BALASORE COLLEGE OF ENGINEERING & TECHNOLOGY,

SERGARH, BALASORE

Lecture Notes on

Subject -: HYDROLOGY & IRRIGATION ENGG.

(As per the latest syllabus of BPUT, Rourkela, Odisha)

Year - 3^{rd} **Semester -** 6^{th}

Prepared by -:

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Department – Civil Engineering

Checked By

Name and Designation

MODULE WISE DISTRIBUTION OF LOADS

Module	Chapter with title	Assigned Hours (as per BPUT)	Actual Session Needed	Range of Marks of Questions to be being asked (BPUT)
1	1 2 3	09 Hrs	20 Hrs	20 - 40
2	4 5 6	09 Hrs	15 Hrs	20 - 40
3	7 8 9	09 Hrs	20 Hrs	15 - 33
4	10 11 12	09 Hrs	15 Hrs	20 - 35
	Total -	**36hrs**	**70hrs**	

SYLLABUS

MODULE-I **09HOURS**

Hydrologic cycle, World water balance; Forms, types & measurement of precipitation; Mean precipitation over an area; Curves of precipitation: Depth-area-duration, Intensity-duration-frequency & Depth-duration-frequency; Probable maximum precipitation; World's greatest observed rainfalls; Abstractions of precipitation: Measurement of evaporation; Evapotranspiration & its equations; Infiltration: measurement & indices.

MODULE-II **09HOURS**

Major methods for Measurement of stage, velocity & streamflow; Stage-discharge relationship: linear & log-log; Runoff characteristics of streams; Runoff volume estimation by Curve Number method; Flow mass curve & reservoir capacity estimation; Hydrographs: components, affecting factors & base flow separation methods; Unit hydrographs (UHs): derivation, use & limitations; UHs of different durations; Peak flood estimation by Rational method, empirical formulae, enveloping curves & Gumbel's Method.

MODULE-III **09HOURS**

Irrigation: necessity, advantages & disadvantages; Water distribution techniques in farms: free flooding, border flooding, check flooding, basin flooding, furrow irrigation, sprinkler irrigation & drip irrigation; Crop water requirement: duty, delta, base period & crop period; Irrigation efficiencies; Soil moisture - irrigation frequency relationship; Irrigation channels: classification & alignment; Distribution system, water losses in irrigation channels; Stable & regime channel design: comparison of Kennedy's & Lacey's Theories; Irrigation canal lining: types, advantages, economics & preliminary design.

MODULE-IV **09HOURS**

Types of Cross-Drainage (CD) Works, , Design considerations for CD works; Diversion Head works: Types of weirs and barrages, Layout of a diversion head works; Design of weirs and barrages: Comparison among Bligh's creep theory, Lane's weighted creep theory and Khosla's method of independent variables, Exit gradient; Canal Falls: Necessity, Proper location, Types,Gravity Dams: Typical cross section, Various forces acting on gravity dam, Combination of forces for design, Modes of failure and criteria for structural stability, High and low gravity dams, Typical section of low gravity dam; Earth Dams: Types, Causes of failure, Preliminary section, Seepage control. Spillways: Brief study of various types.

Books:

1. Irrigation Engineering and Hydraulic Structures by S. K. Garg, Khanna Publication, New Delhi
2. Irrigation Engg. By B.C. Punmia and Pande, Laxmi Publication, New Delhi
3. Engineering Hydrology by K Subramanya, McGraw Hill Education, New Delhi
4. Hydrology Principles Analysis Design by H M Raghunath, New Age International Publishers, New Delhi

Digital Learning Resources: Course Name	IRRIGATION AND DRAINAGE
Course Link	*https://nptel.ac.in/courses/126/105/1261050/*
Course Instructor	*PROF. DAMODHARA RAO MAILAPALLI Department of Agricultural and Food Engineering IIT Kharag*

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CONTENTS

MODULE-1 CHAPTER-1

LECTURE:-1

HYDROLOGIC CYCLE

Learning objectives

1.1 Introduction
1.2 Hydrology
1.3 Scope Of Hydrology
1.4 Importance Of Hydrology

1.1 INTRODUCTION

The world's total water resources are estimated to be around 1.36X 1014 ha-m. 92.7% of this water is salty and is stored in oceans and seas. Only 2.8% of total available water is fresh water. Out of this 2.8% fresh water, 2.2% is available as surface water and 0.6% as ground water. Out Of the 2.2% surface water, 2.15% is stored in glaciers and ice caps, 0.01% in lakes and streams and the rest is in circulation among the different components of the Earth's atmosphere.

Out of the 0.6% ground water only about 0.25% can be economically extracted. It can be summarized that less than 0.26% of fresh water is available for use by humans and hence water has become a very important resource. Water is never stagnant (except in deep aquifers), it moves from one component to other component of the earth through various process of precipitation, run off, infiltration, evaporation etc. For a civil engineer, it is important to know the occurrence, flow, distribution etc. it important to design and construct many structures in contact with water.

1.2 HYDROLOGY

Hydrology may be defined as applied science concerned with water of the Earth in all its states, their occurrences, distribution and circulation through the unending hydrologic cycle of precipitation, consequent runoff, stream flow, infiltration and storage, eventual evaporation and re-precipitation. Hydrology is a highly inter-disciplinary science. It draws many principles from other branches of science like:-

- Meteorology and Climatology
- Physical Geography
- Agronomy and Forestry
- Geology and Soil science
- Oceanography
- Hydraulics
- Probability and Statistics
- Ecology

Hydrology concerns itself with three forms of water:-

- Above land as atmospheric water or precipitation.
- On land or surface as stored water or runoff
- Below the land surface as ground water or percolation

1.3 SCOPE OF HYDROLOGY

The study of hydrology helps us to know:

1. The maximum probable flood that may occur at given sit and its frequency; this is required for the safe design of drains, bridges & culverts, dams & reservoirs, channels and other flood control system.
2. The water yield from a basin –its occurrence, quantity and frequency etc; this is necessary for the design of dams, municipal water supply, water power, river navigation etc.
3. The ground water development for which a knowledge of Hydro geology of the area i.e. formation of the soils, recharge facilities like streams and reservoirs, rainfall pattern, climate; cropping pattern etc are required.
4. The maximum intensity of storm & its frequency for the design of drainage project in the area.

1.4 IMPORTANCE OF HYDROLOGY

- Design of Hydraulic Structures: Structures such as bridges, causeways, dams, spillways etc. are in contact with water. Accurate hydrological predictions are necessary for their proper functioning. Due to a storm, the flow below a bridge has to be properly predicted. Improper prediction may cause failure of the structure. Similarly the spillway in case of a dam which is meant for disposing excess water in a dam should also be designed properly otherwise flooding water may overtop the dam.

- Municipal and Industrial Water supply: Growth of towns and cities and also industries around them is often dependent on fresh water availability in their vicinity. Water should be drawn from rivers, streams, ground water. Proper estimation of water resources in a place will help planning and implementation of facilities for municipal (domestic) and industrial water supply.

- Irrigation: Dams are constructed to store water for multiple uses. For estimating maximum storage capacity seepage, evaporation and other losses should be properly estimated. These can be done with proper understanding of hydrology of a given river basin and thus making the irrigation project a successful one. Artificial recharge will also increase ground water storage. It has been estimated that ground water potential of gangetic basin is 40 times more than its surface flow.

Hydroelectric Power Generation

A hydroelectric power plant need continuous water supply without much variations in the stream flow. Variations will affect the functioning of turbines in the electric plant. Hence proper estimation of river flow and also flood occurrences will help to construct efficient balancing reservoirs and these will supply water to turbines at a constant rate.

- Flood control in rivers: Controlling floods in a river is a complicated task. The flow occurring due to a storm can be predicted if the catchment characteristics are properly known. In many cases damages due to floods are high. Joint work of hydrologist and meteorologists in threatening areas may reduce damage due to floods. Flood plain zones maybe demarked to avoid losses.
- Navigation: Big canals in an irrigation scheme can be used for inland navigation. The depth of water should be maintained at a constant level. This can be achieved by lock gates provided and proper draft to be maintained. If the river water contains sediments, they will settle in the channel and cause problems for navigation. Hence the catchment characteristics should be considered and sediment entry into the canals should be done.

- Erosion & sediment control: Excessive erosion in the catchment feeds the sediment into the runoff. The reservoir may lose their capacity at a faster rate reducing their economic span drastically. Tones of fertile top soil will be lost every year resulting in crop yields. Hydrology of the catchment along with the knowledge of the existing water shed management practices will help in finding out the effective erosion. These measures includes the fixing crop pattern & cropping procedures, formation of contour bunds, aforestation etc. effective erosion control measures not only decreases the sediment load in the stream but also reduces peak flood discharges because of increased infiltration opportunities in the catchment.

- Pollution control: It is an easy way to dispose sewage generated in a city or town into streams and rivers. If large stream flow is available compared to the sewage discharge, pollution problems do not arise as sewage gets diluted and flowing water also has self-purifying capacity. The problem arises when each of the flows are not properly estimated. In case sewage flow is high it should be treated before disposal into a river or stream.

LECTURE:-2

Learning objectives

1.5 Hydrological Cycle

1.5 HYDROLOGICAL CYCLE

Water exists on the earth in gaseous form (water vapor), liquid and solid (ice) forms and is circulated among the different components of the Earth mainly by solar energy and planetary forces. Sunlight evaporates sea water and this evaporated form is kept in circulation by gravitational forces of Earth and wind action. The different paths through which water in nature circulates and is transformed is called hydrological cycle. Hydrological cycle is defined as the circulation of water from the sea to the land through the atmosphere back to the sea often with delays through process like precipitation, interception, runoff, infiltration, percolation, ground water storage, evaporation and transpiration also water that returns to the atmosphere without reaching the sea.

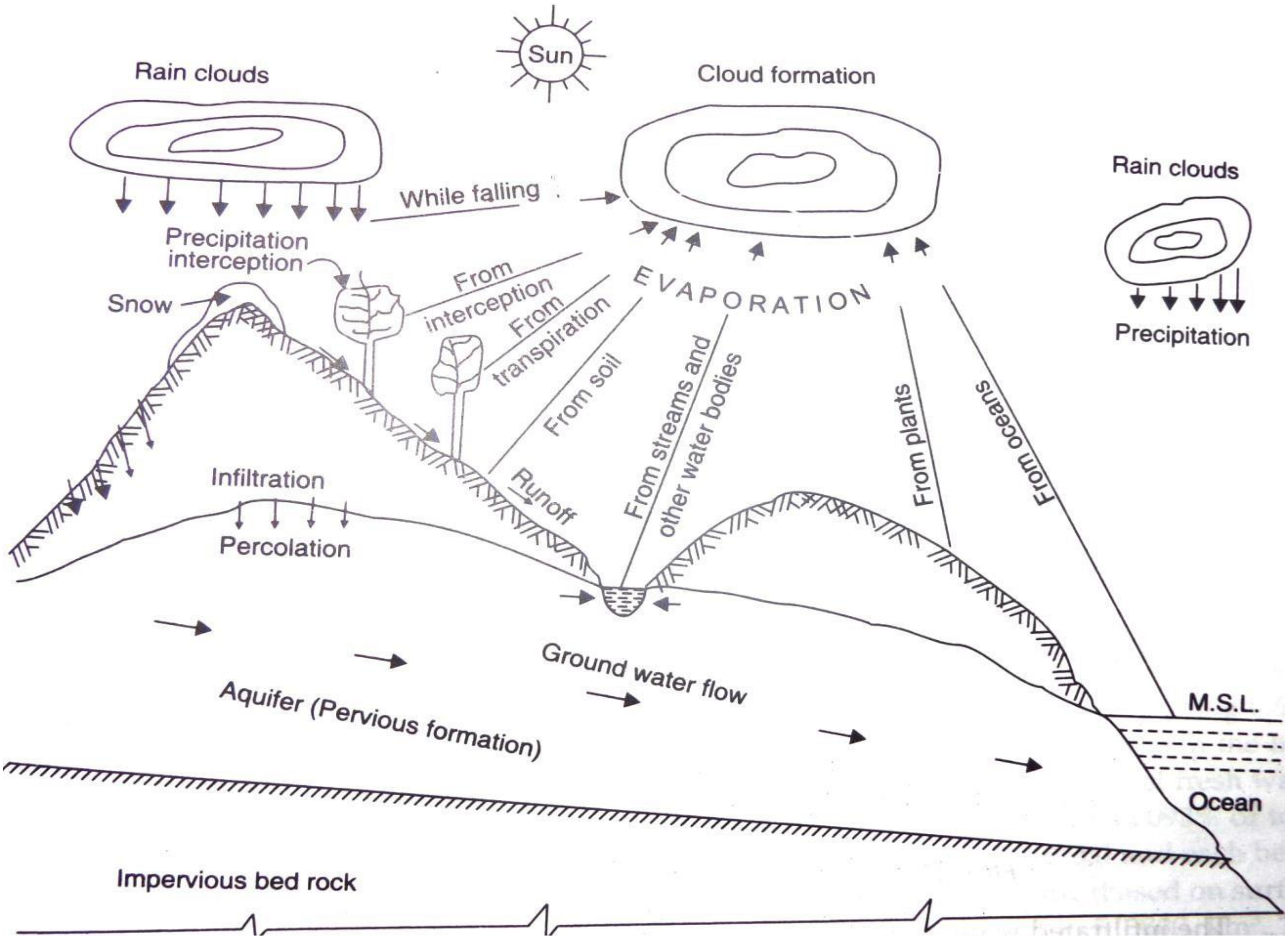

FIG 1: Descriptive representation of hydrological cycle

The hydrological cycle has 3 important phases:

1. Evaporation & Evapotranspiratrion
2. Precipitation
3. Run off

Evaporation takes place from the surface of ponds, lakes, reservoirs and ocean surfaces. Transpiration takes place from surface vegetation i.e. from plant leaves of cropped land forest etc. These vapours rise to sky and are condensed at higher altitude and form the clouds. The clouds melt and sometime burst resulting in precipitation of different forms like rain, snow, hail, mist and frosts. A part of this precipitation flows over the land as runoff and a part infiltrate into the soil which build up ground water table. The surface run-off joins the stream and thus water stored in the reservoir. A portion of the surface runoff and ground water flows back to ocean. Again evaporation starts from surfaces of lakes, reservoirs and ocean & thus the cycle repeats.

The hydrological cycle can also be represented in many different ways in diagrammatic forms as

1. Horton's Qualitative representation
2. Horton's Engineering representation

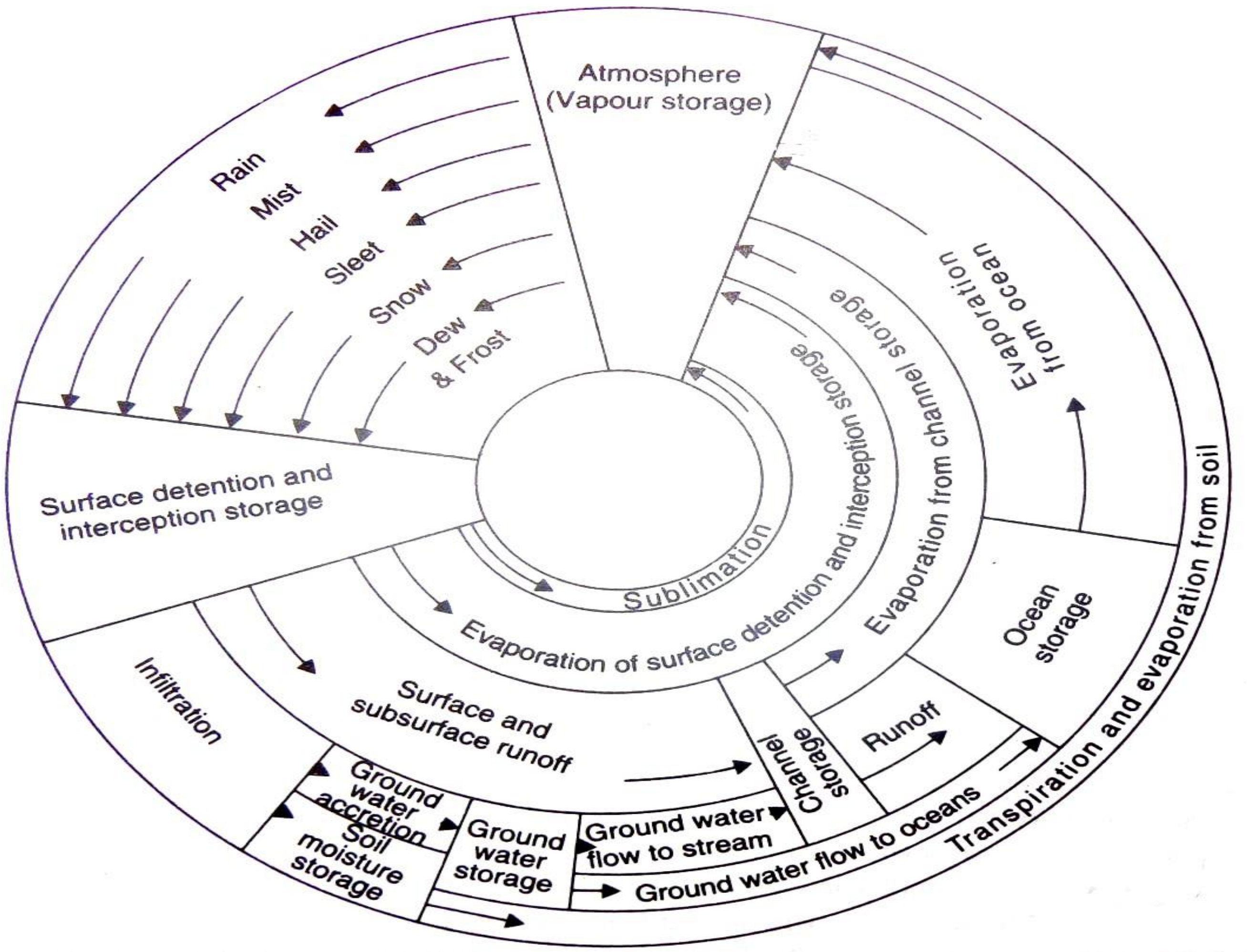

FIG 2: Descriptive representation of hydrological cycle

The hydrological cycle has 3 important phases:

4. Evaporation & Evapotranspiratrion
5. Precipitation
6. Run off

Evaporation takes place from the surface of ponds, lakes, reservoirs and ocean surfaces. Transpiration takes place from surface vegetation i.e. from plant leaves of cropped land forest

Etc. These vapours rise to sky and are condensed at higher altitude and form the clouds. The clouds melt and sometime burst resulting in precipitation of different forms like rain, snow, hail, mist and frosts. A part of this precipitation flows over the land as runoff and a part infiltrate into the soil which build up ground water table. The surface run-off joins the stream and thus water stored in the reservoir. A portion of the surface runoff and ground water flows back to ocean. Again evaporation starts from surfaces of lakes, reservoirs and ocean & thus the cycle repeats.

