water and sewer system
→ Determine the water balance for a region
→ Hydrology is used to find out maximum probable flood at proposed sites (Ex:-Dams)
→ The variation of water production from catchment can be calculated and described by hydrology.

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→ Engineering Hydrology enables to find out the relationship between a catchment surface and groundwater resources.

→ Hydrological investigations help us to know the required reservoir capacity to assure adequate water for irrigation (or) Municipal water supply in drought's condition.

→ Hydrology is an essential tool in planning and building hydraulic structures.

→ Hydrology is used for city water supply design such which is based on catchment area, amount of rainfall, storage capacity.

→ Dam construction, reservoir capacity, spillway capacity, sizes of water supply pipelines all are designed on basis of hydrological equations.

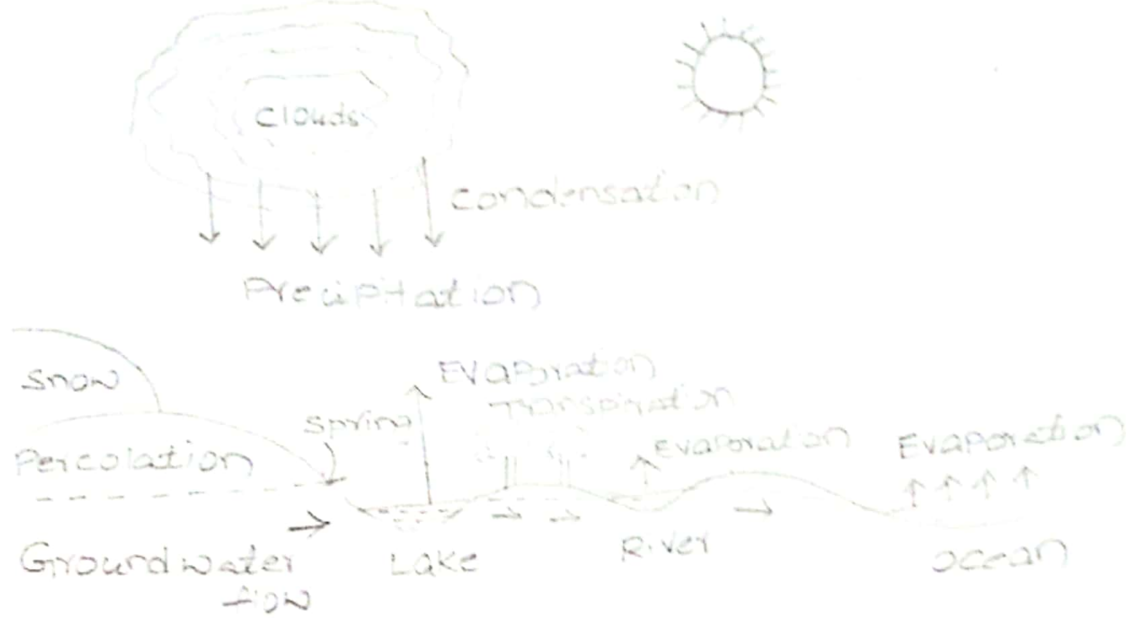
→ Designing dams for water supply (or) hydroelectric Power Generation.

→ It tell us what hydrologic hardware (eg rain gauges, stream gauges etc) and software (computer Models) are needed for real time flood forecasting.

Hydrological cycle:-

An irrigation engineer is not only concerned with the collection and distribution of water from irrigation, but it is also essential for him to know about the occurance, distribution and movement of water on earth.

Hydrology is the science which deals with the occurance, distribution and movement of water on the earth, including that in the atmosphere and below the surface of the earth. water occures in the atmosphere in the form of vapour on the surface as water, snow (or) ice and below the surface as ground water occupying all the voids with in a geologic stratum.



Hydrologic cycle

Except for the deep ground water, the total water supply of earth is in constant circulation from earth to atmosphere, and back to the earth. The earth's water circulatory system is known as the "hydrologic cycle".

Hydrologic cycle is the process of transfer of moisture from the atmosphere to the earth in the form of precipitation, conveyance of the precipitated water by streams and rivers to ocean and lakes ..etc. and evaporation of water back to the atmosphere.

The hydrologic cycle consists of the following processes are,

1) Evaporation and Transpiration (E)
2) Precipitation (P)
3) Runoff (R).

Evaporation and transpiration:-

The water from the surface of ocean, rivers lakes 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. Thus, the total evaporation (E), inclusive of the transpiration consists of,

1) surface evaporation.
2) water surface evaporation
   (a) From river surface
   (b) From oceans
3) Evaporation from plants and leaves
4) Atmospheric evaporation.

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2) Precipitation (P):-

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

Precipitation may be two forms,

(a) liquid precipitation i,e rainfall

(b) Frozen precipitation : This consists of,

(i) snow ii) Hail iii) sleet iv) Freezing rain

3) Run off (R):-

Run off is that portion of precipitation that is not evaporated. when moisture falls to the earth surface as precipitation, a part of it's evaporated from the water surface, soil and vegetation and through transpiration by plants, and the reminder precipitation is avalable as run off which ultimately runs to the ocean through surface (or) sub-surface streams.

The run off may be classified as follows,

(i) Surface Run off:-

water flows over the land and is first to reach the streams and rivers, which ultimately discharge the water to the sea.

ii) sub-surface Run off:-

A portion of precipitation infiltrates into surface soil and depending upon the geology of the basins, runs as sub-surface runoff and reaches the streams and rivers.

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iii) Ground water flow (or) base flow:-

It is that portion of precipitation, which after infiltration, percolates down and joins the ground water reservoir which is ultimately connect to the ocean.

The hydrologic cycle may be expressed by the following simplified equation.

Precipitation = Evaporation + Runoff

$$\boxed{\therefore \quad P = E + R}$$

Hydrological Data:-

The main components of the hydrologic cycle are,

(i) precipitation
ii) evaporation including transpiration
iii) Run off

including direct runoff, infiltration, deep percolation and ground water runoff.

The following hydrological data are required

(1) weather and climate records
(2) precipitation data
(3) stream flow data
(4) Evaporation and transpiration Data
(5) Infiltration characteristics of the area.
(6) Ground water characteristics
(7) physical and Geological characteristics.