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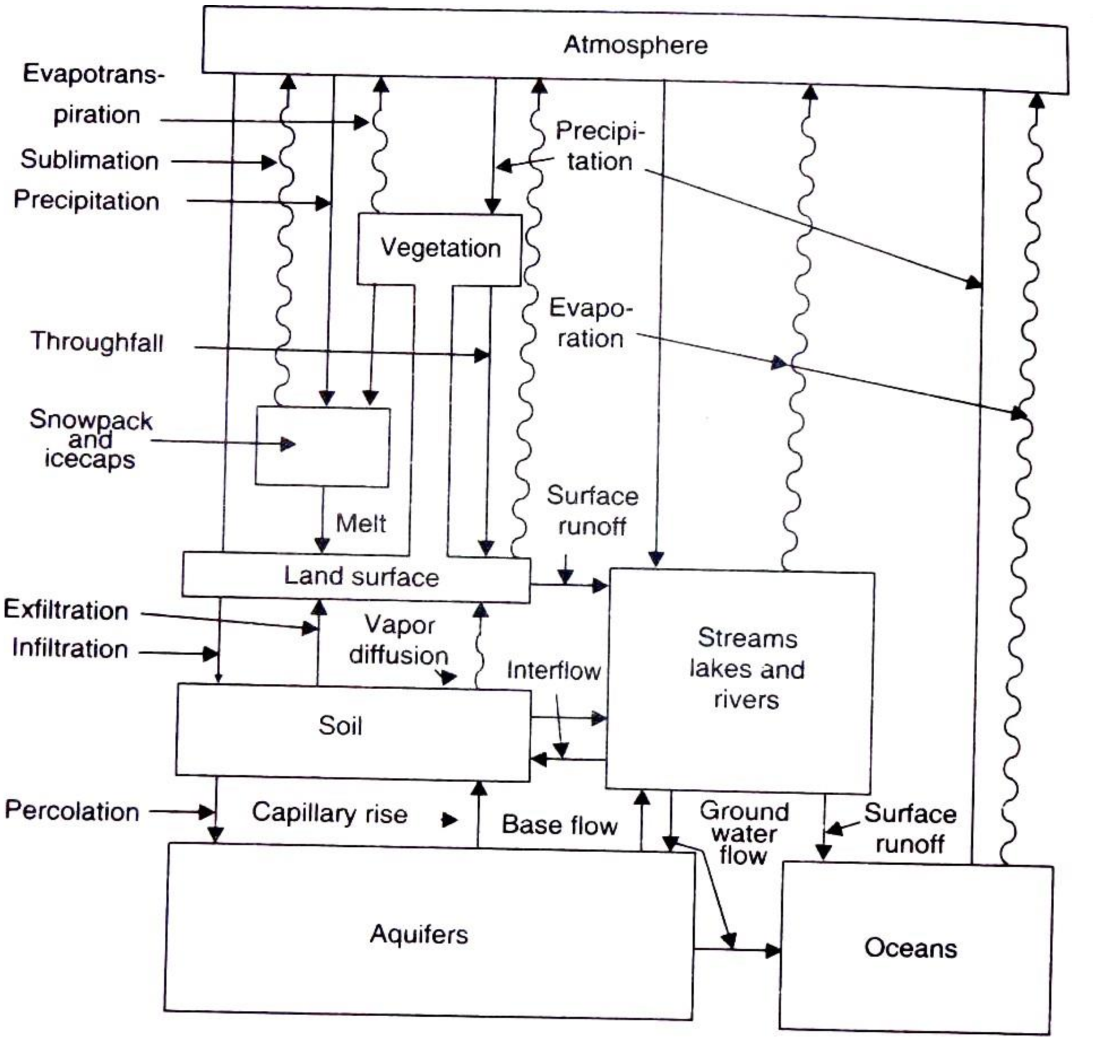


FIG-3: Engineering representation of Horton's hydrological Cycle

LECTURE:- 3

Learning objectives

1.6 World Water Balance

1.7 Water Budget Equation

1.6 WORLD WATER BALANCE

Water balance is the most important integral physiographic characteristic of any territory—it determines its specific climate features, typical landscapes and opportunities for human land use. Assessment of mean long-term water balances of large regions at a sufficient accuracy depends on reliable estimation of the major water balance components—precipitation, evaporation and runoff (surface and subsurface).

In this chapter quantitative characteristics of water balances of different regions, continents, oceans and the Earth as a whole are mainly based on the use of data from the world hydrometeorological network, on scientific generalizations of observation data, and water balance computations made by Russian scientists, including recent data.

The water balance of each continent (except Antarctica) is given separately for the areas of external runoff and internal runoff (endorheic areas) where precipitation is completely lost to evaporation. All balance components are estimated by independent methods which provide a computation of a balance discrepancy and thus assessment of reliability of the obtained results.

Areas of external runoff occupy about 80% of the Earth's land area. These areas receive 93% of precipitation onto the land; 88% of evaporation occurs there and 100% of the freshwater inflow to the World Ocean.

The whole land area (with islands) receives about 119 000 km^3 of precipitation during ayear, or 800 mm. The maximum precipitation layer is observed in South America (1600 mm), the minimum precipitation layer (177 mm) occurs in Antarctica. On the other continents mean precipitation varies within 740 to 790 mm.

The total freshwater inflow to the World Ocean from the continents (without Antarctica) equals 39 500 km^3/year. The oceans also receive about 2400 km^3/year as subsurface runoff not drained by rivers, and 2300 km^3 of freshwater mainly as icebergs and melt runoff from the glaciers of Antarctica. Thus, the total freshwater inflow to the World Ocean from land is about 44 200 km^3/year; this is equivalent to about 370 mm over the areas of external runoff or 300 mm, if related to the whole land area.

Evapotranspiration over continents varies from 420 mm to 850 mm (without Antarctica, where it is about zero). Evapotranspiration from the areas of external runoff is about 1.5 to 2 times greater than that from endorheic areas.

Evapotranspiration values given in the balance include runoff in endorheic areas where it is completely lost for evaporation. It also includes the amount of water used for human activities.

Analysis of water balance discrepancies shows good reliability of present assessment of long-term water balance for continents and large physiographic regions of the world.

Freshwater inflow to the World Ocean equals 502 000 km^3/year, of which 91% is contributed by precipitation (458 000 km^3, or 1390 mm). More than a half of this amount is contributed to the Pacific Ocean.

The Arctic and Pacific Oceans have freshwater excess while the Atlantic and Indian Oceans have freshwater shortage. Freshwater excess is most significant in the southern areas of the Pacific, Atlantic and Indian Oceans because of the surplus of precipitation over evaporation there.

Evaporation from the surface of the World Ocean is about 1390 mm, varying from 220 mm from the Arctic Ocean to 1500 mm from the Pacific Ocean.

The highest freshwater inflow (49% of the total volume) from the continents occurs to the Atlantic Ocean. The effect of freshwater inflow is most important in the Arctic Ocean because its volume equals only 1.2% of the World Ocean volume.

Annual precipitation over the globe (numerically equal to evaporation) equals 577 000 km^3, or 1130 mm. The depth of the evaporation layer from the ocean surface is three times greater than that from land. The volume of water annually evaporating from the ocean surface equals 87% and that from land is 13% of the total evapotranspiration fromthe Earth's surface.

The data presented in this chapter on global water balance are average figures for a long-term period—the data are characteristic of a stationary climate situation. Scientists are now facing a fundamentally new research problem, i.e. study of world water balance taking account of both natural and anthropogenic factors. Anthropogenic factors are of a particular importance under conditions of ever-increasing human impact on the global climate. This is likely to lead to evident change in the global water balance during the coming decades.

1.7 WATER BUDGET EQUATION

WATER BUDGET EQUATION FOR A CATCHMENT

The area of land draining into a stream at a given location is known as catchment area or drainage area or drainage basin or water shed.

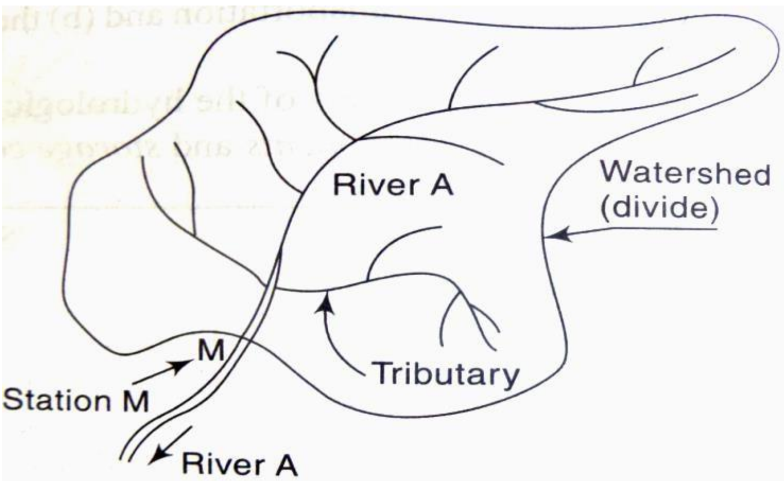


FIG-4

For a given catchment area in any interval of time, the continuity equation for water balance is given as: (Change in mass storage) = (mass in flow) - (mass outflow)

$$\Delta s = V_i - V_o$$

The water budget equation for a catchment considering all process for a time interval Δt is written as: $\Delta s = P - R - G - E - T$

Where, Δs represent change in storage

P- Precipitation, G- Net ground water flowing outside the catchment, R- Surface runoff

E- Evaporation, T- Transpiration

Storage of water in a catchment occurs in 3 different forms and it can be written as:

$$S = S_s + S_m + S_g$$

Where, S- storage, Ss - Surface water storage, S_m - soil moisture storage,

Sg - ground water storage

Hence change in storage maybe expressed as:

$$\Delta S = \Delta S_s + \Delta S_m + \Delta S_g$$

The rainfall runoff relationship can be written as: R= P - L

R- Surface runoff, P- Precipitation, L- Losses

i.e. water not available to runoff due to infiltration, evaporation, transpiration and surface storage.

IMPORTANT QUESTIONS

1.Explain Horton’s Qualitative Hydrologic Cycle?

2.Describe World Water Balance ?

3. Write The Water Budget Equeation ?

CHAPTER-2

LECTURE -4

Learning objectives

2.1 Precipitation
2.2 Forms Of Precipitation
2.3 . Types Of Precipitation

2.1 PRECIPITATION

It is defined as the return of atmospheric moisture to the ground in the form of solids or liquids. Precipitation is the fall of water in various forms on the earth from the cloud. The usual form of precipitation is rain and snow. In India snowfall occurs only in Himalayan region during water. Most of the precipitation occur in India is the form of rain.

The following are the main characteristics of rainfall:

a. Amount or quantity: The amount of rainfall is usually given as a depth over a specified area, assuming that all the rainfall accumulates over the surface and the unit for measuringamount of rainfall is cm. The volume of rainfall = Area x Depth of Rainfall (m^3)

The amount of rainfall occurring is measured with the help of rain gauges.

b. Intensity: This is usually average of rainfall rate of rainfall during the special periods of a storm and is usually expressed as cm/ hour.

c. Duration of Storm: In the case of a complex storm, we can divide it into a series of storms of different durations, during which the intensity is more or less uniform.

d. Aerial distribution: During a storm, the rainfall intensity or depth etc. will not be uniform over the entire area. Hence we must consider the variation over the area i.e. the aerial distribution of rainfall over which rainfall is uniform.

2.2 FORMS OF PRECIPITATION

1. Drizzle – This is a form of precipitation consisting of water droplets of diameter less than 0.05 cm with intensity less than 0.01cm/ hour. In this drops are so small that they appear to flow in the air.
2. Rainfall – This is a form of precipitation of water drops larger than 0.05cm diameter up to 0.6cm diameter. Water drops of size greater than 0.6 cm diameter tend to break up as they fall through the atmosphere. Intensity varies from 0.25 cm/ hour to 0.75cm/ hour.
   Light Rain – Traced to 0.25cm/hr
   Moderate rain – 0.25cm/hr to 0.75cm/hr
   Heavy rain – greater than 0.75cm/hr
3. Snow – This is precipitation in the form of ice crystals. These crystals usually carry a thin coating of liquid water and form large flakes when they collide with each other.
4. Hail – The precipitation in the form of balls are irregular of ice of diameter 5mm or more is called Hail.
5. Glaze (Freezing Rain) – This is the ice coating formed when a drizzle or rainfall comes in contact with very old objects on the ground. It occurs when there is cold layer of air with temperature below 0^0C
6. Sleet – Sleet is the precipitation in the form of melting snow. It is a mixture of snow and rain. It is in the form of pellet of diameter 1mm-4mm. Sleet is also known as small hail.
7. Frost – Frost is a form of precipitation which occurs in the form of scales, needles, feathers or fans.
8. Dew – Dew is a form of precipitation which doesn't occur because of condensation in higher layer of atmosphere but it is formed by condensation directly on the ground. Dew occurs in the night when the ground surface is cooled by outgoing radiation.

LECTURE -5

2.3 .TYPES OF PRECIPITATION

One of the essential requirements for precipitation to occur is the cooling of large masses of moist air. Lifting of air masses to higher altitudes is the only large scale process of cooling. Hence the types of precipitation based on the mechanism which causes lifting of air masses are as follows:

1. Convective precipitation: This is due to the lifting of warm air which is lighter than the surroundings. Generally this type of precipitation occurs in the tropics where on a hot

day, the ground surface gets heated unequally causing the warmer air to lift up and precipitation occurs in the form of high intensity and short duration. This usually occurs in the form of a local whirling thunder storm and for very short duration, it is called 'tornado', when accompanied by very high velocity destructive winds. Convective precipitation covers small area and rainfall intensity may be very high (10cm/hr).

2. Orographic Precipitation: It is the most important precipitation and is responsible for most of heavy rains in India. Orographic precipitation is caused by air masses which strike some natural topographic barriers like mountains and cannot move forward and hence the rising amount of precipitation. The greatest amount of precipitation falls on the windward side and leeward side has very little precipitation.

   Ex: Cherrapunji, Agumbe in Western Ghats of southern India gets heavy Orographic precipitation.

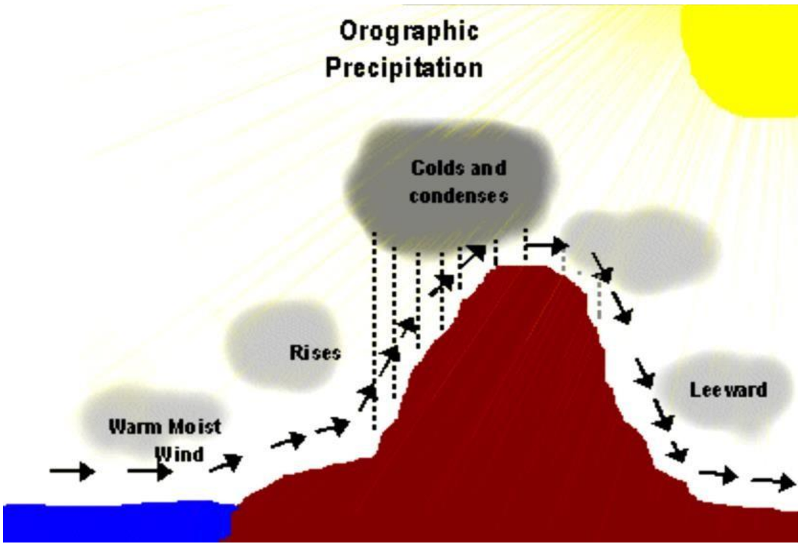


FIGURE-5

3. Cyclonic Precipitation: This is the precipitation associated with cyclones or moving masses of air and involves the presence of low pressures. A cyclone is a large zone of low pressure which is surrounded by a circular wind motion. This type of precipitation occur dye to pressure differences created by the unequal heating of earth's surface. Air tends to move into low pressure zone from surrounding areas and displaces low pressure air upwards. The wind blows spirally inward counter clockwise in the northern hemisphere and clockwise in the southern hemisphere.

   This is further sub divided into 2 categories

a. Non Frontal cyclonic precipitation: In this, a low pressure area develops. (Low-pressure area is a region where the atmospheric pressure is lower than that of surrounding locations). The air from surroundings converges laterally towards the low pressure area. This reults in lifting of air and hence cooling. It may result in precipitation.

b. <u>Frontal cyclonic precipitation:</u> FRONT is a barrier region between two air masses having different temperature, densities, moisture, content etc. If a warm and moist air mass moves upwards over a mass of cold and heavier air mass, the warm air gets lifted, cooled and may result in precipitation. Such a precipitation is known as warm front precipitation.