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(i) Weather and climate records:-

Data about temperature, humidity, radiation wind etc, since these directly affect hydrological parameters.

ii) Precipitation Data:-

The study of precipitation forms a major portion of the subject hydro-Meteorology The precipitation data helps in predicting runoff volume and it's peak. and also estimating water budget equation for the basin.

iii) stream flow data:-

This helps in the planning of reservoirs, design of spillways, bridges, culverts, levees and water power development and installation. The data is utilised for determination of maxim (Peak) flood, flood frequency, reservoir elevation water budget etc.

iv) Evaporation and transpiration Data:-

This data is required for determining (i) water budget for the river basin (ii) reservoir capacity for water resource development and iii) evaporation supression technique.

v) Infiltration characteristics of the data:-

This data helps in determining rainfall

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excess and run off computation.

vi) Ground water characteristics:-

This helps in estimation and location of ground water reservoir, for ground water development

vii) Physical and Geological characteristics:-

This helps in the determination of runoff pattren and silt load movement, Indian Meteorological Department (IMD) is largely responsible for the collection for Meteorological data along with some state government agencies.

Water Budget (or) sources of Data:-

Water budgets are classified into two types they are,

(i) ~~water budget~~ Global water budget

(ii) India's water budget.

(i) Global water budget:-

→ Water is the natural resource which is vital all forms of life on the earth. Water is a crucial element in development planning.

→ The total quantity of water in the world is roughly 1360 Million cubic kilometers [$1 MKM^3 = 10^{15} M^3$] out of which about 97.2% is held up in seas and oceans while about 2.1% is frozen in ice caps, and 0.31% is available as deep ground water.

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ii) India's water budget:-

→ India has a geographical area of nearly 3.3 million square kilometers.

→ Normal annual rainfall varies from 100mm in westren Rajasthan to over 11000mm at cherrapunji in Meghalaya.

→ The annual avg. rainfall over the country is of the order of 1170mm depth which is nearly 4000 km^3 of the total precipitation, a part goes towards increasing ground water storage.

→ The avg flow in the river system of the country has been estimated to be 1880 km^3.

→ central water commission (cwc) indicate that the water resource utilisable through surface structu is about 690 KM^3 only.

→ The preliminary estimate of the central Ground water board indicate that the utilisable ground water is about 450 km^3.

precipitation:-

precipitation is defind as the general term for all forms of moisture emanating from the clouds and falling to the ground is known as "precipitation".

The following are the essential requirements for precipitation are,

1) some Mechanism is required to cool the air sufficiently to cause condensation and droplet growth.

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2. condensation nuclii are also necessary for formation of droplets. they are usually present in the atmosphere in adequate quantities.

3. Large scale cooling is essential for significant amount of precipitation.

Types of precipitation:-

precipitation is often classify according to the factors responsible for lifting.

There are four types of precipitation are.

(1) cyclone precipitation

(2) convective precipitation

(3) orographic precipitation

(4) precipitation due to turbulent ascent.

1. cyclone precipitation:-

cyclonic precipitation results from lifting of air masses converging into low pressure area of cyclone. The cyclonic precipitation may be devided into

(i) Frontal precipitation

(ii) Non-frontal precipitation.

(i) Frontal precipitation:-

→ A border region between ~~the~~ two adjacent air masses having different characteristics such as temperature and humidity is called a front.

→ when a flow of warm and moist air mass from the south meets and cold air mass of Polar region the cold air being ~~behaviour~~ heavie under the run warm air flow in the form of flat wedge forcing the warm air aloft.

→ the lifted warm air mass cools down at high altitudes, causing precipitation

→ A front may be warm front (or) cold front depending upon whether there is active (or) passive ascent of warm air mass over cold air mass.

ii) Non-Frontal precipitation:-

→ In Non-frontal precipitation, the moist warm air mass is stationary and the moving cold air mass meets it.

→ Thus, due to lightness of the warm air there is passive ascent of warm air over cold air owing to the active under cutting.

→ when the lifted warm air cools down at higher altitude precipitation occurs.

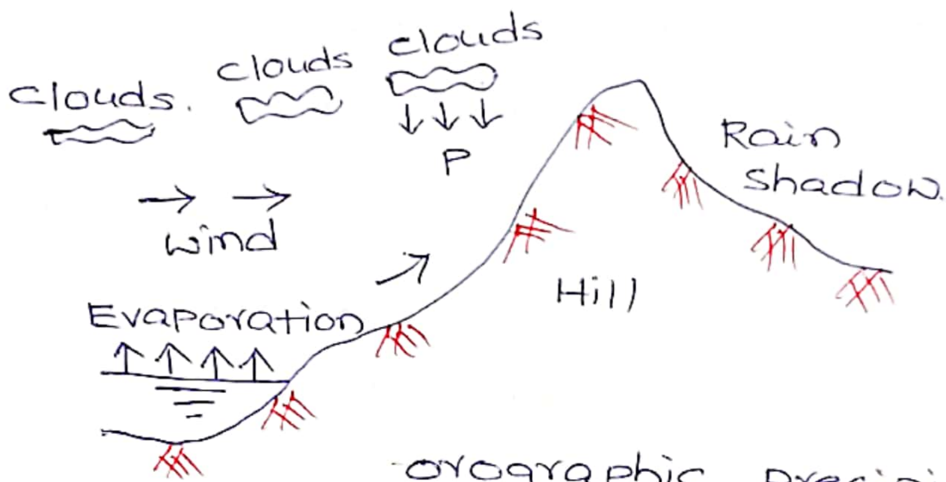
(2) convective precipitation:-

→ convective precipitation is caused by natural rising of warmer lighter air in colder, denser surroundings.

→ The difference in temperature may result from unequal heating at the surface, unequal cooling at the top of the air layer or Mechanical lifting when air is forced to pass over a denser colder air masses.

→ Convective precipitation is spotty and its intensity may vary from light showers to cloud bursts.

3. Orographic Precipitation:-



Orographic precipitation

→ Orographic precipitation is due to the lifting of warm moisture laden air masses due to topographic barriers (such as mountains).

→ As it reaches higher elevation, it comes in contact with cold air and precipitation occurs.

→ The zone to the other side of the mountain will be the zone of rain shadow area where the rainfall may not occur,

→ All the precipitation we have in Himalayan region is because of the orographic ascent of air masses rich in moisture content because of their long travel over oceans.

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4) Precipitation Due to turbulent ascent:-

→ Air mass is forced to rise up due to greater friction of earth surface after it's travel over ocean.

→ The air mass rises up because of increased turbulence and friction, when it ultimately condenses and precipitation occurs.

→ winter rainfall in Madras state in mainly due to this process.

→ In nature, the effects of these various types of cooling are often inter related and the resulting precipitation can not be identified.

Forms of precipitation:-

The various forms of precipitation are,

1) Drizzle
2) rain
3) Glaze
4) sleet
5) snow
6) snow flakes
7) hail

Drizzle:-

When the size of water droplets is under 0.5mm, and its intensity is <1mm per hour. Because of the lightness the droplets appear to be floating in air.

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ii) Rain:-

when the size of the ~~wat~~ drops is more than 0.5mm. The upper size of water drop is generally 6.25mm, as drops greater than this tend to break up as they fall through the air.

iii) Glaze:-

when the drizzle (or) rain freezes as it comes in contact with cold objects it is known as "glaze".

iv) sleet:-

It is frozen rain drops cooled to the ice stage while falling through air at subfreezing tempera ture.

v) snow:-

Precipitation in the form of ice crystals resulting from sublimations (i/e water vapour changed directly to ice)

vi) snowflakes:-

Number of ice crystals fused together form snow flakes.

vii) Hail:-

Hail is lumps (or) bulbs of ice ~~water~~ over 5mm diameter formed by alternate freezing (or) melting as they are carried up and down in highly turbulent air currents.

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Rainfall:-

The major rainfall season in India is from June to october. India lies in the tropical belt (i,e North of Equator) and has the following four distinct weather periods.

(i) Monsoon period
(ii) Post monsoon period
iii) winter rainfall period
iv) summer rainfall period.

Measurement of rain fall:-

Rainfall is the source of all water used for irrigation purposes and therefore a knowledge of its amount, character, seasons (or) periods and the effects produced by it is prime important of all whose duty is to design, carry out, improve (or) maintain irrigation works.

The amount of precipitation is expressed as depth in centimeters which falls on a level surface, and is measured by "rain gauge."

The following are the main types of rain gauges used for measurement of rainfall.

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1. Non - automatic rain gauge
2. Automatic rain gauge.

1. Non - Automatic rain gauge:-

This is also known as non-recording rain gauge. symon's rain gauge is the instrument prescribed by use at all government rain-gauge stations throughout India.

2. Automatic rain gauge:-

This are integrating type recording rain gauges are of three types

1) Weighing bucket rain gauge
2) Tipping bucket rain gauge
3) Float type rain gauge.

1. Symon's ~~Weighing bucket~~ rain gauge:-

→ symon's rain gauge is most common type of non- automatic rain gauge. and used by Meterological Department of government of India.

→ It consists of cylindrical vessel 127 mm in diameter with a base enlarged to 210mm.

→ The top section is a funnel provided with circular brass rim exactly 127 mm internal diameter.

→ A funnel shank is inserted in the neck of a receiving bottle which is 75mm to 100mm diameter.

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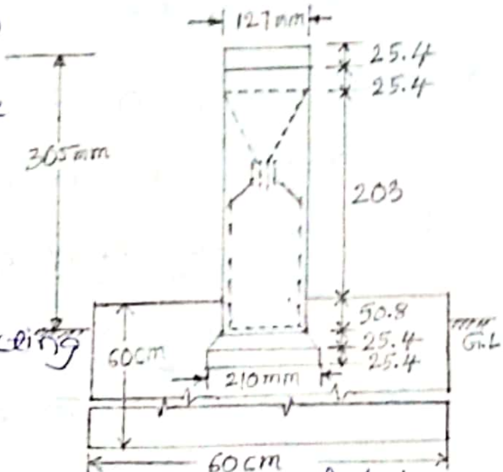
→ A receiving bottle of rain gauge has a capacity of about 75 mm to 100mm of rainfall and as during a heavy rainfall this quantity is frequently exceeded, the rain should be measured 3 or 4 times in a day on day of heavy rainfall the reciever fill should overflow.

→ A cylindrical graduated measuring glass is furnished with each instrument which reads to 0.2mm. The rainfall should be estimated to the nearest 0.1 mm.

Symon's Raingauge

→ The raingauge is set up in a concrete block 60 cm × 60 cm × 60 cm

→ The rim should be 305 mm above the surface of the ground.



→ The following important points should be kept mind while selecting site for a rain gauge station.

→ The site where a rain gauge is set up should be an open place.

→ The distance b/w the rain gauge and nearest object should be atleast twice the height of the object. In no case should it be nearer to the obstruction than 30 meters.

→ The raingauge should never be situated on the side or top of a hill if a suitable site on a level ground can be found.

→ In the hills, where it is difficult to find level space, the size for the gauge should be chosen where it is best shielded from high winds, and where the wind does not cause eddies.

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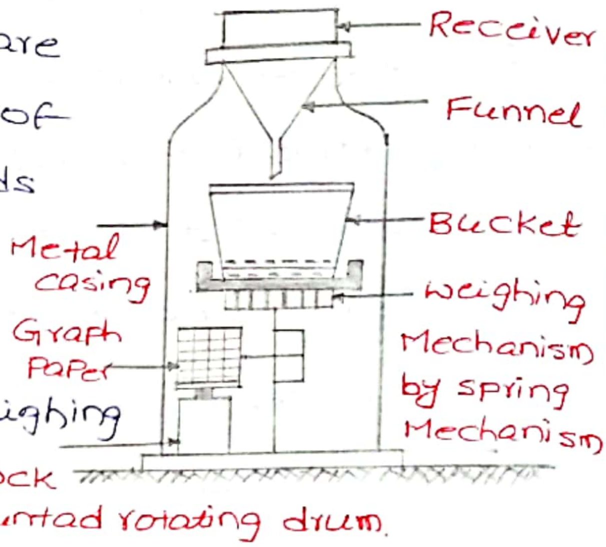
→ A fence, if erected to protect gauge from cattle should be so located that distance of the fence is not less than twice its height.

2. Weighing bucket rain gauge:-



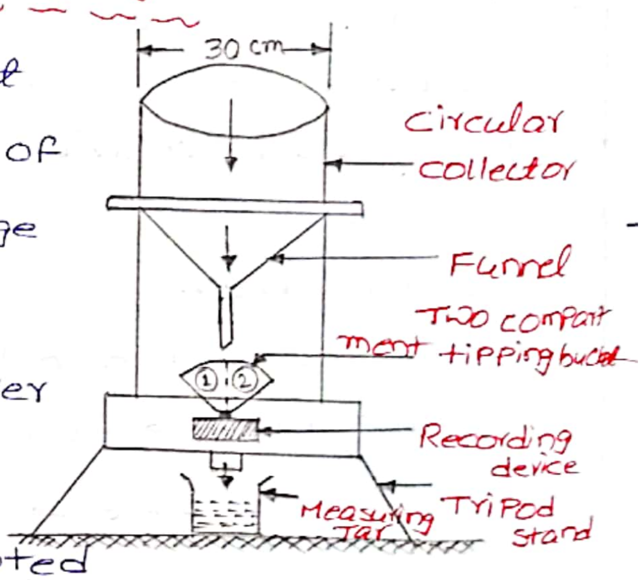
→ Self recording gauges are used to determine rates of rainfall over short periods of time.