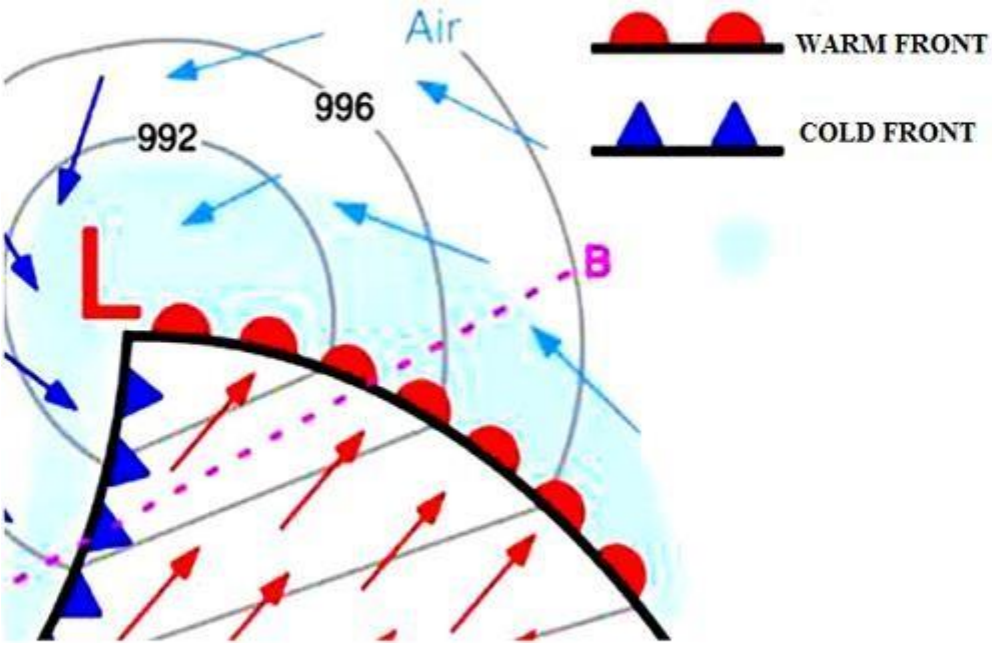


FIG-6: Cyclonic precipitation

4. <u>Turbulent Precipitation:</u> This precipitation is usually due to a combination of the several of the above cooling mechanisms. The change in frictional resistance as warm and moist air moves from the ocean onto the land surface may cause lifting of air masses and hence precipitation due to cooling. This precipitation results in heavy rainfall. The winter rainfall in Tamilnadu is mainly due to this type of turbulent ascent.

LECTURE-5

Learning objectives

2.4 Measurement Of Rainfall
2.5 Type Of Non Recording And Recording Raingauge

2.4 MEASUREMENT OF RAINFALL

Rainfall is measured on the basis of the vertical depth of water accumulated on a level surface during an interval of time, if all the rainfall remained where it fell. It is measured in mm‘. The instrument used for measurement of rainfall is called “Rain gauge”. These are classified as:

- Non recording type Raingauge
- Recording type Raingauge

NON RECORDING TYPE RAINGAUGES

These rain gauges which do not record the depth of rainfall, but only collect rainfall. Symon‘s rain gauge is the usual non recording type of rain gauge. It gives the total rainfall that has .occurred at a particular period. It essentially consists of a circular collecting area 127 mm in diameter connected to a funnel. The funnel discharges the rainfall into a receiving vessel. Thefunnel and the receiving vessel are housed in a metallic container. The components of this rain gauge are a shown in fig below.

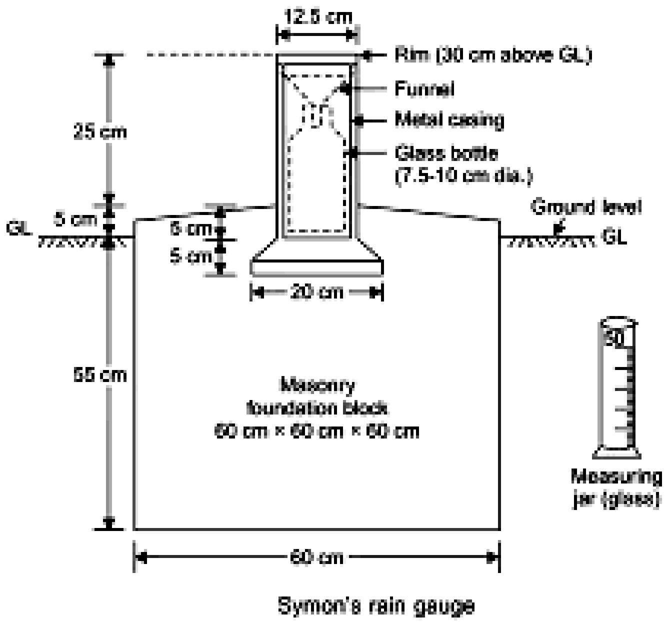


FIG -7: Symons Raingauge

The water collected in the receiving bottle is measured by a graduated measuring jar with an accuracy of 0.1 ml. the rainfall is measured every day at 8:30 am IST and hence this

Raingauge gives only depth of rainfall for previous 24 hours. During heavy rains, measurement is done 3 to 4 times a day.

Thus Symons Raingauge gives only the total depth of rainfall for previous 24 hours and doesn't provide intensity and rainfall duration of the rainfall during different time interval of the day.

RECORDING TYPE RAINGAUGES

These are rain gauges which can give a permanent, automatic rainfall record (without any bottle recording) in the form of a pen mounted on a clock driven chart. From the chart intensity or rate of rainfall in cm per hour or 6 hrs, 12 hrs…... besides the total amount of rainfall can be obtained.

<u>Advantages of recording rain gauges:</u>

1. Necessity of an attendant does not arise
2. Intensity of rainfall at anytime as well as total rainfall is obtained, where as non recording gauge gives only total rainfall.

Data from in accessible places (hilly regions) can be continuously obtained.

3. Human errors are eliminated.
4. Capacity of gauges is large.
5. Time intervals are also recorded.
6. <u>Disadvantages of recording rain gauges:</u>

1. High initial investment cost.
2. Recording is not reliable when faults in gauge arise (mechanical or electrical) till faults are corrected.

TYPES OF RECORDING RAINGAUGE

1. Tipping bucket rain gauge:

This is the most common type of automatic rain gauge adopted by U S Meteorological Department.

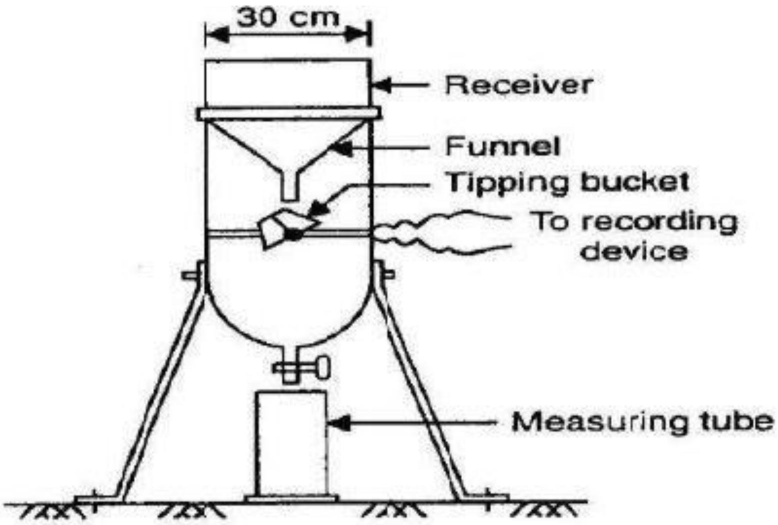


FIG -8: Tipping Bucket Raingauge

This consists of receiver draining into a funnel of 30 cm diameter. The catch (rainfall) from funnel falls into one of the pair of small buckets (tipping buckets). These buckets are so balanced that when 0.25 mm of rainfall collects in one bucket, it tips and brings the other bucket into position.

Tipping of bucket completes an electric circuit causing the movement of pen to mark on clock driven receiving drum which carries a recorded sheet. These electric pulses generated are recorded at the control room far away from the rain gauge station. This instrument is further suited for digitalizing the output signal.

The tipping bucket Raingauge is quiet durable, simple to operate and convenient but it has following disadvantage:

- It doesn't give accurate result in case of intense rainfall, because some of rain which fallsduring the tipping of bucket is not measured.
- Because of discontinuous nature of the record, the instrument is not satisfactory for usinglight drizzle or very light rain.
- The time of beginning and ending of rainfall cannot be determined accurately.
- This gauge is not suitable for measuring snow without heating the collector.

2. Weighing bucket rain gauge:

This is the most common type of recording or automatic rain gauge adopted by Indian Meteorological Department. The construction of this rain gauge is shown in figure below.

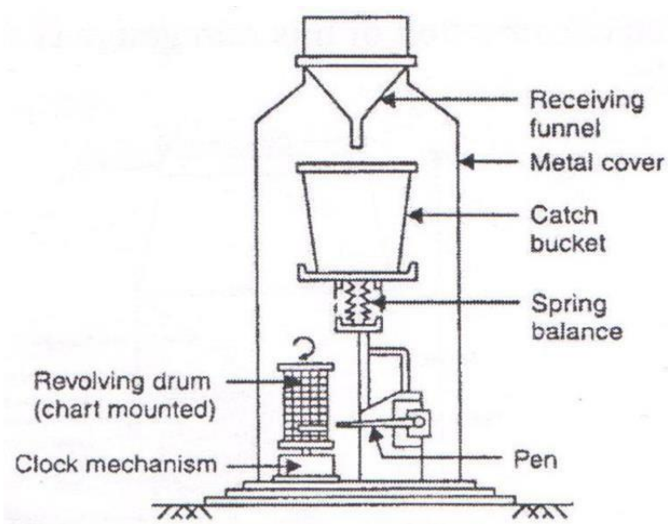
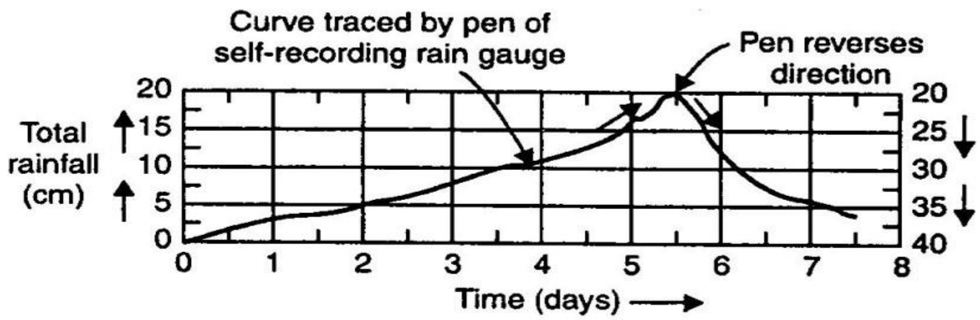


FIG- 9: Weighing Bucket Raingauge

It consists of a receiving bucket supported by a spring or lever. The receiving bucket is pushed down due to the increase in weight (due to accumulating rain fall). The pen attached to the arm continuously records the weight on a clock driven chart. The chart obtained from this rain gauge is a mass curve of rain fall.



Mass curve of rainfall

From the mass curve the average intensity of rainfall (cm/hr) can be obtained by calculating the slope of the curve at any instant of time. The patterns as well as total depth of rain fall at different instants can also be obtained.

The advantages of this raingauge are that it can record snow, hail and mixture of rain and snow.

The disadvantages are:

- The effect of temperature and friction on weighing mechanism may introduce error.
- Failure of reverse mechanism results in loss of record.
- Because of wind action on bucket, erotic traces may be recorded on the chart.

3. Siphon or float type rain gauge

This is also called integrating rain gauge as it depicts an integrated graph of rain fall with respect to time. The construction of this rain gauge is shown in figure below.

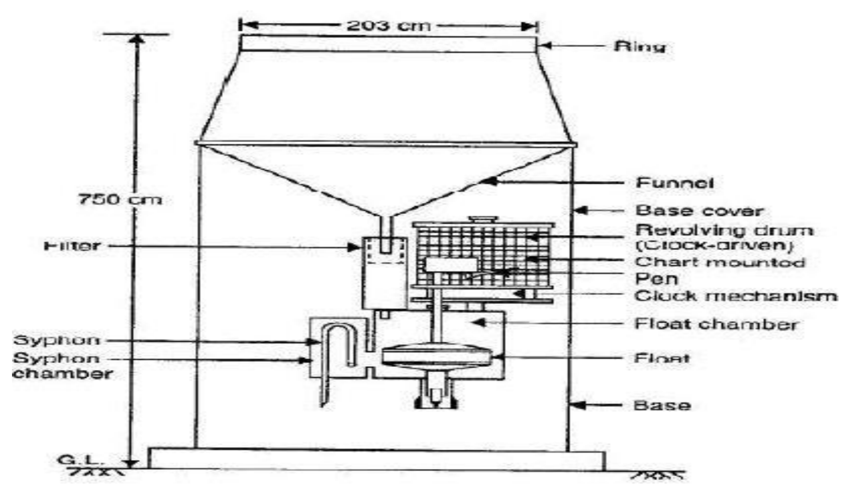


FIG 10: SIPHON RAINGAUGE

A receiver and funnel arrangement drain the rainfall into a container, in which a float mechanism at the bottom is provided. As water accumulates, the float rises. A pen arm attached to the float mechanism continuously records the rainfall on a clock driven chart and also produces a mass curve of rain fall. When the water level rises above the crest of the siphon, the accumulated water in the container will be drained off by siphonic action. The rain gauge is ready to receive the new rainfall.

LECTURE-6

Learning objectives

2.6 Determination Of Average Precipitation Over An Area

2.6 DETERMINATION OF AVERAGE PRECIPITATION OVER AN AREA

The rainfall measured by a rain gauge is called point precipitation because it represents the rainfall pattern over a small area surrounding the rain gauge station. However in nature rain fall pattern varies widely. The average precipitation over an area can be obtained only if several rain gauges are evenly distributed over the area. But there is always limitation to establish several rain gauges. However this draw back can be overcome by adopting certain methods as mentioned below, which give fair results.

Arithmetic mean method: In this method to determine the average precipitation over an area the rainfall data of all available stations are added and divided by the number of stations to give an arithmetic mean for the area. That is if P1, P2 and P3 are the precipitations recorded at three stations A, B and C respectively, then average precipitation over the area covered by the rain gauges is given by

$$P_{av} = P_1+P_2+P_3/3$$

This method can be used if the area is reasonably flat and individual gauge readings do not deviate from the mean (average). This method does not consider aerial variation of rainfall, non-even distribution of gauges, Orographic influences (presence of hills), etc. This method can also be used to determine the missing rain fall reading from any station also in the given area.

Thiessen Polygon method: This is also known as weighted mean method. This method is very accurate for catchments having areas from 500 to 5000 km2. In this method rainfall recorded at each station is given a weight age on the basis of the area enclosing the area. The procedure adopted is as follows.

The rain gauge station positions are marked on the catchment plan.

- Each of these station positions are joined by straight lines.

- Perpendicular bisectors to the previous lines are drawn and extended up to the boundaryof the catchment to form a polygon around each station.
- Using a planimeter, the area enclosed by each polygon is measured.
- The average precipitation over an area is given as

$$(P_{av} = P_1A_1+P_2A_2+P_3A_3+\ldots\ldots\ldots\ldots +P_nA_n / A_1+A_2+A_3+\ldots\ldots\ldots +A_n)$$

Where P_1, P2, P3………… P_n are rainfall amounts obtained from 1 to n rain gauge stations respectively are areas of polygons surrounding each station.

A_1, A_2, A_3……… A_n are areas of polygons surrounding each station.

<u>Isohyetal Method</u>: Isohyets are imaginary line joining points of equal precipitation in a

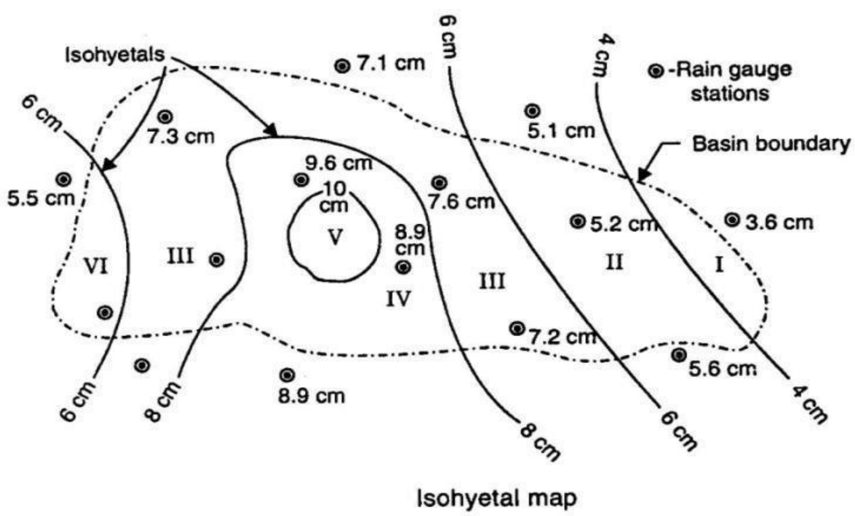


FIG-11

given area similar to contours in a given area. In Isohyetal Method for determining the average precipitation over an area, Isohyets of different values are sketched in a manner similar to contours in surveying in a given area. Themean (average) of two adjacent Isohyetal values is assumed to be the precipitation over thearea lying between the two isohyets. To get the average precipitation over an area theprocedure to be followed is with the corresponding mean Isohyetal value(precipitation).

- All such products are summed up.
- The sum obtained from above is divided by the total area of the catchment (gauging area).
- The quotient obtained from above represents average precipitation over gauging area.

LECTURE-7

Learning objectives

2.7 Estimation Of Missing Precipitation Record

2.7 ESTIMATION OF MISSING PRECIPITATION RECORD

A sufficiently long precipitation record is required for frequency analysis of rainfall data. But a particular rain gauge may not be operative for sometime due to many reasons it becomes necessary to estimate missing record & fill the gap rather than to leave it empty. This is done by the following method.

1. Interpolation from Isohyetal map

In an Isohyetal map of the area the passion of the station (rain gauge) where record is missing is marked by interpolation techniques the missing record is worked out the factors like storm factor, topography nearness to sea are considered for proper estimation.