→ The most common type of self recording gauge is weighing bucket type.

→ The weighing bucket rain gauge essentially consists of reciever bucket supported by a spring (or) lever balance (or) any other weighing mechanism.

→ The Movement of the bucket due to it's increasing weight is transmitted to a pen which traces the record clock on a clock driven chart.

3. Tipping Bucket Type rain gauge:-



→ A steven's tipping bucket type rain gauge consists of 300mm diameter sharp edge reciever.

→ At the end of the reciever is provided a funnel.

→ A pair of bucket are pivoted under the funnel in suchway that when one bucket recieves 0.25mm of precipitation it tips,

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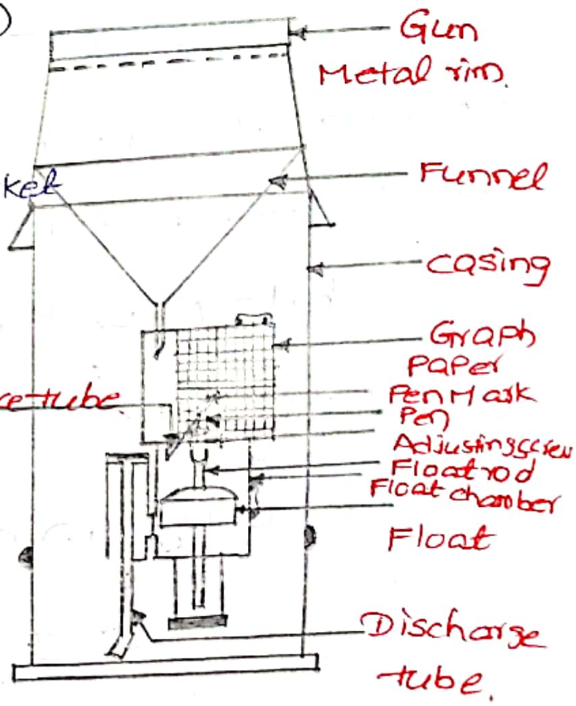
discharging it's contents into a container.
bringing the other bucket compleles an electric circuit causing the movement of Pen to mark on clock driven revolving drum which carries a record sheet.

→ The electric Pulses generated due to the tipping of the bucket is recorded at the control room far away from the rain gauge station.

4. Float (or) syphon type raingauge:-



→ The working of a float (or) syphon type rain gauge is similar to the weighing bucket type gauge.

→ A funnel recieves the rain water which is collected in a rectangular container.

→ A float is provided at the bottom of 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 container rises 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.

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Advantages of Recording rain-gauges:-

The following are the advantages of recording type rain gauge over the non-recording type,

→ The rainfall is recorded automatically and therefore, there is no necessity of any attendant.

→ The recording rain gauge also give the intensity of rainfall at any time while the non-recording gauge gives the total rainfall in any particular interval of time.

→ As no attendant is required such rain gauge can be installed in far-off places also.

→ Possibility of human error is obviated.

Disadvantages:-

→ It is costly in comparision with non-recording gauge.

→ Fault may develop in electrical (or) Mechanical mechanism (or) recording the rainfall.

Raingauge Network:-

→ It is absolutely essential to design a proper network raingauges in a given catchment to collect the necessary precipitation Data.

→ The raingauge density (or) Network density is defined as the ratio of total area of catchment to the total number of gauges in the catchment.

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→ It is also recomonded that 10% of the gauges are of recording type. The network arrived at based on the above ~~recomonden~~ recommendations should be located that all the gauges will have more (or) less equal. Thissen weights.

The optimum No. of rain gauge station (N) is given by,

$$N = \left[\frac{C_V}{P}\right]^2$$

where,

C_V = co-efficient of variation of the rainfall values of existing stations.

$$= \frac{\sigma_x}{\bar{x}} \times 100$$

σ_x = standared deviation

$\bar{x}$ = Mean of rainfall values of existing stations.

P = Desired degree of error in estimating mean rainfall.

Note:-

→ If $N < n$, the number of existing stations, the existing network estimates the avg depth of rainfall with an error less than allowable value P. and no more gauges are required.

→ If $N > n$, the number of additional rain gauge station will be $(N-n)$, and should be distributed in different zones in proportion to their areas and depend upon spatial distribution of the existing raingauge

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stations and the variability of the rainfall over the basin.

1) A catchment has five raingauge stations. In a year, the annual rainfall recorded by the gauges are 78.8cm, 90.2cm, 98.6cm, 102.4cm and 70.4cm. For a 6% error in estimation of the mean rainfall, Determine the additional number of gauges needed.

Sol:-

Given Data:-

Rain gauges are = 78.8cm, 90.2cm, 98.6cm, 102.4cm and 70.4cm.

∴ Mean rainfall $(\bar{x}) = \frac{1}{n}\sum x_i$

$$= \frac{78.8+90.2+98.6+102.4+70.4}{5}$$

$$= 88.08 \text{ cm}.$$

∴ The standared deviation of the rainfall is given by,

$$\sigma_x^2 = \frac{\sum(x_i - \bar{x})^2}{n-1}$$

$$\sigma_x^2 = \frac{\left[(78.8-88.08)^2+(90.2-88.08)^2+(98.6-88.08)^2+(102.4-88.08)^2+(70.4-88.08)^2\right]}{5-1}$$

$$\sigma_x^2 = 179.732$$

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$\sigma_x = \sqrt{179.732}$

$\sigma_x = 13.41$

Hence, $C_V = \frac{\sigma_x}{\bar{x}} \times 100$

$= \frac{13.41}{88.08} \times 100$

$= 15.22$

$$N = \left[\frac{C_V}{P}\right]^2 = \left[\frac{15.22}{6}\right]^2$$

$= 6.43$

$\simeq 7$

Additional number of stations $= 7 - 5 = 2$ //

Computation of average rainfall over a Basin:-

In order to compute the average rainfall over a basin (or) catchment area, the rainfall is measured at a number of rain gauge stations suitably located in the area.

In a basin (or) catchment are contains more than one rain gauge station, the computation of average precipitation (or) rainfall may be done by following Methods are,

1) Arithmatic average Method
2) Thissen Polygon Method
3) Isohyetal Method
4) Grid Point Method.

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1. Arithmatic average Method:-

If the rainfall is uniformly distributed on its areal pattren, the simplest method of estimating average rainfall is to compute the arithmatic average of the recorded rainfall values at various stations. Thus $P_1, P_2, P_3, \ldots P_n$ etc. are the precipitation values measured at 'n' gauge stations,

we have,

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

$$= \frac{1}{n} \sum_{i=1}^{n} P_i$$

2. Thiessen Polygon Method:-

Thissen Polygon Method is a most common method of weighing the rain gauge observations according to the area. Thiessen polygon is also known as weighted mean Method and more accurate than the arithmatic average Method.

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

→ construct the perpendicular bisector of each of these lines.

→ A Thiessen network is thus constructed. The Polygon formed by the perpendicular bisectors

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around a station encloses an area which is everyone closer to the station than to any other station.

→ compute the average preipitation from the equation is,

$$P_{av} = \frac{A_1P_1 + A_2P_2 + \cdots + A_nP_n}{A_1 + A_2 + \cdots + A_n}$$

$$= \frac{\Sigma(A \times P)}{\Sigma A}$$

$$P_{av} = P_1W_1 + P_2W_2 + \cdots + P_nW_n$$

where,

W_1 = Thissen weights computed as $W_1 = \frac{A_1}{\Sigma A}$.

3. 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.

→ An Isohyet is a line on a rainfall map of the basin, Joining places of equal rainfall readings.

→ An Isohyetal map showing contour of equal rainfall represents a more accurate picture of the rainfall distribution over the basin.

→ The avg rainfall is then computed from the expression as,

$$P_{av} = \frac{\Sigma A \times \left[\frac{P_1 + P_2}{2}\right]}{\Sigma A}$$

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4. Grid Point Method:-

→ In this Method, all the grid stations are marked on the map of the basin, along with the depth of precipitation.

→ on this map, drawn to suitable scale, a uniform rectangular grid at some suitable spacing is super-imposed.

→ The avg. precipitation of the four grid corners is then multiplied by the area of the grid, to give the average precipitation volume of the grid.

Presentation of rainfall Data:-

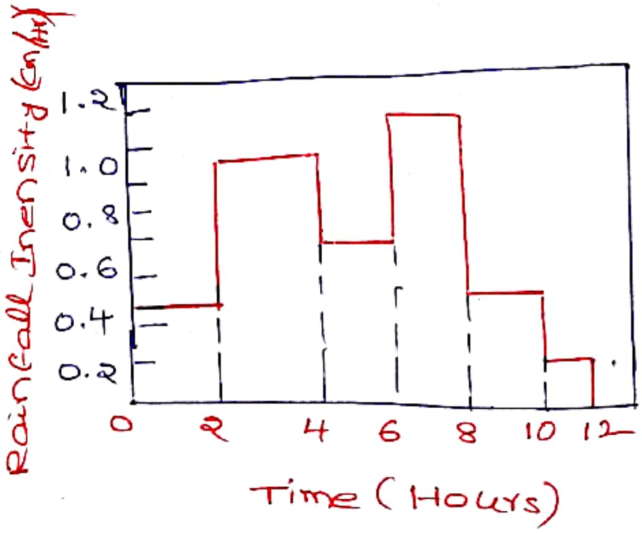
There are three methods of precipitation of rainfall data collected through measurement at a given station. are

1). Hyetograph Method
2) Mass curve of rain-fall Method
3) Point rainfall Method.

1. Hyetograph Method:-

→ A heyetograph ~~is a~~ is a bar graph showing the intensity of rainfall with time.

→ The hyetograph can be prepared either



form the mass curve of rain-fall (or) directly from the data obtained from automatic raingauges.

2. Mass curve of rainfall:-

→ A mass curve of rain-fall is a plot of cumulative depth of rain-fall against time.

→ The steepness of the curve indicates the intensity of rainfall. A horizontal portion of the curve indicates that there was no rain-fall during that period.

→ A to B is the first period of rainfall. There was no rainfall from B to C and therefore the curve is horizontal. C to D shows the second period of rainfall and E to F third period of storm.

→ The mass curve of rain-fall is a rising curve. the intensity rainfall during any period is given by,

$$i = \frac{\Delta P}{\Delta t}.$$

→ The mass curve of a design storm can be obtained from maximising the mass curves of the severe storms in the basin.

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3. Point rainfall Method:-

→ The rainfall data of a station is known as point rainfall.

→ This data can be presented as daily, weekly, monthly, seasonal (or) annual values.

→ The point rainfall data is presented graphically as plots of magnitudes vs chronological time in the form of a bar diagram.

→ Point precipitation data are used collectively to estimate the areal variability of rainfall.

Average Rainfall:-

Normal (or) average rainfall is the amount of precipitation that we expected per year (in a given area).

→ It is obtained and set by calculating the average of precipitation recorded in an area during many years.

→ Annual rainfall precipitation is the sum of daily rainfall in a year.

IMP.

Estimation of Missing Rainfall Data:-

Sometimes it may not be possible to measure the rainfall at a particular measuring station due to absence of the observer (or) instrument failure or any other reason. In that case, the prediction of the missing data can be

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With the help of available data of nearby measuring stations, using the prominent methods,

1. Arithmatic Method
2. Normal Ratio Method
3. Inverse distance Method by US weather service.

1. Arithmatic Method:-

According to this Method, the missing rain fall P_x of the station X is computed by simple arithmatic average of the rainfall at the nearby stations is known as index station

$$P_x = \sum_{i=1}^{n} \frac{P_i}{n}$$

$$= \frac{1}{n}(P_1 + P_2 + -- P_n).$$

where,

n = Number of Index stations.

2. Normal Ratio Method:-

In this Method, the rainfall (P_i) of the surrounding index stations are weighed by the ratio of normal annual rainfalls by using the followin equation.

$$P_x = \frac{1}{n}\left[P_1\frac{N_x}{N_1} + P_2\frac{N_x}{N_2} + -- P_n\frac{N_x}{N_n}\right]$$

$$= \frac{N_x}{n}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + -- \frac{P_n}{N_n}\right]$$

where,

N_x = Normal annual rainfall of missing station.

$N_1, N_2 -- N_n$ = Normal annual rainfall of Index station.

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3. Inverse Distance Method:-

In this Method a set of rectangular co-ordinate axes are passed through the missing rain gauge station so that coordinate are (0,0). The co-ordinates, surrounding the missing data are found.