2. Station Year method

In this method the records of 2 or more stations are combined into one long record provided station records are independent and areas in which stations located are climatologically the same. The missing record at any station in a particular year may be found by ratio of averages or by graphical comparison.

3. Arithmetic average method

Here number of other rain gauge station record surrounding station in question (missing record) is required. The missing rainfall record at the station is taken as average o fall available data surrounding station in question. P1, P2, P3-------- etc Pn are rainfall record from ―n‖ station surrounding a non operative station 'x' the rainfall data for station 'x' is given as

$$P_x = (P_1 + P_2 + P_3 \text{--------} + P_n) / 3$$

This method is applicable when normal annual rainfall at station ―x‖ does not differ by morethan 10% with the surrounding station.

Normal ratio method

This method is applicable when normal annual rainfall at required station differ more than 10% of annual rainfall at surrounding station.

Let P_1, P_2, P_3-------- Pn be rainfall record at 'n' station during a particular storm surrounding station 'x' (with missing record). Let N_1, N_2 -------- N_n be annual normal rainfall for 'n' station. N_x be annual rainfall for station 'x'. Then the rainfall at station 'x' during a given storm is calculated as

$$P_x = 1/n\ (N_x/N_1\ P_1 + N_x/N_2\ P_2 \text{-------} + N_x/\ N_x\ P_n)$$

RAIN GAUGE DENSITY

The catchment area of a rain gauge is very small compared to the areal extent of a storm. It becomes obvious that to get a representative picture of a storm over a catchment, the numberof rain gauges should be as many as possible. On the other hand topographic conditions and accessibility restrict the number of rain gauges to be set up. Hence one aims at optimum number of rain gauges from which accurate information can be obtained. From practical considerations IMD as per IS 4987 has recommended the following rain gauge densities depending upon the type of area.

- Plain areas – 1 station per 520 km^2
- Areas with 1000 m average elevation - 1 station per 260 to 350 km^2
- Predominantly hilly areas with heavy rainfall - 1 station per 130 km^2

OPTIMUM NUMBER OF RAIN GAUGE STATIONS

If there are already some raingauge stations in a catchment, the optimal number of stations that should exist to have an assigned percentage of error in the estimation of mean rainfall is obtained by statistical analysis as

$$N = (C_v/E)^2$$

Where, N= optimal number of stations

E = allowable degree of error in the estimate of mean rainfall

If there are n stations in the catchment each recording rainfall values P_1, P_2……... Pn in aknown time, the coefficient of variation

$$C_v = 100\sigma/P$$

$$P = (P_1 + P_2 + P_3 \text{------------} + P_n) / 3$$

$$P^1 = (P_1^2 + P_2^2 + P_3^2 \text{------} + P_n^2) / 3$$

$$C_v = 100\sigma/P$$

$$\sigma = \sqrt{\ \underline{n-1*}\ [P^{12} - P^2]}$$

TESTS FOR CONSISTENCY OF RAINFALL

If the conditions relevant to the recording of a raingauge station have undergone significant change during the period of record, inconsistency could arise in the rainfall data of that record. Some of the common causes for inconsistency of record are:

1. Shifting the raingauge station to new location.
2. The neighborhood oh the station undergoing a marked change.
3. Change in the ecosystem due to calamities such as forest fires, land slide etc.
4. Occurrence of observational error from certain data.

Checking for inconsistency of a record is done by “double mass curve technique”. This technique is based on the principle that “when each recorded data comes from the same parent population they are consistent.

A group of 5 to 10 base stations in the neighborhood of the problematic station ‘X’ is selected. The data of annual (monthly) mean rainfall of the station X and also the average rainfall of the group of the base stations covering a long period is arranged in reverse chronological order. The accumulated precipitation of station X and the accumulated precipitation values of the average of the group of base station are calculated starting from the latest record. Values of $\sum P_x$ are plotted against $\sum P_{avg}$ for various consecutive time periods. A decided break in the slope of the resulting plot indicate a change in precipitation regime of station ’X’ beyond the period of change of regime is corrected by using the relation:

$$P_{C_X} = P_X * \frac{M_C}{M_a}$$

Where, P_{C_X} = Corrected precipitation at any time period T_1 at station X Px =

Original recorded precipitation at time period T_1 at station XMc =

Corrected slope of the double mass curve

Ma = Original slope of the double mass curve

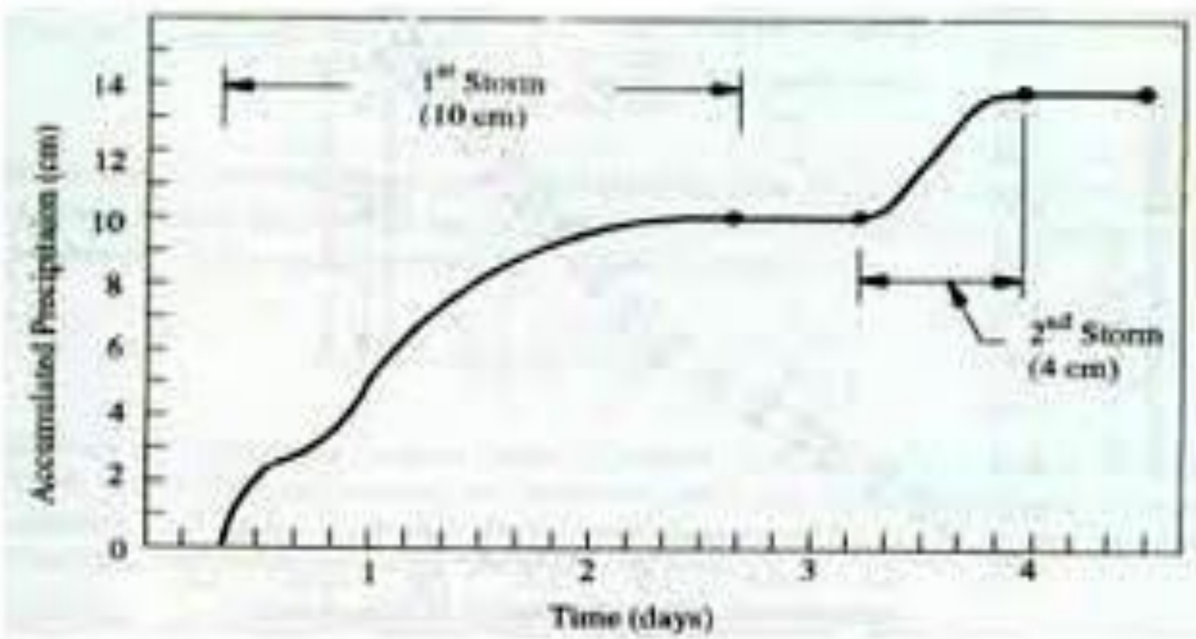


FIG12: Double mass curve

PRESENTATION OF RAINFALL DATA

1. The Mass Curve of Rainfall

The mass curve of rainfall is a plot of the accumulated precipitation against time, plotted in chronological order. Records of float type and weighing bucket type gauges are of this form. A typical mass curve of rainfall at a station during a storm is shown in figure below. Mass curve of rainfall are very useful in extracting the information on the duration and magnitude of a storm. Also, intensities at various time interval s in a storm can be obtained by the slope of the curve. For non recording rain gauges, mass curves are prepared from knowledge of the approximate beginning and end of a storm and by using the mass curve of adjacent recording gauge stations as a guide.

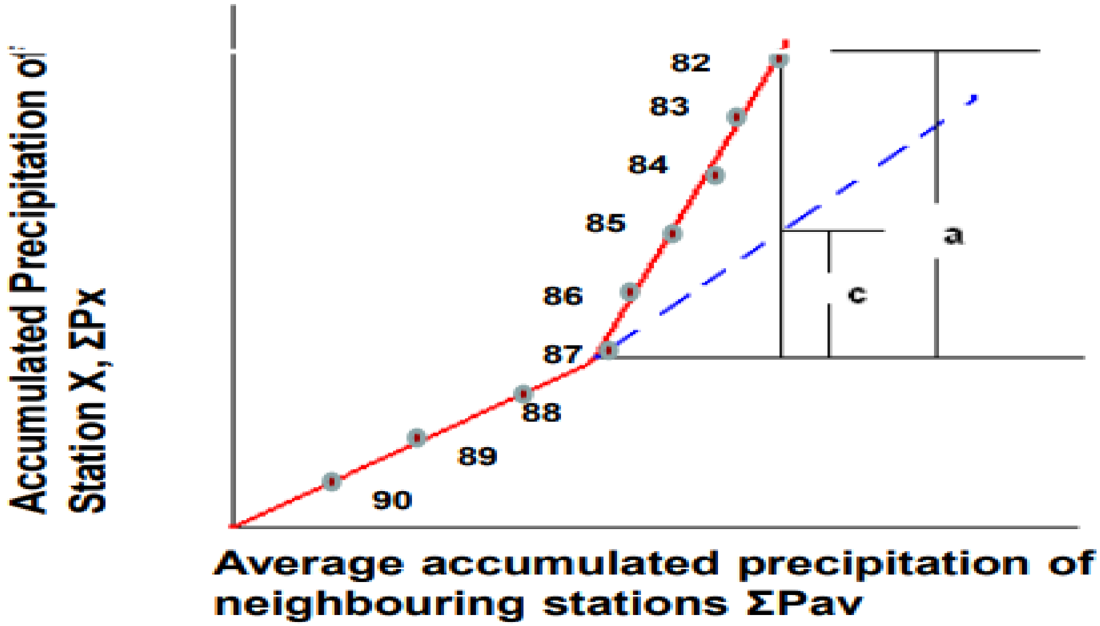


FIG13: Mass Curve of Rainfall

2. Hyetograph

A hyetograph is a plot of the intensity of rainfall against the time interval. The hyetograph is derived from the mass curve and is usually represented as a bar chart. It is very convenient way of representing the characteristics of a storm and is particularly important in the development of design storms to predict extreme floods. The area under a hyetograph represents the total precipitation received in the period. The time interval used depends on the purpose, in urban drainage problems small durations are used while flood flow computations in larger catchments the intervals are about 6h.

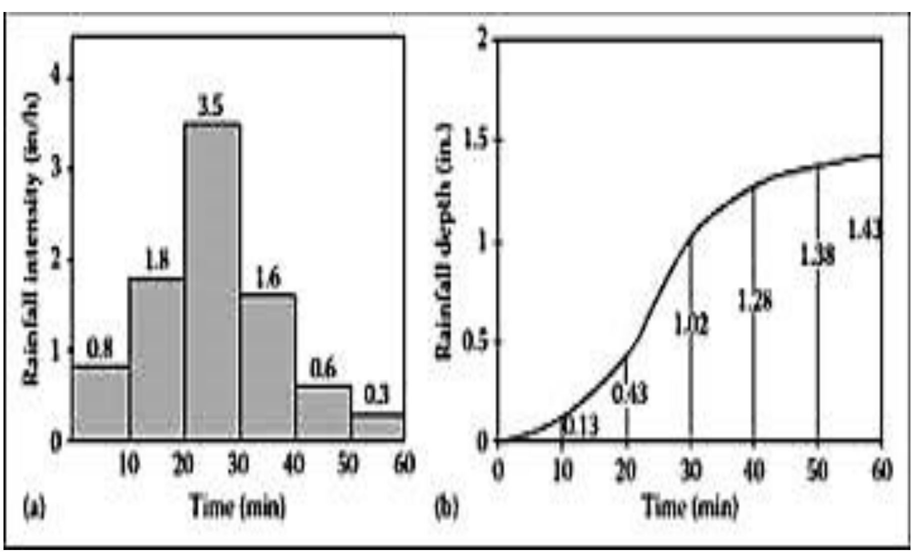


FIG14 : Hyetograph of a storm

3. Point rainfall

It is the total liquid form of precipitation or condensation from the atmosphere as receivedand measured in a rain gauge. It is expressed as so many ‘mm’ of depth of water.

4. Ordinate graph

The ordinate graph represents the rainfall in any year as an ordinate line drawn to some scale at the corresponding year.

5. Moving Average Curve

The graphical representation of rainfall in any of the above methods may not show any trend or cyclic pattern present in the data. The moving average curve smoothens out the extreme variations and indicate the trend or cyclic pattern if any more clearly. It is also known as the moving mean curve.

The procedure to construct the moving average curve is as follows:

The moving average curve is constructed with a moving period (m) year, where m is generally taken to be 3 to 5 years. Let X_1, X_2, X_3…………… Xn be the sequence of given annual rainfall in the chronological order. Let Yi denote the ordinate of the moving average curve for the i^{th} year. Then m = 3, Yi is computed from

$$Y_2 = X_1+X_2+X_3 / 3Y_3 =$$

$$X_2+X_3+X_4 / 3$$

$Y_i = X_{(i-1)}+X_i+X_{(i+1)} / 3$ $Y(n-1) = X_{(n-2)}+X_{(n-1)}+X_n / 3$

From the above equations the computed value of ‘i’ correspond in time, the middle value of ‘x’ being average and therefore it is convenient to use odd values of “m”.

$* [P^{12} - P^2]$

LECTURE-8

Learning objectives

2.8 Presentation of Rainfall Data

2.8 Presentation of Rainfall Data

Depth-Area and Intensity Duration Frequency Curves

A. Depth-Area-Duration Curves:

Once the sufficient rainfall records for the region are collected the basic or raw data can be analysed and processed to produce useful information in the form of curves or statistical values for use in the planning of water resources development projects. Many hydrologic problems require an analysis of time as well as areal distribution of storm rainfall. Depth-Area-Duration (DAD) analysis of a storm is done to determine the maximum amounts of rainfall within various durations over areas of various sizes.

The preparation of DAD curves is done in following steps:

1. Examine the rainfall records of the region in which catchment area under consideration is located. Also consider records of meteorologically similar regions. From it prepare a list of most severe storms with their dates of occurrence and duration.

2. For the listed severe storms prepare iso-hyetal maps and determine the rainfall values over the area of each isohyet (rainfall contour).

3. Draw on a graph curves connecting area and rainfall values for different durations say 1 day rainfall, 2 day rainfall, 3 days rainfall (Refer Fig. 2.12).

The curves shown in Fig. 2.12 are called Depth-Area-Duration curves:

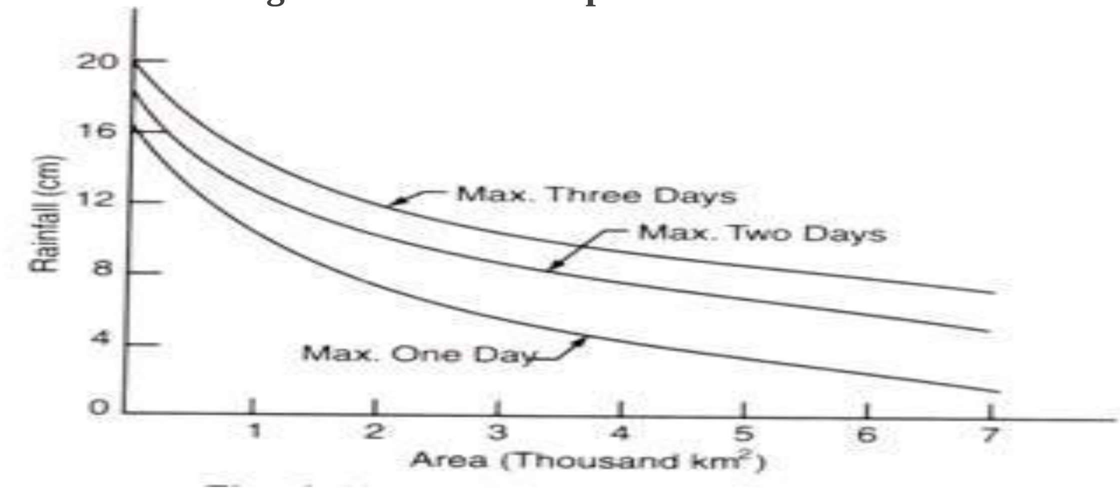


FIG-15

Use of DAD Curves:

Although most severe storm in the listed storms may not have occurred right over the catchment under consideration there is possibility of such occurrence. So from DAD curves 1 day, 2 day, 3 day rainfall depths for the catchment area of the proposed project are read. These give the rainfall depths when the storms are centered over the catchment.

B. Intensity Duration Frequency Curves:

In hydrology, frequency analysis of station rainfall data is done for use in design of bridges and culverts on highways, design of storm drains etc. With the advancement of science of hydrology rainfall frequency analysis is done using Gumble's extreme-value distribution and annual series data.

Now the frequency analysis concept is applied on a seasonal basis and for areal frequency. The rainfall records of deficient length have to be extended by station year method. The results of frequency analysis are plotted on the log-log paper. The typical intensity-duration frequency curves are given in Fig. 2.13.