The weightage (W_i) of each index station is represented by the inverse of the square of it's distance from the missing station is given by,

$$W_i = \frac{1}{D_i^2} = \frac{1}{x_i^2 + y_i^2}$$

The missing rainfall data of the station X is then computed from the following eq,

$$P_x = \frac{\sum_{i=1}^{n} P_i W_i}{\sum_{i=1}^{n} W_i}$$

1). A watershed has four rain gauge stations, A, B, C and D. During a storm, rain gauge station A was inoperative, while stations B, C and D surrounding station A., recorded rainfall of 48 mm, 51 mm and 45 mm respectively. Estimate the missing storm precipitation of station A. using arithmatic mean Method?

Given Data:-

Recorded rainfall are 48 mm, 51 mm and 45 mm.

Index stations $n = 3$.

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From arithmatic mean Method,

$$P_A = \frac{1}{n}(P_1 + P_2 + P_3)$$

$$= \frac{1}{3}(P_B + P_C + P_D)$$

$$P_A = \frac{1}{3}[48 + 51 + 45]$$

$$= 48\text{ mm}.$$

2) A precipitation station X was inoperative for some time during which a storm occured. The storm totals at three stations A, B and C surrounding X, were respectively 6.60, 4.80 and 3.70 cm. The normal annual precipitation amounts at stations X, A, B and C are respectively 65.6, 70.6, 51.8 and 38.2 cm. Estimate the storm precipitation for station X?

Sol:-

If N_x, N_A, N_B and N_C are the average annual precipitation amounts at X, A, B and C and P_A, P_B and P_C are the storm total of stations A, B and C surrounding X,

The storm precipitation p at station X is given by,

$$P_x = \frac{1}{n}\left[\frac{N_x}{N_A}P_A + \frac{N_x}{N_B}P_B + \frac{N_x}{N_C} \times P_C\right]$$

$$= \frac{1}{3}\left[\frac{65.6}{70.6} \times 6.6 + \frac{65.6}{51.8} \times 4.80 + \frac{65.6}{38.2} \times 3.70\right]$$

$$= \frac{1}{3}[18.33]$$

$$= 6.11\text{ cm}//$$

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3) In a river basin a station A was inoperative during a storm, while stations B, C, D and E, surrounding A were in operation, registering 74 mm, 88 mm, 71 mm, and 80 mm of precipitation. The coordinates of B, C, D and E are (9, 6), (12, -9), (-11, -6) and (-7, 7) respectively. With coordinates of A as (0,0). Estimate the missing storm precipitation of station A by the inverse distance Method?

Sol:-

Given Data:-

coordinates of A as (0,0).

→ B, C, D and E precipitation are given as,

74 mm, 88 mm, 71 mm and 80 mm

→ B, C, D and E coordinates are (9, 6); (12, -9), (-11, -6) and (-7, 7).

By using Inverse distance Method,

$$w_i = \frac{1}{D_i^2}$$

Station B:- (9, 6)

$$D_b^2 = (x_1)^2 + (y_1)^2$$

$$= (9)^2 + (6)^2$$

$$= 117$$

$$w_b = \frac{1}{D_b^2} = \frac{1}{117}$$

$$= 8.547 \times 10^{-3}$$

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at station C :- (12, -9)

$$D_c^2 = (12)^2 + (-9)^2$$

$$= 225$$

$$w_c = \frac{1}{D_c^2} = \frac{1}{225}$$

$$= 4.444 \times 10^{-3}.$$

at station D :- (-11, -6)

$$D_d^2 = (-11)^2 + (-6)^2$$

$$= 157$$

$$w_d = \frac{1}{D_d^2} = \frac{1}{157}$$

$$= 6.369 \times 10^{-3}$$

at station E :- (-7, 7)

$$D_e^2 = (-7)^2 + (7)^2$$

$$= 98$$

$$w_e = \frac{1}{D_e^2} = \frac{1}{98}$$

$$= 10.204 \times 10^{-3}.$$

$$\therefore P_x = \frac{\Sigma P_i w_i}{\Sigma w_i}$$

$$= \frac{74 \times 8.547 \times 10^{-3} + 88 \times 4.44 \times 10^{-3} + 71 \times 6.369 \times 10^{-3} + 80 \times 10.204}{8.547 \times 10^{-3} + 4.444 \times 10^{-3} + 6.369 \times 10^{-3} + 10.20 \times 10^{-3}}$$

$$P_A = 77.5 mm //$$

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Interpretation of Rainfall Data:-

Generally, the precipitation information may be required under the following Methods are,

1. Intensity (i)
2. Duration (t)
3. Frequency (f)
4. Areal extent

Intensity of rainfall:-

The intensity of rainfall (i) is defind as the rate at which rainfall occurs, and is express as cm/h or mm/h. The non recording type raingauge measure/records only rainfall depth in a day (or) in a duration (t) of the rainfall.

The intensity of rain fall is given by,

$$i = \frac{P}{t}.$$

Frequency of rain fall:-

The frequency of rainfall of a specified period in determined assuming that the rainfall is a random variable and the mathematical theory of probability is applicable.

The design of hydraulic structures, such as flood control structures, soil conservation structures, waste-water systems, drains and culverts

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etc. is based on the Probability of the occurance of extreme rainfall and the run off.

Frequency:-

The Probability of occurance of an event expressed as a Percentage is known as frequency

Thus, $f = 100\ P_{ro}$

$= \frac{1}{T} \times 100.$

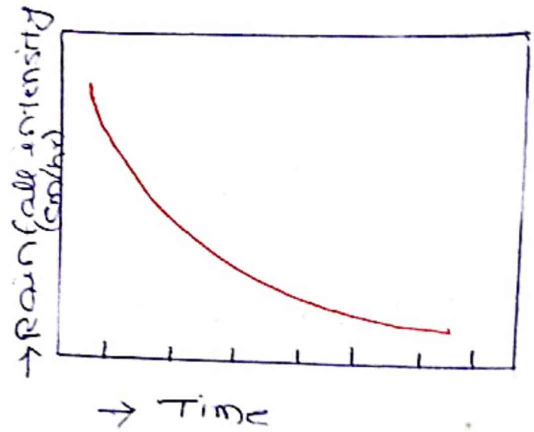
By following Methods are,

1. Intensity Duration analysis
2. Intensity Duration frequency relationship
3. Depth area relationship
4. Depth area Duration relationship.

1. Intensity Duration Analysis:-

→ It has generally been observed that greater the intensity of rainfall, shorter is the length of time.

→ As the duration of storm increases, the maximum intensity of storm decreases.



→ sherman gave the following relation between intensity duration

$$i = \frac{a}{(t+b)^n}.$$

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2. Intensity Duration Frequency Relationship (or) IDF curves:-

→ It is observed that a storm of any given duration will have larger intensity of it's return period is large.