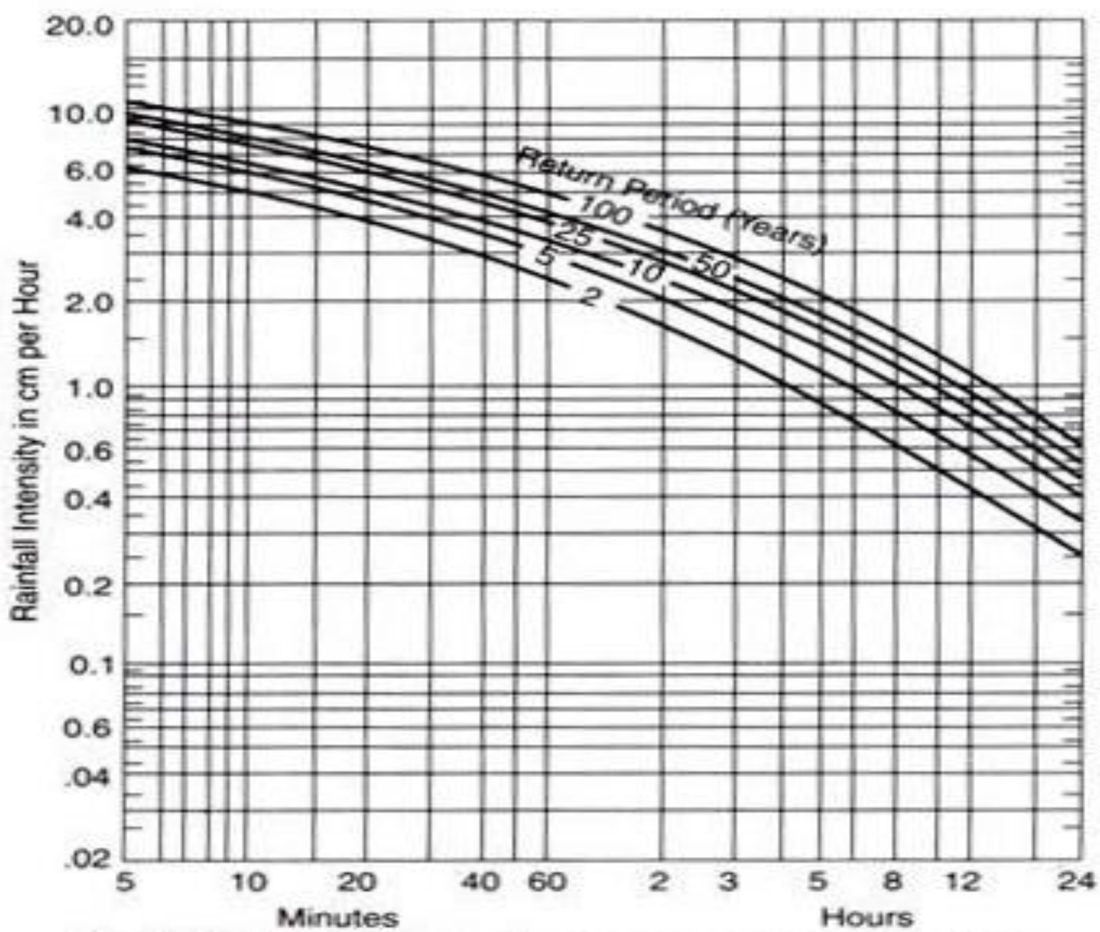

Raintall Intensity in cm per Hour
20.0
10.0
6.0
4.0
2.0
1.0
0.6
0.4
0.2
0.1
0.6
.04
.02
Return Period (Years)
100
50
25
10
5
2
5
10
20
40
60
2
3
5
8
12
24
Minutes
Hours

FIG-16

LECTURE-9

Learning objectives

2.9 Depth-Area-Duration (Dad) Curve
2.10 World's Greatest observed Rainfall

2.9 DEPTH-AREA-DURATION (DAD) CURVE:-

DAD analysis is carried out to obtain a curve relating the depth of precipitation D, area of its coverage A and duration of occurrence of the storm D. A DAD curve is a graphical representation of the gradual decrease of depth of precipitation with the progressive increase of the area of storm, away from the storm center, for a given duration taken as the 3rd parameter. This gives a direct relationship between depth, area and duration of ppt. over the region for which the analysis is carried out. The purpose of DAD analysis is to determine the maximum precipitating amounts that have occurred over various sizes of drainage during the passage of storm periods of say 6h, 12h, 24h or other durations. There are two methods available for carrying out DAD analysis-

1. Mass curve method
2. Incremental-isohyetal method

Probable maximum precipitation (PMP):

It is defined as the estimate of the extreme maximum rainfall of a given duration that is physically possible over a basin under critical hydrological and meteorological conditions. This is used to compute flood by using suitable rainfall runoff model.
Two methods of PMP estimation are:

1. Statistical procedure
2. Meteorological approach

The statistical approach of PMP by using Chow's equation

$$PMP = P + k\sigma$$

Where P is the mean of annual maximum values, ϭ the standard deviation and k is the frequency factor which varies between 5 to 30 according to rainfall duration.

2.10 World's Greatest observed Rainfall

Based upon the rainfall records available all over the world, a listof World's greatest recorded rainfalls of duration can be assembled.When this data is plotted on a log-log paper,an enveloping straright line drawn to plotted points

obeys the equation.

$$Pm = 42.16\, D^{.457}$$

Where Pm=extreme rainfall depth in cm and D=duration in hours
The values obtained from equation are use in PMP estimations.

IMPORTANT QUESTIONS

1. Explain with a neat sketch Siphon’s rain gauge?
2. Define precipitation. Explain various forms of precipitation?
3. Describe various methods of precipitation over an area of rain fall
4. Explain briefly the following relationships relating to the precipitation over a basin :
   (a) Depth-Area Relationspthip
   (b) Maximum Depth –Area -Duration curves
   (c) Intensity Duration Frequency Relationship.

5.What is meant by Probable Maximum Precipitation (PMP) over a basin? Explain how PMP is estimated.

6.Explain a procedure for supplementing the missing rainfall data.

CHAPTER -3

ABSTRACTIONS FROM PRECIPITATION

LECTURE-10

Learning objectives

3.1 LOSSES FROM PRECIPITATION

The hydrological equation states that ‗Runoff = Rainfall – Losses'. Hence the runoff from a watershed resulting due to a storm is dependent on the losses. Losses may occur due to the following reasons

1. Evaporation
2. Evapotranspiration
3. Infiltration
4. Interception
5. Watershed leakage

The first three contribute to the major amount of losses.

3.1.1 EVAPORATION

It is the process by which a liquid changes to gaseous state at the free surface through transfer of heat energy. In an exposed water body like lakes or ponds, water molecules are in continuous motion with arrange of velocities (faster at the top and slower at the bottom). Additional heat on water body increases the velocities. When some water molecules posses' sufficient kinetic energy they may cross over the water surface. Simultaneously the water molecules in atmosphere surrounding the water body may penetrate the water body due to condensation. If the number of molecules leaving the water body is greater than the number of molecules arriving or returning, difference in vapour pressure occurs, leading to evaporation.

EVAPORATION PROCESS

When the external thermal energy supplied to surface of water body, the kinetic energy of water molecules will be increased. When the molecules near the free surface attain enough kinetic energy, they escape from the water body they eject themselves in to the atmosphere. Out of total atmospheric pressure on the free surface there will be some contribution from the vapour molecules present in the free surface. This partial pressure exerted by the vapour is called vapour pressure. Continued supply of heat energy causes accumulation of more and more vapour molecules and thus gaseous medium can no longer accommodate and reject vapour molecules in the form of condensation at the same rate as vaporization. At this stage the air is said to be saturated. At saturation the partial pressure exerted by water vapour is called the saturation vapour pressure and denoted by (e_s) which increase with temperature.

Thus if vapour pressure of air above free surface of water is already equal to the saturation vapour pressure (e_s) neither evaporation no condensation takes place and then it is called as equilibrium state.

From the above explanation for evaporation to occur it is necessary to have:

(1) A supply of water
(2) A source of heat
(3) Vapour pressure deficit, i.e difference b/w saturated vapour pressure of water correspond to water temperature.

FACTORS AFFECTING EVAPORATION

1. Vapour pressure difference: The number of molecules leaving or entering a water body depends on the vapour pressure of water body at the surface and also the vapour pressure of air. Higher water temperature leads to high vapour pressure at surface and tends to increase the rate of evaporation. High humidity in air tends to increase vapour pressure in air and in turn reduces rate of evaporation.

2. Temperature of air and water: The rate of emission of molecules from a water body is a function of its temperature. At higher temperature molecules of water have greater energy to escape. Hence maximum evaporation from water bodies takes place in summer. It has been estimated that for every 1o C rise in atmospheric temperature increases 5 cm of evaporation annually.

3. Wind Velocity: When wind velocity is more the saturated air (humid air) is drifted away and dry air comes in contact with water surface which is ready to absorb moisture. Hence rate of evaporation is dependent on wind velocity. It has been estimated that 10% increase in wind velocity increases 2 – 3% of evaporation.

4. Quality of water: The rate of evaporation of fresh water is greater than saline water. (Specific gravity of saline water is greater than that of fresh water. It is established that saline water has lesser vapour pressure and it is observed that evaporation from fresh water is 3 – 4% more than sea water.

5. Atmospheric pressure and Altitude: Evaporation decreases with increase in atmospheric pressure as the rate of diffusion from water body into the air is suppressed. At higher altitude the atmospheric pressure is usually lesser and there by evaporation rate is higher.

6. Depth of water body: Evaporation shallow water bodies is greater when compared to deep water bodies as the water at lower levels in deep water bodies is not heated much and vapour pressure at lower levels is also reduced.

Humidity: If the humidity of the atmosphere is more the evaporation will be less because during the process of evaporation, water vapour, moving from the point of higher moisture content to lower moisture content and rate of this movement is grounded by this difference of their moisture content or moisture gradient existing in air.

7. Radiation: Since the evaporation requires continuous supply of energy which is derived mainly from solar radiation. The radiation will be a factor of considerable importance. Evaporation increase and the radiation increases and vice versa.

DALTONS LAW OF EVAPORATION

The rate of evaporation is function of the difference in vapour pressure at the water surface and the atmosphere. Dalton‘s law of evaporation states that ―Evaporation is proportional to the difference in vapour pressures of water and air.

i.e. $E \propto (e_w - e_a)$ or $E = k\,(e_w - e_a)$

Where, E = daily evaporation

e_w = saturated vapour pressure of water at a given temperature e_a = vapour pressure of air

k = proportionality constant

Considering the effect of wind Dalton‘s Law is expressed as $E = k^l\,(e_w - e_a)\,(a+b*V)$ Where,

V = wind velocity in km/hour k^l, a & b are constants for a given area.

LECTURE-11

Learning objectives

3.1.2 MEASUREMENT OF EVAPORATION

3.1.2 MEASUREMENT OF EVAPORATION

In order to ensure proper planning and operation of reservoirs and irrigation systems estimation of evaporation is necessary. However exact measurement of evaporation is not possible. But the following methods are adopted as they give reliable results.

1. Pan measurement methods
2. Use of empirical formulae
3. Storage equation method
4. Energy budget method

PAN MEASUREMENT METHOD

Any galvanized iron cylindrical vessel of 1.2 m to 1.8 m diameter, 300 mm depth with opening at the top can be used as an evapometer or evaporation pan. During any interval of time evaporation is measured as the drop in water level in the pan. Rainfall data, atmospheric pressure data, temperature, etc should also be recorded. It has been correlated that

evaporation from a pan is not exactly the same as that taking place from a water body. Hence while using a pan measurement data for measuring evaporation from a lake or a water body, a correction factor has to be applied or multiplied by a pan co-efficient.

Pan co-efficient = (actual evaporation from reservoir / measured evaporation from pan)The evaporation pans adopted in practice have a pan coefficient of 0.7 to 0.8.

The popularly used evaporation pans are:

1. ISI standard pan or Class A pan
2. US Class A pan
3. Colorado sunken pan
4. US Geological Survey floating pan

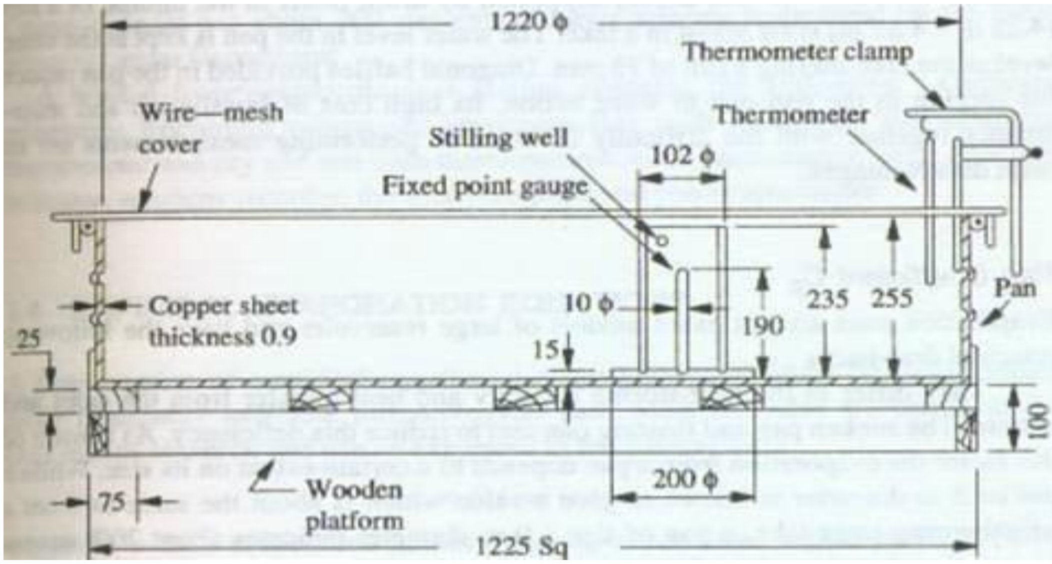


Fig 17 : ISI standard pan or Class A pan

This evaporation pan should confirm to IS – 5973:1976 and is also called Class A pan. It consists of a circular copper vessel of 1220 mm effective diameter, 255 mm effective depth and a wall thickness of 0.9 mm. A thermometer is assembled to record the variation in temperature. A wire mesh cover with hexagonal openings is provided at the top to prevent entry of foreign matter. A fixed gauge housed in a stilling well as shown in figure is provided. During evaporation measurement a constant water level is maintained at the top level of fixed gauge. For this purpose water has to be added or removed periodically. The water level measurements are done using micrometer hook gauge. The entire assembly is mounted on a level wooden platform.

PAN CO-EFFICCIENT

Evaporation pans are not exact models of large reservoirs or lakes, because of the exposure conditions which are not identical in both the cases. Specially the heat storing capacity and the heat transformed from the side & bottom of pan are quite different from those of large lake are reservoir, also the height of the rim above the water surface in the pan effects the wind action over the surface and creates a shadow of variable magnitude over water surface which effects radiation incident to the water surface. In view of the above evaporation measured from the pans has to be corrected to get the evaporation from the lake under a similar climatic exposure condition. Thus a co-efficient called pan co-efficient is introduced and is given by:

Pan Co-efficient (Cp) = (Actual evaporation from the lakes or reservoirs/ Measured evaporation from the pan)

The pan co-efficient for different types of pans are tabulated below:-

Type of Pan	Range of Cp	Average Cp
ISI Pan	0.65-1.0	0.80
Class A load pan	0.60-0.80	0.70
Colorado Sunken pan	0.75-0.86	0.78
Floating Pan	0.70-0.80	0.80

USE OF EMPIRICAL FORMULAE

Based on Dalton's law of evaporation, various formulae have been suggested to estimate evaporation.

1. Meyer's formula:

$$E = C*(e_s – e_a)*(1+0.06215V)$$

Where, E = evaporation from water body (mm/month)

e_s= saturation vapour pressure at water surface (mm of mercury) corresponding tomean monthly temperature of water

e_a= actual vapour pressure of air based on mean monthly temperature & relativehumidity

v = monthly mean wind velocity in Km/hr, 10m above the groundc = 50 (small shallow ponds)

= 11 (for large or deep water bodies)

Rohwer's formula:

$$E = 0.771(1.465 – 0.000732Pa)*(0.44+0.7334v)*(e_s – e_a)$$

Where, E = evaporation in mm/day

Pa = Mean Barometric Reading in mm mercury

e_s= saturation vapour pressure at water surface (mm of mercury) corresponding tomean monthly temperature of water

e_a= actual vapour pressure of air based on mean monthly temperature & relativehumidity

v = monthly mean wind velocity in Km/hr, 10m above the ground

LECTURE-12

Learning objectives

3.1.3 Methods To Control Evaporation From Lakes

3.1.3 METHODS TO CONTROL EVAPORATION FROM LAKES

Following are some recommended measures to reduce evaporation from water surfaces.

1) Storage reservoirs should have more depth and less surface area. The site for construction of a dam should be so chosen that a deep reservoir with minimum surface area exposed to atmosphere is formed.

2) Tall trees on the wind ward side of the reservoir should be planted so that they act as wind breakers.

3) By spraying a chemical such as Acetyl Alcohol on water surface, a film of 0.15 microns thickness is produced on the surface. This film allows precipitation in but does not allow evaporation. This is suitable when wind velocities are less and for small and medium sized reservoirs.

4) In case of ponds and lakes entire water body can be covered by thin polythene sheets as mechanical covering.

5) In reservoirs outlet arrangements should be so done to let out warmer water at top than cold water from bottom.

6) De-weeding the reservoirs should be done such that water consumed by weeds is reduced.

7) The streams and channels to be straightened so that length and in turn exposed area to atmosphere are reduced.

ANALYTICAL METHODS:-

1) Water budget method

- Simplest of the 5 method and least reliable.
- Involves hydrological continuity equation for the lake evaporationdetermination.
- Considering the daily average values for a lake ,the continuityequation:

  $P+V_{is}+V_{ig}=V_{os}+V_{og}+E_L+S$
  $+T_L$P=daily precipitation

V_{is}=daily surface inflow into lake V_{ig}=daily groundwater inflow V_{os}=daily surface outflow from the lakeV_{og}=daily seepage outflow
E_L=daily lake evaporation S=increase in lake storage in a dayT_L=daily transpiration loss
All quantities are in unit of volume (m^3) or depth (mm)

2) **Energy budget method**

- Application of the law of conservation of energy
- Energy available for evaporation is determined by considering the incoming energy, outgoing energy and energy stored in the water body.
- Energy balance to the evaporating surface in a period of one day is:

$$H_n=H_a+H_e+H_g+H_s+H_i \text{ --------- (1)}$$

Where, $H_n=(H_c-rH_c)-H_b$
$=H_c(1-r)-H_b$

H_n=net heat received by the water surface in which, $H_c(1-r)$ = incoming solarradiation into a surface of reflection coefficient 'r'
H_b=Back radiation (long wave) from water body
H_a=Sensible heat transfer from water body H_e=Heat energy used up in evaporation
$=\rho LE_L$, ρ=density of water, L=latent heat of evaporation
E_L=evaporation in mm
H_g=Heat flux into the ground
H_s=Head stored in water body
H_i=net heat conducted out of the system by water flow (advected energy)

- All energies are in cal per sq mm per day
- If the time period is small, H_s, H_i can be neglected
- H_a can't be measured directly. It is estimated using Bowen's ratio β

$$\beta=H_a/\rho LE_L=6.1\times10^{-4}\times\rho_a\{(T_w-T_a)/(e_w-e_a)\} \text{ ------- (2)}$$

where, ρ_a=Atmospheric pressure in mm of Hg
T_w=Temperature of water surface in ^oC
T_a=Temperature of air

From eq^n(1) and (2),$E_L=(H_n-H_g-H_s-H_i)/\{\rho L(1+\beta)\}$

3) **Mass transfer method**:

- Based on theories of turbulent mass transfer in boundary layer to calculate the mass of water vapour transferred from the surface to the surrounding atmosphere.

Eq^n proposed by Thornthwait and Holtzman(1939),

$E=\{0.000119(e_1-e_2)(u_2-u_1)\}/[P\times\{\log_e(h_2/h_1)\}^2]$
Where, u_1,u_2=wind velocity in m/s at heights h_1 and h_2 meter respectivelye_1,e_2=vapour pressure of air in Pa (1Pa=1N/m^2)
P=Mean atmospheric pressure in Pa between lower height $h_1$and upper height h_2

- Height $h_1$is taken close to water surface.

LECTURE-13

Learning objectives

3.2 EVAPOTRANSPIRATION

3.2.1 Factors Affecting Evapotranspiration

3.3 INFILTRATION

3.3.1 Factors Affecting Infiltration Capacity

3.2 EVAPOTRANSPIRATION

5. **Evapotranspiration:** In agricultural fields apart from transpiration, water is also lost due to evaporation from adjacent soil. The sum of these two losses is often termed as evapotranspiration (Et) or consumptive use (Cu).
6. **Potential evapotranspiration**: When sufficient moisture is freely available to completely meet the needs of the vegetation fully covering an area, the resulting evapotranspiration iscalled potential evapotranspiration.
7. **Actual evapotranspiration**: The real evapotranspiration occurring in a specific situation in the field is called actual evapotranspiration. The knowledge of evapotranspiration, potential evapotranspiration and actual evapotranspiration are very much useful in designing irrigation systems (in deciding the amount of water to be supplied for raising crops).

3.2.1 FACTORS AFFECTING EVAPOTRANSPIRATION

Potential evapotranspiration is controlled by meteorological facts but actual evapotranspiration is affected by plant and soil factors. In total the factors affecting evapotranspiration are:

1. Temperature
2. Humidity

3. Percentage sunshine hours

4. Wind speed

5. Type of crop

6. Season

7. Moisture holding capacity of soil

8. Irrigation Methods

9. Cropping patterns

DETERMINATION OF EVAPOTRANSPIRATION (ET) OR CONSUMPTIVE USE OF WATER

The time interval for supplying water to agricultural crops, is a factor dependent on water requirement of crops, soil properties and as well as consumptive use. Hence accurate determination of consumptive use or evapotranspiration is very much essential. The methods of determining consumptive use are:-

Direct measurement method

i) By use of empirical formulae

❖ **Direct measurement methods**

The different methods of direct measurement are

a. Soil moisture studies on plots

b. Tank and lysimeter method

c. Field experimental plots

d. Integration method

e. Inflow and outflow studies for large areas

a) Soil moisture studies on plots

Soil moisture measurements are done before and after supplying water. The quantity of water extracted per day from the soil is computed for each required period. A curve is drawn by plotting the rate of water consumed against time. This curve is useful for determining the average consumption daily or on monthly basis.

b) Tank and lysimeter method

Tanks are watertight cylindrical containers which are open at one end. They have a diameter of 1-3 m and depth of 2-3 m. They are set in ground with the rim in flush with the ground surface. The quantity of water to keep a constant moisture content (for optimum growth) is determined, which itself represents consumptive use. A lysimeter is a container similar to tank but has pervious bottom free drainage through the bottom is collected in a pan which is kept below. The consumptive use of water in this case therefore the difference between the water applied and drainage collected in the pan.

c) Field experimental plots

In this method water is applied to selected field plots in such a way that there is neither runoff nor deep percolation. Yield obtained from different plots is plotted against total water used. It can be observed that increase in yield occurs with increase in water applied up to a certain point. Further increase in water content reduces yield. This break point in water application istaken as consumptive use.

Integration method

In this method the consumptive use of water for large areas is determined as the sum of thefollowing products.

I) Consumptive use of each crop and its area

II) Consumptive use of natural vegetation and its area

III) Evaporation from water surfaces and their area

IV) Evaporation from open lands and their area

d) Inflow and outflow studies for large areas

In this method consumptive use of water for large areas is given by the equation:

$$Cu = I + P + (Gs - Ge) - O$$

Where, I= Total inflow into the area during a

yearP = Total precipitation in the area

during a year

Gs = Ground water storage at the beginning of the

yearGe = Ground water storage at the end of the

year

O = Outflow from the area during the year

❖ **By Use of Empirical formulae**

Following are some of the empirical methods or relations suggested for calculating consumptive use

a) Blaney Criddle method

b) Penman method

c) Lowry and Johnson method

d) Hargreaves pan method

BLANEY CRIDDLE EQUATION

Blaney and Criddle developed a simple equation for estimating evapotranspiration. It is assumed that the evapotranspiration is closely correlated with the mean monthly temperaturesand daylight hours. The monthly consumptive use factor ‘f’ is defined as:

$$\mathbf{f = (p*Tm / 100)}$$

Where Tm is the monthly mean temperature in ^{0}F, p is the monthly daylight hours expressed as percent of the daylight hours of the year and f is in inches.

In other words p is obtained from the expression

p = (possible sunshine hours for the particular month/ possible sunshine hours for the wholeyear) * 100

p = (possible sunshine hours for the particular month/ 365*12)

* 100The value of p depends on the latitude of the place and the month of the year.

The monthly consumptive use is then obtained as:

$$\mathbf{u = k*f}$$

Where k is an empirical crop co-efficient. The monthly consumptive use u are added for all the months of the crop to yield the seasonal consumptive use or the total evapotranspiration in inches. The value of k depends on the month and the place.

The Blaney – Criddle equation gives reasonably accurate estimates of evapotranspiration provided a locally developed crop co-efficient is used. However it takes only temperature and daylight hours into account and the other important factors like humidity and wind are ignored.

3.3 INFILTRATION

The water entering the soil at the ground surface after overcoming resistance to flow is called infiltration. The process is also termed as infiltration. Infiltration fills the voids in the soil. Excess water moves down by gravity and it is known as percolation. Percolation takes place till water reaches ground water table. For continuous infiltration to occur it is essential that percolation should also be continuous, which is also dependent of ground water movement. Infiltration process: Infiltration plays an important role in the runoff process and it can be easily understood by a simple analogy as shown below. The soil medium where infiltration is to be observed may be considered as a small container covered with a wire gauge mesh. If water is poured over the gauge, part of it enters the soil and some part over flows. Further the runoff and infiltration depend on the condition of soil. When soil reaches saturated condition infiltration stops and all input becomes runoff. Usually at the beginning of a storm infiltration is more and runoff is less and when storm continues infiltration becomes lesser and runoff become constant. The volume of rainfall that will result in runoff is called _Rainfall excess‘.

8. **Infiltration rate** (f): It is actually the prevailing rate at which the water is entering the given soil at any given instant of time. It is expressed in cm/hr (i.e. depth of water entering soil per unit time).
9. **Infiltration Capacity** (fp): It is the maximum rate at which a soil in any given condition is capable of absorbing water.

3.3.1 FACTORS AFFECTING INFILTRATION CAPACITY

The variations in the infiltration capacity are large. The infiltration capacity is influenced by many factors. Some factors contribute to long term variation, but some cause temporary variations.

a. <u>Depth of surface retention and thickness of saturated layer of soil:</u>
   Infiltration takes place due to combined influence of gravity and capillary force. Due to this a layer of soil near the surface becomes saturated. If the thickness of saturated soil at any given time and at any given section is ‘L’ the water will flow through a series of tiny tubes of length ‘L’. Therefore infiltration capacity should decrease

with time in a continuous rain and become a constant ultimately.

b. Soil Moisture:

The soil moisture affects the infiltration capacity in 2 ways:

(i) If the soil is quiet dry at the beginning of the rain, there is a strong capillary attraction for moisture in subsurface layers that acts in the same direction as gravity and given high initial value of infiltration. As water percolates down the surface layer becomes semi saturated & capillary forces diminish hence f also reduces.

(ii) When the soil is subjected to wetting very fine soil particles called colloids will swell slightly and reduce the size of the voids. This leads to reduce of ‘f’ with time.

c. Compactness of soil:

(i) Due to rain – The clay surfaced soils are compacted even by the impact of rain drops which reduce ‘f’. This compaction not only reduces the porosity but also pore sizes. This effect is negligible in sandy soil. Protection by vegetative cover or practically eliminate this effect even in fine textured soils.

(ii) Due to man & animals – where heavy pedestrian or vehicular traffic moves on the soil, the surface is rendered relatively impervious and this reduces ‘f’.

d. In wash of fines:

When the soil becomes very dry, the surface often contains many fine particles. When rain falls and infiltration begins, these fines are carried into the soils and are deposited in the voids, thus reduce the infiltration capacity.

e. Vegetative covers:

The natural surface cover has also an important influence on infiltration. The presence of dense cover on vegetation on the surface increase ‘f’. The vegetative covers retard the movement of overland flow and causes high depth of detention. Vegetative cover also reduces the raindrop compaction and provides a layer of decaying organic matter which

promotes the activity of borrowing insects and animals which in turn produces permeable soil structures. Transpiration by vegetation tends to keep the soil moisture at low levels. Also these factors tend to increase the infiltration capacity ‘f’. Surfaces covered with snow paved urban area will obviously have very low or zero infiltration capacity.

f. Temperature:

The effect of temperature on infiltration capacity is explained through viscosity. The flow through soil pores is almost laminar for which the resistance is directly proportional to the viscosity. At high temperature viscosity of water is low high filtration capacity is expected. During winter season the temperature is less and thus infiltration capacity becomes less. This is one of the factors responsible for seasonable variation in ‘f’.

LECTURE-14

Learning objectives

3.3.2 MEASUREMENT OF INFILTRATION

3.3.2 MEASUREMENT OF INFILTRATION

Infiltration rates are required in many hydrological problems such as runoff estimation, soil moisture studies in agriculture, etc. The different methods of determination of infiltration are

1. Use of Infiltro-meters
2. Hydrograph analysis method

The infiltrometer always gives the infiltration capacity at a particular site and infiltration from this at various locations in the basin may give fairly satisfactory estimate average infiltration capacity for the entire basin. In the hydrograph analysis method the actual infiltration rate curve is obtained, provided the accurate measurement of rainfall and runoff from the basin made.

Infiltro-meters are of two types.

a) Flooding type Infiltro-meters

b) Rainfall simulators

In flooding type Infiltro-meters water is applied in form of a sheet, with constant depth of flooding. The depletion of water depth is observed with respect to time. In case of rainfall simulators water is applied by sprinkling at a constant rate in excess of infiltration capacity and the runoff occurring is also recorded. Infiltro-meters adopted in practice are,

1. Simple (Tube Type) Infiltro-meters
2. Double ring Infiltro-meters

10. **Simple (Tube Type) Infiltro-meters** It is essentially a metal cylinder with openings at both ends. It has a diameter of 30 cm and length of 60 cm. This is driven into the groundas shown and water is poured from the top till the pointer level as shown. As infiltration

continues the depleted volume of water is made up by adding water from a burette or measuring jar to maintain constant water level. Knowing the volume of water added during different time intervals the infiltration capacity curve is plotted. The experiment is continued till a uniform rate of infiltration is obtained, which may take 2 to 3 hours.

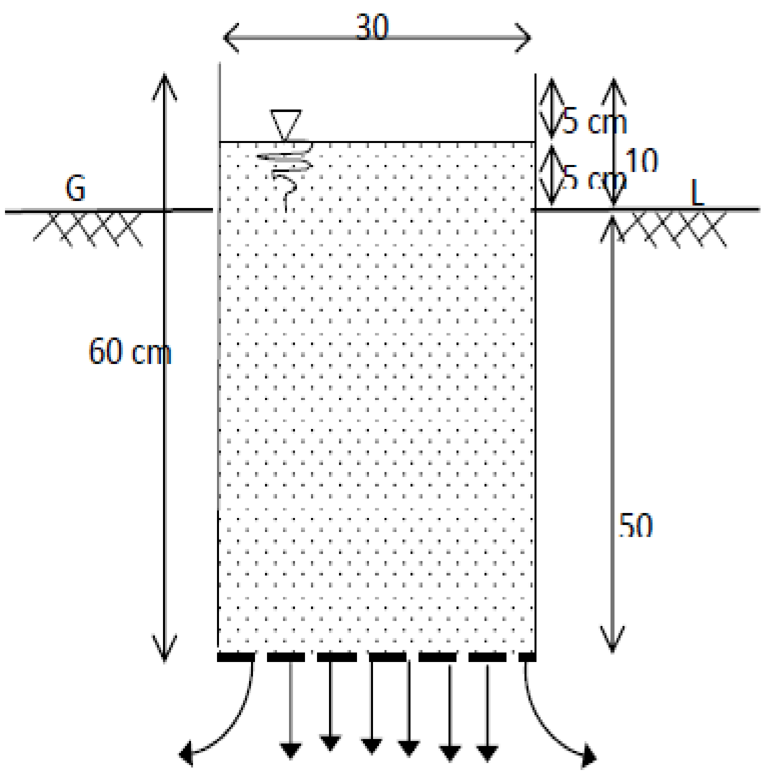


FIG-18

11. Double ring Infiltro-meters

A tube infiltrometer has a drawback that infiltration in it does not represent or simulate the actual field conditions because the water tends to disperse laterally after coming out at the bottom. To overcome this draw back a Double ring Infiltro-meter is widely used. It consists of two consecutive rings driven into the ground as shown in the figure below. The inner ring has a diameter of 30 cm and outer ring has a diameter of 60 cm. They are concentrically driven into the ground as shown in figure. A constant water depth of 5 cm is maintained in both the rings. The outer ring provides a water jacket to the water infiltrating from the inner ring and thus simulates the natural conditions. The water depths in both the rings are maintained constant during the observation period. The measurement of water volume added into the inner ring is only noted. The experiment is carried out till constant infiltration arte is obtained. To prevent any disturbance or accidental fall of foreign matter the top of the infiltrometer is covered with a perforated disc.

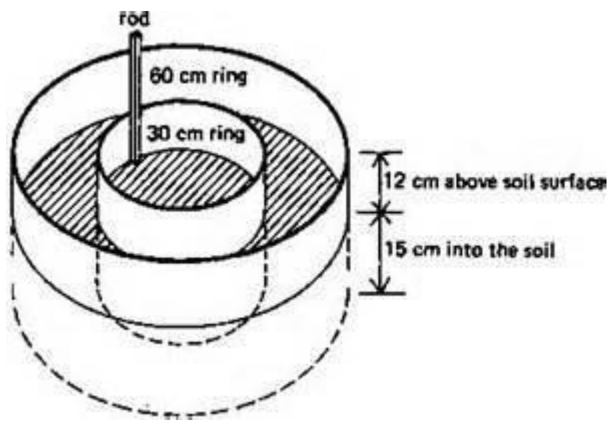


FIG-19

Infiltration capacity curve: It is the graphical representation of variation of infiltration capacity with time, during and a little after rain many factors affect infiltration capacity of a given soil. Typical infiltration capacity curves for a soil are as follows.

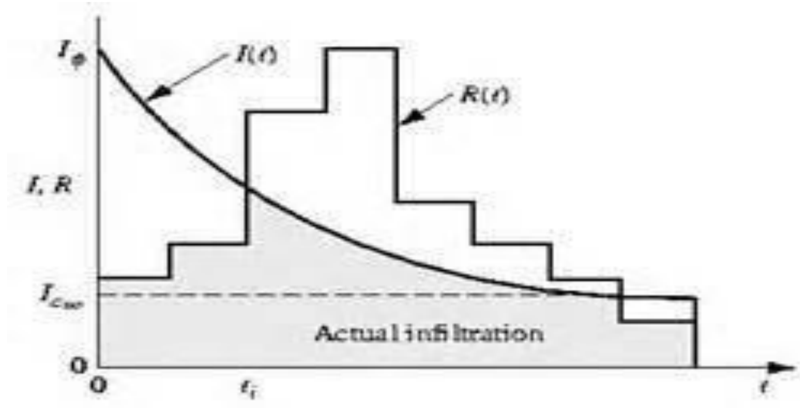


FIG-20

INFILTRATION EQUATIONS

The data from Infiltro-meters can be used to plot an infiltration capacity curve. Infiltration capacity curve is a decaying curve which shows high infiltration capacity rate at beginning and decreases exponentially and attains minimum or constant value over time. Many mathematical equations have been proposed to describe the shape of the curve. The most commonly used equation is ―Horton‘s Equation‖.

The infiltration rate (f) at any time ‘t‘ is given by Horton‘s equation

$$Fp= Fc + (Fo - Fc)\, e^{-Kt}$$

F_o= initial rate of infiltration capacity

F_c= final constant rate of infiltration at saturation

K= a constant depending primarily upon soil and

vegetatione= base of Napier an logarithm

t= time from beginning of storm

Fc= shaded area obtained as shown from the graph also known as field capacity is the amountof rainfall which can be absorbed by soil.

This equation when conjunctively used with rain fall data (hyetograph) can be used tocalculate surface runoff volumes occurring during a storm.

INFILTRATION INDICES

The infiltration capacity curves which are developed either from infiltrometer tests or the hydrograph analyses methods can be used to estimate the runoff from a given storm. The infiltration rate curve appropriate to the soil, vegetation and antecedent moisture conditions existing at the time of occurrence of storm is superimposed on the rainfall hyetograph with base lines coincident as shown in figure below.