→ This means that for storm of given duration, storms of higher intensity in that duration are rarer than storms of smaller intensity.

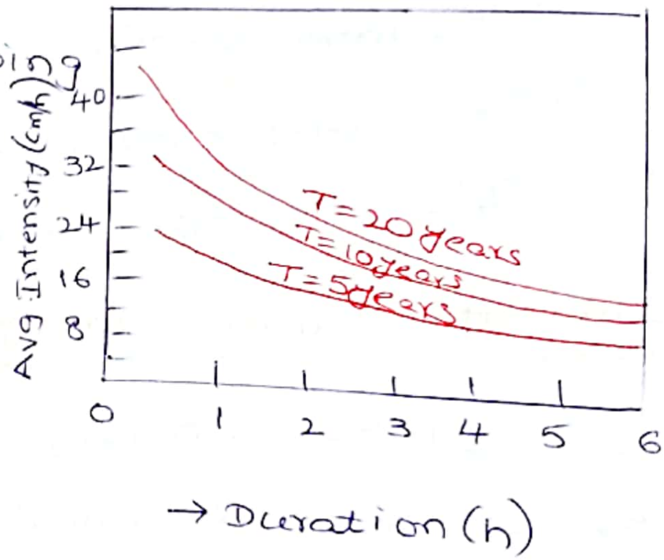
→ The relationship between intensity, Duration return period can be expressed by following eq is

$$i = \frac{KT^{x}}{(t+b)^{n}}$$

where,

n = constant for the catchments

T = return period.



→ Sherman gave the following relation

$$i = \frac{KT^{x}}{t^{n}}$$

3. Depth area relationship:-

→ The areal distribution characteristics of a storm of given duration is reflected in the depth area relationship and depth area curves.

→ Precipitation rarely occurs uniformly over the

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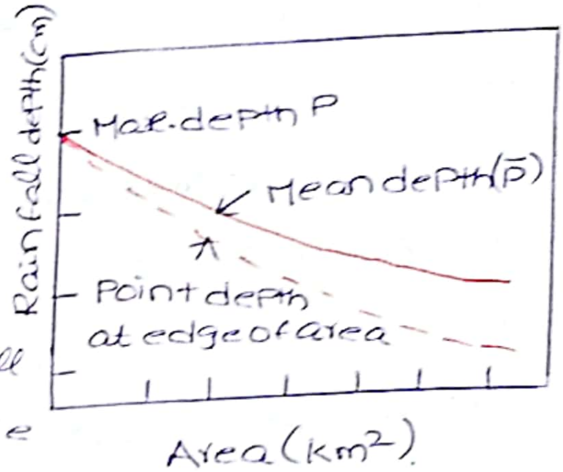
whole area. For a rainfall of a given duration the average depth of rainfall decreases from the maximum value as the considered area increases.

→ The relation ship is expressed as,

$$\bar{P} = P_n \, \varepsilon^{-kA^n}$$



where,

P_n = highest amount of rainfall observed at the storm centre

A = Area (km^2)

k, n = constants

$\bar{P}$ = Avg. depth in cm,

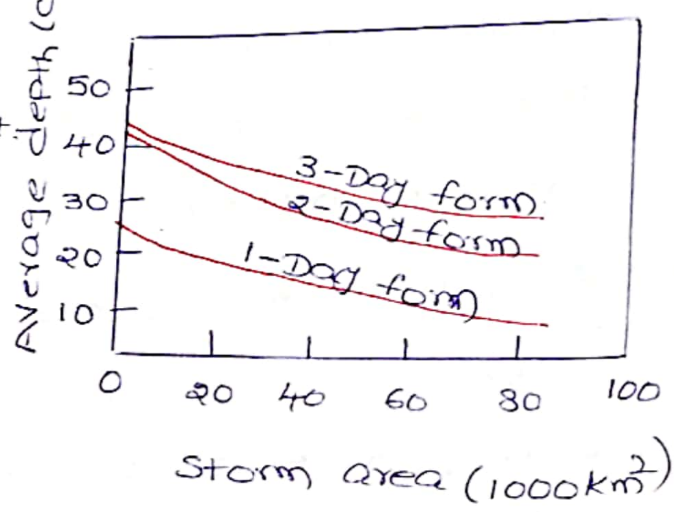
Typical values of K and N:-

Duration Of Storm	K	N.
1 Day	8.256×10^{-4}	0.6614
2 Days	9.877×10^{-4}	0.6306
3 Days	1.745×10^{-3}	0.5961

Depth area Duration curves (DAD) curves:-

→ Rainfall rarely occures uniformly over the whole of the catchment.

→ variations in total depth of rainfall and intensity occur from the centres to the peripheris of storms.



DAD curve

→ The knowledge of maximum depth of rainfall occuring on areas of various sizes for storms of different durations is great importance in many hydrological design problems.

→ The development of relationship between max. depth, area and duration for a region is known as DAD analysis.

→ DAD analysis performed to determine the max. amount of precipitation of various durations over areas of various sizes.

Double Mass curve (or) Rainfall:-

→ Double Mass curve is a technique used for checking the consistency of a record. The trend in the rainfall records at a station may slightly change after some years due to change in the environment of a station (or) tampering of the instrument (or) shift in the observation practices.

→ The change due to Meteorological factors will equally affect all stations in the test and thus will not cause a lack of consistency created by external effects.

→ A double mass curve is a graph plotted between the accumulated annual rainfall at a given station(x) versus accumulated annual values of the average of group of base

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station, for various consecutive time periods.

→ The following relationship as,

$$P_{xc} = P_x \cdot \frac{a}{b}$$

Where,

P_{xc} = corrected precipitation

P_x = recorded precipitation.

Probable Maximum Precipitation (PMP):-

→ The probable maximum precipitation commonly known as PMP for a region is the precipitation resulting for the most critical meteorological combinations that are considered probable of occurance.

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

→ The PMP can be estimated by maximising the different parameters like humidity, temperature, wind velocity and other connected meteorological factors of an observed serve storm over the basin.

There are two approaches for determining PMP are,

1. Meteorological approach
2. statistical approach.

For a statistical studies, PMP can also be estimated from the following eq

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$$PMP = \bar{P} + k\sigma$$

where,

$\bar{P}$ = Mean of annual maximum rainfall

σ = standared deviation

k = Frequency factor.