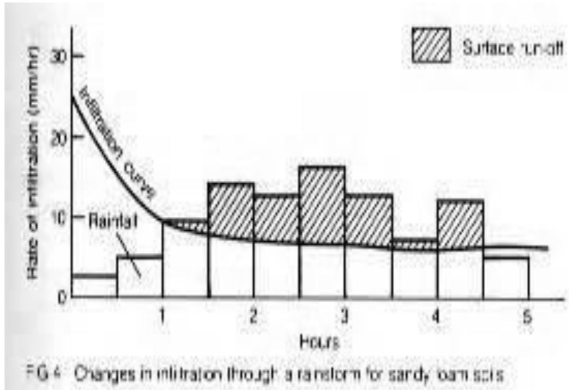


FIG-21

The area of the rainfall hyetograph above the infiltration curve would then represents the runoff volume whose time distribution may be obtained through the application of unit hydrograph principle. The rainfall volume below the infiltration curve represents the total depth of infiltration during the storm. Though this approach appears to be simple there are some difficulties. If the rainfall intensity is always more than the infiltration capacity the results are satisfactory. If the rainfall intensity fluctuates above & below the infiltration capacity rate curve the problem is complicated. The above difficulties led to the use of infiltration indices. These indices in general express the infiltration as an average rate throughout the storm. Since the infiltration capacity actually decrease with prolonged rainfall the use of an average value assumes too little infiltration during the first part of the storm and too much near the end of it.

1. Φ - Index

The Φ - Index is an average rainfall intensity above which the rainfall volume equals the runoff volume. The rainfall hyetograph is plotted on a time based and a horizontal line is drawn such that the shaded area above the line exactly equals the measured runoff. Since the unshaded area below the line is also measured rainfall but did not appear, as runoff it represents all the losses including depression storage, evaporation, interception as well as infiltration. However, infiltration is the largest loss compared to the other losses. The Φ - Index can be determined for each flood event for which the runoff measurements are available.

2. W – Index

The W – Index is refined version of Φ - Index. It excludes the depression storage and interpolation from the total losses. It is the average infiltration rate during the t ime rainfall intensity exceeds the capacity rate.

That is, W= F/t= (P-Q-S)/ t

Where F is the total infiltration, t is the time during which rainfall intensity exceeds infiltration capacity, P is the total precipitation corresponding to t, Q is the total storm runoff and S is the volume of depression, storage and interception. Thus W- index is essentially equal to Φ - Index minus the depression and interception storage.

3. W_{min} – Index

This is the lowest value of W – Index which is observed under very wet initial conditions. Under these conditions since the retention rate is very low W - Index and Φ - Index tend to be equal. This index is principally used in studies of maximum flood potential.

MODULE-1

HYDROLOGY

Part – A (Short Questions and Answers)

1. Define Hydrology.

Hydrology means science of water. It is the science that deals with occurrence, distribution and movement of water is on, above and beneath the earth.

2. What is the objective of the hydrological study?

* Estimation of water resources
* Study the processes such as precipitation, runoff, evaporation, transpiration, infiltration and their interactions.
* Study of floods, droughts and strategies to combat them
* Hydro power

3. What is the importance of hydrology?

The importance of hydrology is the assessment, development, utilization and management of water resources of any region.

4. Enlist the various phases of a hydrological cycle?

i) Precipitation ii) Infiltration iii) Evaporation
iv)Transpiration v) Runoff

5. Define Precipitation?

Any form of moisture reaching the earth surface is called precipitation. The usual forms of precipitation are rainfall, snow, hail, sleet, frost, dew etc.

6. Define infiltration?

It is defined as the process by which water enters the sub-surface strata of the earth. The infiltrated water first meet the soil moisture deficiency and there after moves vertically downwards to reach the ground water table.

7. Define evaporation?

It is the process by which water from liquid state passes into vapour state under the action of sunrays.

8. Define transpiration?

The process by which water passes from liquid to vapour through plant metabolism is termed as transpiration.

9. Define runoff?

It is the precipitation excess after meeting the demands of evaporation, transpiration and infiltration

10. Enlist the various forms of precipitation?

The usual forms of precipitation are

i) Rainfall ii) Drizzle iii) Hail iv) Dew

v) Glaze vi) Snow vii) Frost

11. What are all the types of precipitation?

i) Cyclonic precipitation ii) Convective precipitation

iii) Oragraphic precipitation iv) Frontal precipitation

12. How the precipitation can be measured?

It can be measured by rain gauge. The rain gauge may be

i) Recording type rain gauge ii) Non- recording type rain gauge

13. What are all the demerits of Non- recording type rain gauge?

It does not give information regarding

- Beginning of the rain
- End of the rain
- Intensity of rainfall

14. Enlist the three types of recording type rain gauge?

* Tipping bucket * Weighing bucket * Floating bucket

15. Write short notes on rain gauge density?

It is the no. of rain gauges is to erected in an given area

Rain gauge density = No. of rain gauges / Area

16. What are all the methods available to find the average depth of precipitation over an area?

i) Arithmetic mean method ii) Thiessen polygon method

iii) Isohyetal method

17. Define isohyet?

An isohyet is the line joining the points of equal rainfall.

18. What is the use of Double mass curve?

It is used to check the consistency of the rainfall record. In double mass curve a graph is drawn between the cumulative value of average rainfall of base stations as the abscissa against the corresponding cumulative value of rainfall of the station under test as ordinate.

19. Define Hyetograph?

It is a plot of rainfall intensity against time interval. It is derived from mass curve and is usually represented as bar chart. It is used to predict the extreme floods.

20. Write short notes on intensity-duration curves?

Short duration – High intensity
Long duration – Less intensity

21. What is the use of frequency analysis?

It is used to find the probability of occurrence of extreme rainfall. The probability of occurrence of rainfall whose magnitude is equal to or greater than specified magnitude is given by

T = N+1/m where T = Return period
m= Rank
N= No. of years of rainfall record

22. Enlist the factors affecting evaporation?

i) Temperature ii) Wind
iii) Atmospheric pressure iv) Soluble salts

23. Enumerate the methods used to estimate the amount of evaporation from a water surface?

i) Evaporimeters ii) Analytical methods iii) Empirical formulae

23. Write short notes on evaporimeters?

It is a device used to measure evaporation. These are water containing chambers which are exposed to atmosphere and the loss of water by evaporation is measured at regular intervals.

24. Enlist the types of evaporimeters?

i) Class A evaporation pan ii) ISI standard pan
iii) Colarodo sunken pan iv) US geological survey floating pan

25. Define pan coefficient?

Pan coefficient = Lake evaporation / Pan evaporation

26. State the Daltons law of evaporation?

It states that the rate of evaporation is proportional to the difference between the saturation vapour pressure to the actual vapour pressure of air.

27. Name the analytical methods of determining the lake evaporation?

* Water budget method * Energy balance method

28. How will you reduce the evaporation from a water surface?

i) Reduction of surface ii) Mechanical covers iii) Chemical films

29. What are all the factors affecting transpiration?

i) Atmospheric pressure ii) Wind iii) Sunshine
iv) Temperature v) Characteristics of plants

30. Enlist the instruments used tomeasure transpiration?

* Lysimeter * Field plots

31. Define infiltration capacity?

The maximum rate at which the ground can absorb water is called infiltrationcapacity.

32. Enumerate the factors affecting infiltration capacity?

i) Compaction ii) Surface cover iii) Temperature
iv) Characteristics of soil v) Nature of water

33. Define infiltrometer and mention its types?

Infiltrometres are the devices used to measure infiltration. There are two kinds of infiltrometers

i) Flooding type infiltrometer ii) Rainfall simulator

34. Write short notes on Hortons equation?

Horton developed the mathematical expression defining the infiltration capacitywas given by

35. Define o index?

It is the average rainfall above which rainfall volume equals the runoff volume.

Long Questions

1 Explain “Hydrological cycle” with neat sketch.
2 Explain with sketch non-automatic type of rain gauge. (Symon’s rain gauge)
3 Enlist different recording type of rain gauges and explain any one of type rain gauge with suitable sketch in brief.
4 Explain the following methods for computing average rainfall over a basin.
- Arithmetic average method
- Thiesson’s polygon method
- Isohyetal method

5 How to determine statically the optimum number required to be installed ina given catchment?
6 How to estimate the missing precipitation record of any rain gauge station? Discuss various methods for it in brief.
7 Give short note on:
- Depth area duration curve
- Double mass curve

8 Define the term “Evaporation”. Describe the factors affecting for evaporationlosses.

9 Discuss various methods of measurement of Evaporation.
10 Describe briefly the various measures to reduce loss of water due toevaporation in reservoir.
11 Define the term “Infiltration”. Describe the factors affecting for infiltration rates.
12 Explain the following terms in brief:
- Infiltration capacity
- Infiltration rate
- Infiltration indices (w-index and ϕ-index)

13.Explain the factors affecting infiltration capacity.

14.Describe the method of determining infiltration capacity using double ring infiltrometer.

15. Difference between :

(a)W-index & ϕ index (b) AET & PET (c) Infiltrometer & Lysimeter.

STREAM FLOW MEASUREMENT

Learning objectives

4.1 Measure methods for velocity of stage :stream flow

4.2 Area velocity Method

- Stream-flow represent runoff phase of a hydrologic cycle. So this is the basicdata required.
- Precipitation, Evaporation, Evapotranspiration, all is difficult to measureexactly and accurately.
- Interestingly only stream-flow part of hydrologic cycle can be measured withaccuracy.
- Stream can be defined as flow channel into which the surface runoff from aspecified basin drains.
- Stream-flow measurement has the same unit as discharge (m^3/s)
- Discharge from a stream plays an important role in hydrometry (science &Practice of water measurement).
- Stream-flow can be measured :

Direct method

1. Area velocity method
2. Dilution technique
3. Electro magnetic method
4. Ultrasonic method

Indirect method

1. Flow measuring structures
2. Slope area method

Step-1

Plot a relation between stage and discharge

Step-2

Measure the stage and relate it to discharge

LECTURE-16

Learning objective-

Area velocity Method

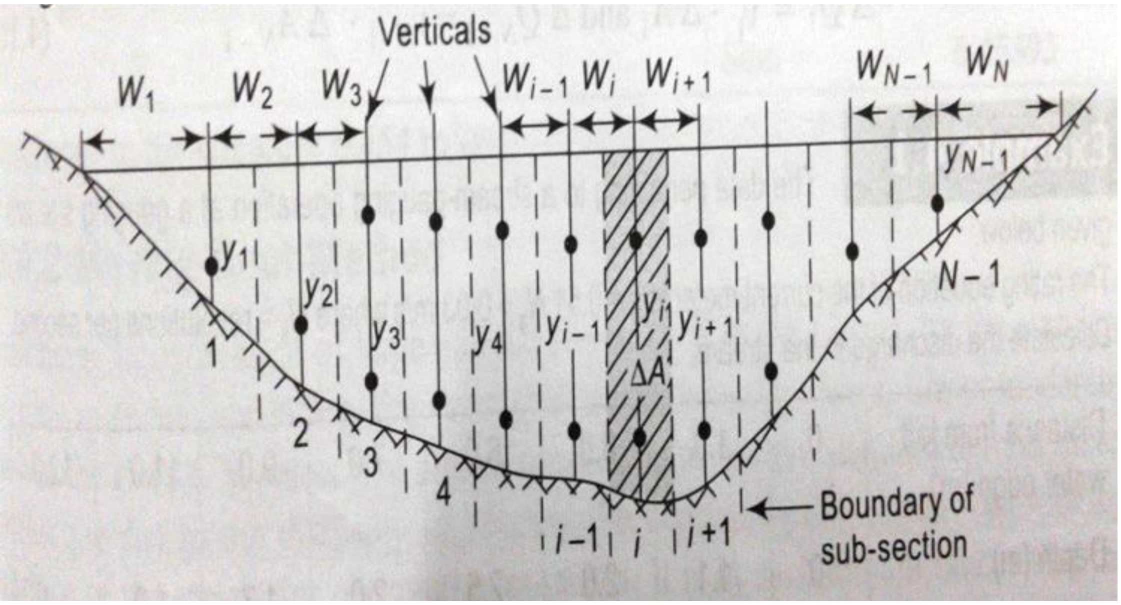
(1.)**AREA VELOCITY METHOD**

This method consists of measuring the area of Cross section of the river at a selectedsection called gauging site & measuring the velocity of flow through the Cross sectional area.

- ❖ The site must be selected so that the stage-discharge curve is reasonably const over a long period of about a few year.
  - ✓ The Cross section of the stream should be well defined which does not charge in various seasons.
  - ✓ Should be easily accessible in all seasons.
  - ✓ Site should be in a straight stable reach.
  - ✓ Site should be free from backwater effects in the channel.
- ❖ At the selected site the section line is marked off by permanent survey markings andthe Cross section is determined.
- ❖ Depth at various locations is measured by sounding rods or sounding weights.
- ❖ For accurate depth measurement, electro acoustic instrument called echo-depth recorder is used.
- ❖ In this a high frequency sound wave is sent down by a transducer kept immersed at the water surface and the echo reflected by the bed is also picked up by the same transducer. By comparing the time interval between the transmission of the signal and the receipt of its echo, the distance of the bed is obtained & recorded in the instrument. Advantageous in high-velocity streams, deep streams & streams with soft or mobile beds.
- ❖ For discharge estimation, the Cross section is divided into a large No. of sub- sections by verticals.
- ❖ The velocity in these sub-sections is measured by current meters.
- ❖ Accuracy & discharge estimation increases with the No. of subsections used. But the effort, time & expenditure will also be involved.
- ❖ Guidelines for selecting sub-sections are
  - ✓ Segment width should not be greater than $1/15^{th}$ to $1/20^{th}$ of the width ofthe river.
  - ✓ Segment discharge < 10% of total discharge
  - ✓ Difference in velocity in adjacent segments not greater than 20%.
- ❖ Area –velocity method using current meter is called as standard current metermethod.

CALCULATION OF DISCHARGE

- ❖ In this cross section (N-1) verticals are drawn
- ❖ The velocity averaged over the vertical at each section is known.
- ❖ Considering the total area to be divided into (N-1) segments, the total discharge is calculated by the method of mid-sections:



Where $W_1 = (W_1 +)W_{N-1} = (W_{N-1} +)W1$

$\Delta Q_1 = V_1 \, \Delta A_1$ & $\Delta Q_{N-1} = V_{N-1} \, \Delta A_{N-1}$

Where ΔQ_i = Dischage in the i[th] segment

=Area x velocity

=(width x Depth) x velocity

= (Depth at the i[th] segment) x (½width to left + ½ to right) x (Avg. velocity at the i[th] vertical)

x Velocity

For i= 2 to (N-2)

For the 1[st] & last sections, the segments are taken to have triangular areas and

Area = $\Delta A_1 = W_1.Y$, & $\Delta A_{N-1} = W_{N-1}$

$. Y_{N-1}$

LECTURE -17

Learning objective

4.3 Stage –discharge relationship

STAGE-DISCHARGE RELATIONSHIP

- Measurement of discharge by direct method involves a 2 step procedure.
- Development of stage – discharge relationship (G-Q)
- Then after measuring stage (G), discharge Q can be calculated from the (G-Q) relationship
- Thus the aim of current – meter and other direct discharge measurements is to prepare a (G-Q) relationship for the channel gauging station.
- This curve is otherwise known as Rating Curve.

- The measured value of discharges when plotted against the corresponding sages gives relationship that represents the integrated effect of a wide range of channel and flow parameters.
- The combined effect of these parameters is termed as control.
- If the (G-Q) relation is const for a gauging station & does not change with time, the control is permanent.
- If it changes with time it is called shifting control.

PERMANENT CONTROL

- Majority of streams and rivers especially non alluvial rivers exhibit permanent control.
- For this the relationship between stage and discharge is a single valued relationwhich is expressed as

$Q = C_r\,(G-a)^{\beta}$

Q = Stream dischargeG

= Gauge Height

a = Constant which represents stage @ zero dischargeC_r,

β: Rating curve constant

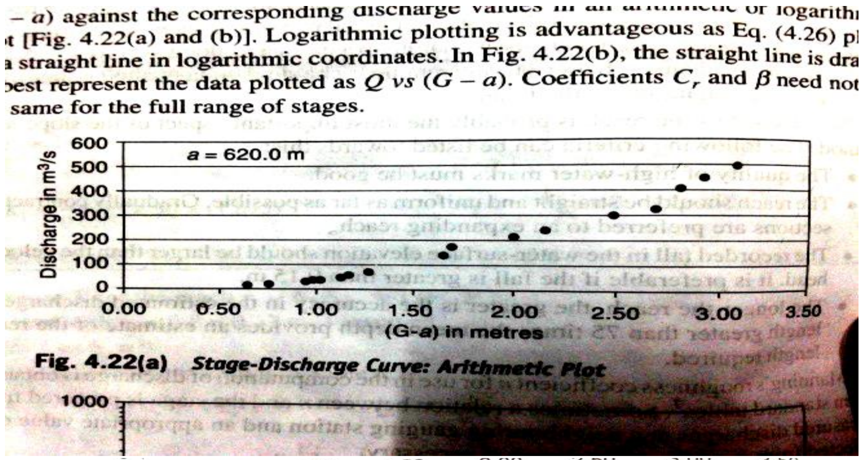


Fig. 4.22(a) *Stage-Discharge Curve: Arithmetic Plot*

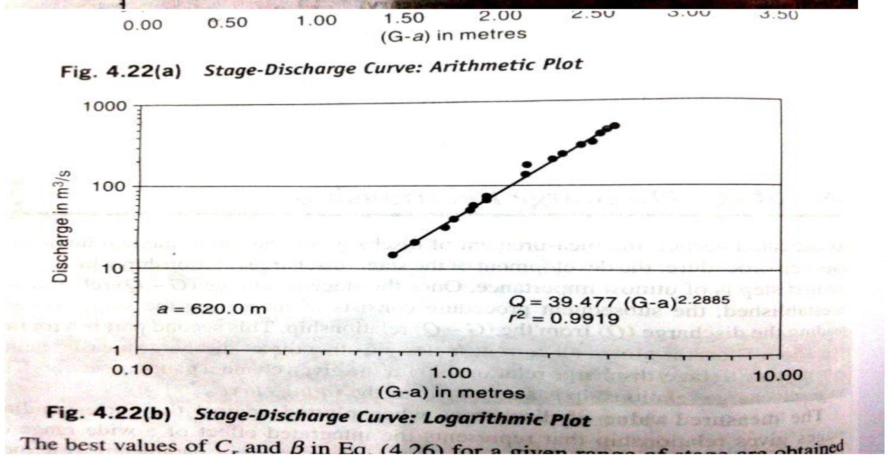


Fig. 4.22(a) *Stage-Discharge Curve: Arithmetic Plot*

Fig. 4.22(b) *Stage-Discharge Curve: Logarithmic Plot*

- ❖ This relationship can be expressed graphically by plotting the observed relative stage (G-a) against the corresponding discharge values in an arithmetic or logarithmic plot.
- ❖ The best values of Cr and β in equation for a given range of stage are obtained by the least square-error method. By taking logarithms

$$\text{Log } Q = \beta \text{ Log } (G\text{-}a) + \text{Log } C_r$$

$$\text{Or, } Y = \beta X + b$$

In which the dependent variable = Y = log Q
Independent variable = X = log (G-a)

$$b = \log C_r$$

For the best fit straight line of N observations of X & Y, by regressing X = Log (G-a) on Y = log Q

'r' reflects the extent of linear relationship between 2 data sets.