1). The ordinates (in mm) of a rainfall mass curve for a storm, which commenced at 06:30 hours, recorded by self recording raingauge at 15 min interval are as under. 0, 12.4, 22.1, 35.1, 52.7, 63.7, 81.9, 109.2, 123.5, 132.6, 143.3, 146 and 146. construct the hyetograph of this storm for a uniform interval of 15 minutes.

Sol:-

Interval (or) cumulative rainfall (mm) = 0, 12.4, 22.1, 35.1, 52.7, 63.7, 81.9, 109.2, 123.5, 132.6, 143.3, 146, 146.

The computation are done in tabular form below, which is self explanatory.

S. No	Time	cumulative Rainfall (mm)	Rainfall in successive 15 min interval (mm)	Rainfall intensity (mm/hr)
1	06:30	0	–	–
2	06:45	12.4	12.4	$\frac{12.4}{0.25} = 49.6$
3	07:00	22.1	9.7	38.8
4	07:15	35.1	13.0	52.0
5	07:30	52.7	17.6	70.4
6	07:45	63.7	11.0	44.0
7	08:00	81.9	18.2	72.8
8	08:15	109.2	27.3	109.2
9	08:30	123.5	14.3	57.2
10	08:45	132.6	9.1	36.4
11	09:00	143.3	10.7	42.8
12	09:15	146.0	2.7	10.8
13	09:30	146.0.	0.0	0.0.

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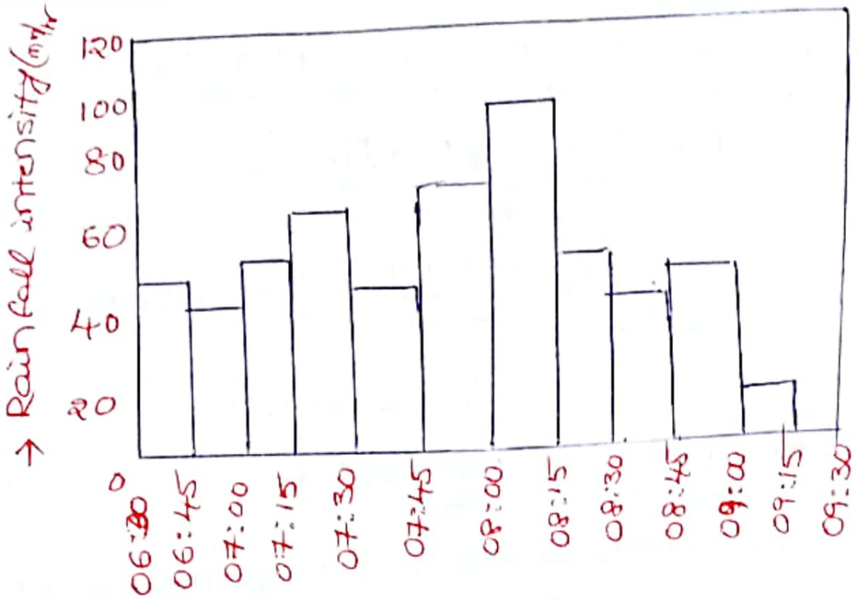

Rainfall hyetograph

V.IMP

Q). The shape of catchment approximately resembles a square of side 8km. with reference to an x-y co-ordinates. frame whose origin is coinciding with one of the corners of the catchment the locations of the four corners of the catchment are (0,0), (8,0), (8,8) and (0,8). There are four rain gauges A, B, C and D with in this catchment whose position with reference to the same coordinate frame are (2,2), (6,2) (6,6) and (2,6) respectively. The rainfall recorded by the rain gauges A, B, C and D during a storm of 8, 6, 9 and 11cm respectively. Determine the avg depths of rainfall over the catchment by arithmatic ~~method~~ mean Method and Thiessen Method?

Sol:-

Given that:-

Catchment area = 8 km

Rainfall recorded by the raingauges = 8, 6, 9 & 11 cm.

Total number of gauges = 4

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1) By using arithmatic mean Method:-

$$\bar{P} = \frac{P_A + P_B + P_C + P_D}{n}$$

$$= \frac{8+6+9+11}{4} = \frac{34}{4} = 8.5\,cm.$$

$$\bar{P} = 8.5\,cm$$

2) Thiessen polygon Method:-

To determine $\bar{P}$ by the Thiessen Polygon Method first the catchment is drawn to scale and the raingauges A, B, C and D are located on the same area, using the given information on the positional coordinates.

The raingauge stations are connected by dashed lines and perpendicular bisectors to these dashed lines are then drawn as solid lines. Thiessen Polygon formed around all the 4 raingauge stations are square of same size $4\,km \times 4\,km = 16\,km^2$

The area of catchment is $A = 8\,km \times 8\,km$
$= 64\,km^2$.

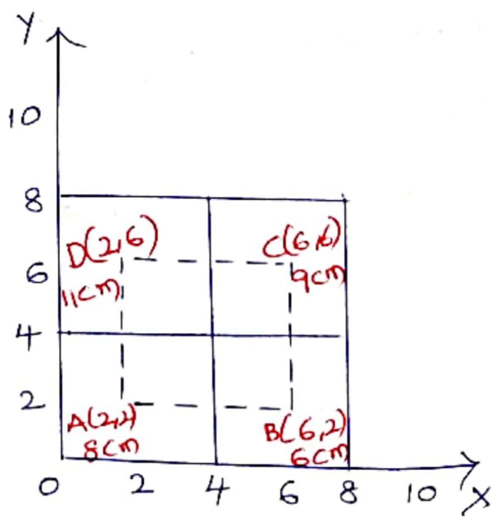
$$\bar{P} = \frac{A_A}{A} P_A + \frac{A_B}{A} P_B + \frac{A_C}{A} P_C + \frac{A_D}{A} P_D$$

$$= \frac{16}{64} \times 8 + \frac{16}{64} \times 6 + \frac{16}{64} \times 9 + \frac{16}{64} \times 11$$

$$= \frac{1}{4}(8+6+9+11)$$

$$= \frac{34}{4}$$

$$\bar{P} = 8.5\,cm.$$



Thiessen polygon Method

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Design Storm:-

→ Drainage means the removal of excess water from a given place.

Two types of drainage can be identified.

1. Land Drainage
2. Field Drainage.

Land Drainage:-

→ Large scale drainage where the objective is to drain surplus water from a large area by such means as large open drains, existing dykes and pumping.

Field Drainage:-

→ This is the drainage that concerns us in agriculture

→ It is the removal of excess water from the root zone of crops.

→ Design storm means a hypothetical discrete rainstorm characterized by a specific Duration, rain-fall intensity, return frequency and total depth of rainfall.

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