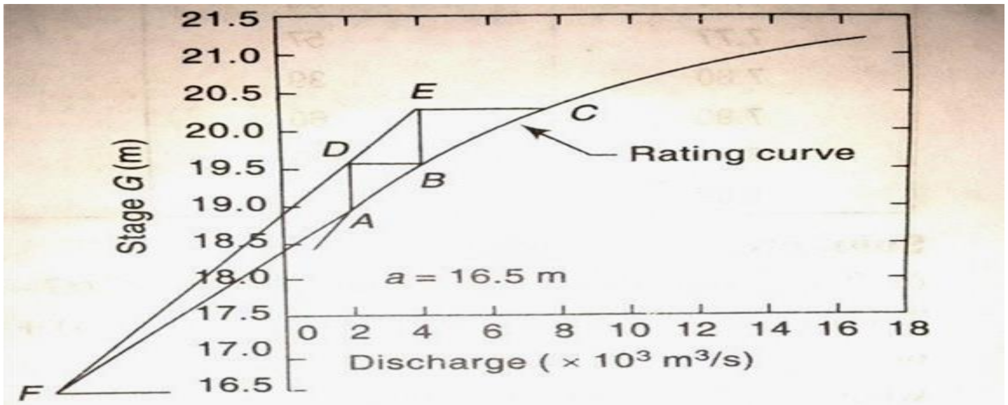


Fig. 4.23 ***Running's Method for Estimation of the Constant a***

For a perfect co-relation r =1. r = 0.6-1 is good

- ❖ Here Q α (G-a) => 'r' is +ve => +vely co- related
- ❖ Equation 7 is called rating equation of the stream and can be used for estimating the discharge of the stream for a given gaugereading G within range of data used in its derivation.

CHAPTER-4 **MODULE- 2**

LECTURE-18

Learning Objective

4.3.1 Stage For Zero Discharge

4.3.2 Effect Of Changing Stage On Stage Discharge Curve

4.3.3 Effect Of Shifting Control On Discharge Values

<u>STAGE FOR ZERO DISCHARGE</u>

$$Q = C_r (G-a)^{\beta}$$

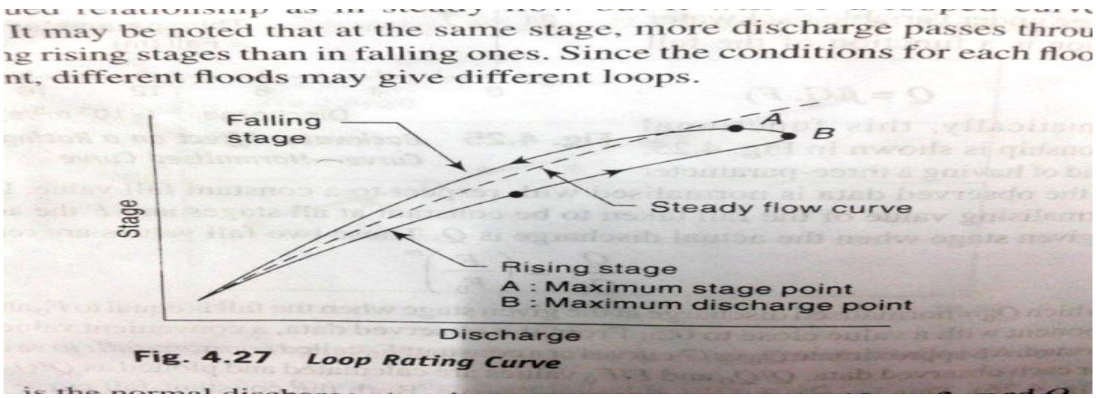
- ❖ In this equation Constant 'a' = Stage (gauge ht.) for zero discharge in the stream
- ❖ This is a hypothetical parameter & can't be measured in field.
- ❖ The alternative methods for determining 'a' are
  1. Plot Q vs G on an arithmetic graph paper and draw a best fit curve. By extrapolating the curve through eye judgment find 'a' as the value of G corresponding to Q = 0 Using the value of 'a' plot logQ vs log(G-a) and verify whether the data plots as a straight line. If not, select another value in the neighbourhood of previously assumed value and by trial and error find an acceptable value of 'a' which gives a straight line plot of logQ vs log(G-a)
  2. Q vs G data are plotted in arithmetic scale.
  - ❖ A smooth curve is drawn

- Three points A, B & C are selected such that their discharges are in GP $Q_A/Q_B = Q_B/Q_C$

- At A,B, vertical lines are drawn and at B,C horizontal lines are drawn
- Their intersections are D,E points respectively.
- Two straight lines ED and BA are extended so that they will intersect at F.
- The ordinate at F, is the required value of ‘a’ the gauge height corresponding tozero discharge.
- This method assumes the lower part of Rating curve to be a parabola.

3. Plot Q vs G to an arithmetic scale and draw a smooth good-fitting curve byeye-judgment.
   - Select three discharges Q1, Q2 and Q3 s.t.
     $Q_1/Q_2 = Q_2/Q_3$
   - Note from the curve, corresponding values of gauge readings G1, G2,and G3.

A No. of optimization procedures are available to estimate the best value of ‘a’. A trial & error search for ‘a’which gives the best value ofthe co-relation co-efficient is one of them.



EFFECT OF CHANGING STAGE ON STAGE DISCHARGE CURVE

The discharge measured for a particular given stage is different for a changing stage than for a constant stage.

- The stage of a river may be constant, may be rising or may be falling

- During the rising stage of a river, the measured discharge is more that for a const stage. (reverse in case for falling stage)
- While plotting a stage-discharge curve, the values of discharges must be taken for a constant stage. But practically these discharges are measured either at rising or at falling stage.
- During a rising stage, the measured discharge > true discharge for a given gauge height.
- So in order to make this observed point fall on the true discharge curve, either the discharge should be reduced or the gauge height should be increased.
- Hence a –ve correction should be applied to the discharge value or a +ve correction to the gauge reading for a rising river stage.
- The results of discharge measurements for a rising stage fall to the right side and thatfor a falling stage to the left side of the true discharge curve.
- The amount of deviation from the true discharge curve does not depend upon the totalrise or fall but depends upon the rate of change of stage.

- ❖ Graph can be plotted between the rate of change of stage and the % correction applied to the observed discharge values in order to obtain true discharge.
- ❖ This curve is different for rising & falling stages generally the relation is found to bea st. line or a very flat curve as shown above.
- ❖ These corrections (+ve for falling stage & -ve for rising) can be applied to the observed discharge values.

EFFECT OF SHIFTING CONTROL ON DISCHARGE VALUES

- ❖ A control does not always behave as a permanent control while fixing a velocity area station.

Due to this shift, the observed discharge values are not true values

- ❖ For a fixed control either the discharge should fall right side or left side of true value as rising or falling stage.
- ❖ But if on plotting, if it is found that the points are not falling on true or rising or falling i.e. if for a rising stage, the observed points fall to the left side or for falling to the right side or for a const. stage, the observed points don't fall on the true discharge curve then there may be possibility of change in control.
- ❖ If the control is changing, then we have to find out the speed of changing.
- ❖ If the control is changing very slowly or only at the time of floods, then the best method to deal with the problem is to draw a new rating curve. This new curve is then applied for a period till sufficient deviation due to change in control is again detected.
- ❖ Almost once a year, the rating curve has to be changed.
- ❖ But on many other rivers, the control changes quite rapidly and constantly. In this case daily discharge records are obtained and corrected

---------8----------

Expected question-chapter 4

1.What factors should be considered in selecting a site for a stream gauging station?

2.Explain stream flow measurement by area-velocioty method.

3.Explain the procedure for obtaining the stage-discharge relationship of a stream by using the stage-discharge data from a site with permanent control.

LECTURE-19

Learning o bjective
5.1 Runoff characteristics of streams

RUNOFF

It means the draining/flowing off of precipitation from catchment area through a surface channel.

Otherwise it represents the output from the catchment in a basin unit of time.

BASIN:

- Area bounded by the highest contour called ridge line from where precipitated water is collected by surface and subsurface flows & drained out through the natural river.
- The ridge line divides one basin from the other basin/catchment/watershed/drainage basin.
- Watershed discharge 'Q' can be related to the area 'A' as
  $Q=x.A^y$
  Where x, y = parameters (Depending on this values Q = peak flow min. or meanflow.

STREAM:-

It is a natural flow channel in which water from a basin is collected and drained out to thewater body.

OVERLOAD FLOW & SURFACE RUNOFF-

- After meeting all the losses, the excess rain water flows over the land surface inthe form of a sheet of water to join the nearest stream and is called over land flow.
- The surface runoff is considered as overland flow so long as it does not join the nearest stream.
  L_{of} =

  L_{of} = Length of overland flowD_s
  = Stream density

SURFACE RUNOFF

The flow where it travels all the time over the surface is overland flow and through the channels as open channel flow and reaches the catchment outlet is called surface runoff.

SUBSURFACE RUNOFF

- ❖ Otherwise known as interflow/ subsurface flow/ through flow/Storm seepage/ quick return flow.
- ❖ The part of precipitation which infiltrates into the ground and moves laterally/ horizontally in the soil and returns to the surface at some location away from the point of entry into the soil is called as interflow.
- ❖ Depending upon the time delay between the infiltration and outflow,

  Prompt (with least time log)

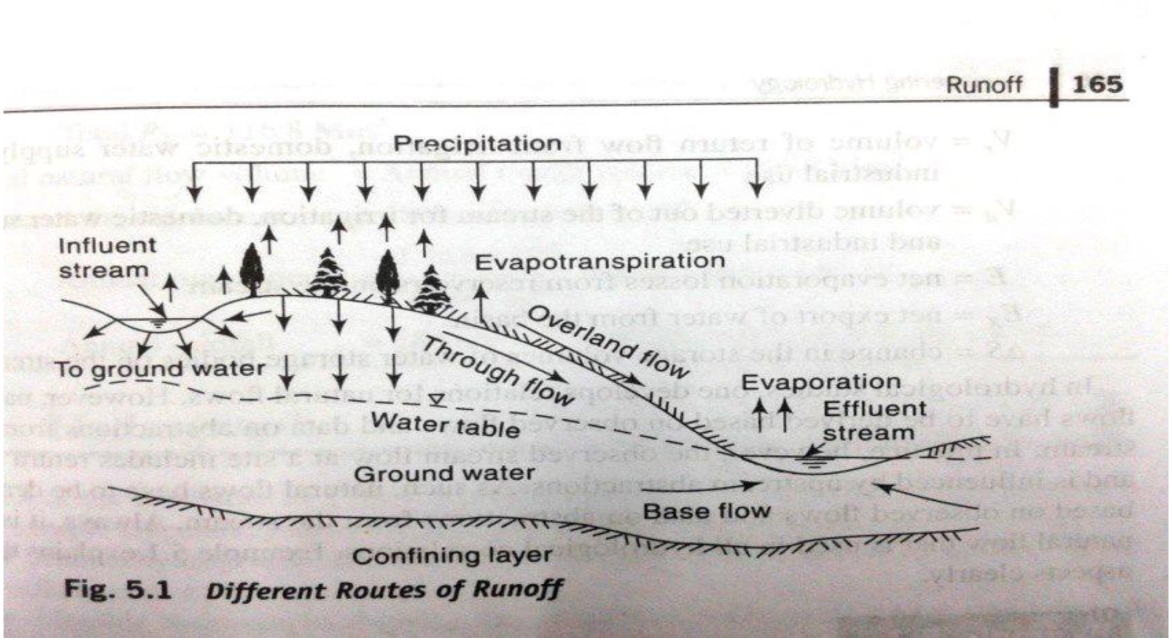


Fig. 5.1 *Different Routes of Runoff*

GROUND WATER FLOW

- ❖ Another route for the infiltrated water is to undergo deep resolution and reach the ground water storage in the soil.
- ❖ The part of runoff is calledwater runoff/ flow.
- ❖

STREAM FLOW

The total runoff consisting of surface flow, subsurface flow, ground water or base flow & the precipitation falling directly in the stream is the stream flow/ total runoff of a basin.

Effluent stream (When the ground water table is higher than the water level of stream, then the stream receives water fromground water reservoir)

Stream Influent stream (When the position of ground water table is lower then the water level of stream, s.t. water from thestream contributes to the ground water storage. e.g. In early part of rainy season all rivers of India.
Based on the time delay between the precipitation and the runoff,
Direct runoff and base flow.

DIRECT RUNOFF

Direct/storm runoff is that part of stream flow occurring promptly as precipitationstarts & contributes for an acceptable period after the storm ceases. Contribution from subsurface flow is considered constant during the period.

BASE FLOW

It is that part of stream flow available mainly from ground water reservoir anddelayed sub-surface flow appearing during dry period.

Direct runoff and base flow are distinguished by mainly on time of arrivalof flow to the catchment

RAINFALL EXCESS:

The part/percentage of precipitation which is equal to the vol. of direct runoff froma basin is called rainfall excess.

Effective rainfall = Direct runoff volume + subsurface runoff = Rainfall excess +Subsurface runoff

⇨ Effective rainfall > Rainfall excess

CHANNEL STORAGE

At any instant, the water content of a stream within its defined c/s^n is known aschannel storage.

HYDROLOGIC YEAR

The period of one year starting with the time when the ground and surface water storage of a basin is usually the minimum & called as hydrologic year/ water year.

In India it is taken as just before the onset of monsoon to the same period of next year ***(1st June to 31st May***

LECTURE-2O

<u>Learning o bjective-</u>
5.2Factors affecting Run- off

<u>FACTORS AFFECTING RUNOFF:</u>

(i) Climatic factors
(ii) Basin characteristics

(i) CLIMATIC FACTORS :

i. Intensity (rainfall intensity & runoff)
ii. Duration (Duration Runoff volume)
iii Aerial distribution (Area of catchment contributing)

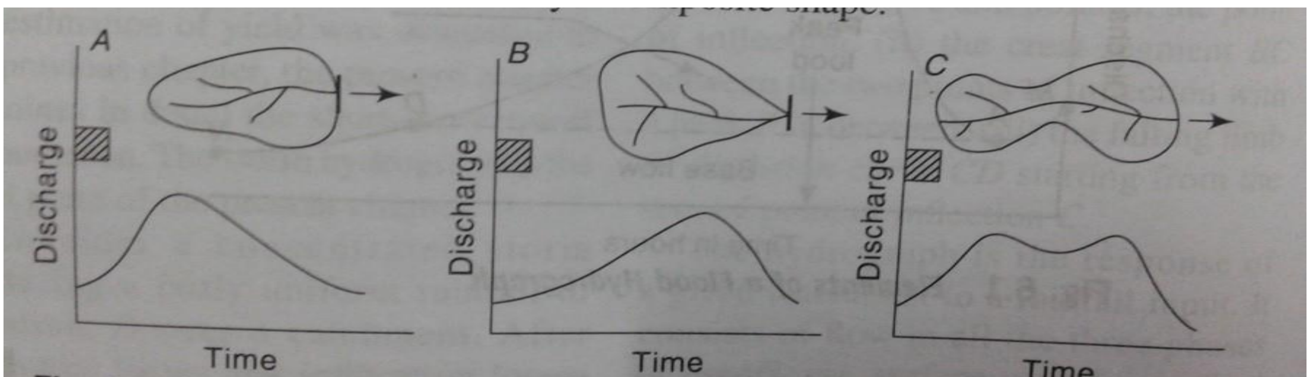


Fig. 6.2(a) ***Effect of Catchment Shape on the Hydrograph***

(ii) BASIN CHARACTERISTICS :

(a) Size (peak flow per unit area α 1/Areaperiod of surface runoff α area)

(b) Shape

(c) Slope

(d) Drainage density

(e) Topography

SHAPE

- An elongated catchment has lower peak and longer runoff than that of a fan shaped.
- In a carrot shaped catchment early peak then other.
- Sometimes multiple peaks depending upon the catchment shape.

SLOPE

- A catchment having extensive flat area gives rise to low peak and less runoff with respect to steep slope catchment.

Rate of infiltration from a flat catchment is more which affects the velocity of overland flow. Therefore the time of arrival of peak flood at the outlet is late and so is the total time period of runoff for such that shaped catchment.

- For a high intensity and long duration of storm, the effect of basin slope is pronounced.

DRAINAGE DENSITY (D_d)

- Ratio of total length of all streams of the catchment divided by its area.
- It indicates the drainage efficiency of the basin.
- The higher the value, quicker is the runoff and lower is the infiltration & other losses.

$$D_d = L_s/A$$

TOPOGRAPHY

Shape factor (B_s)

- Ratio of Sq. of watershed length 'L' to the watershed over A
  $B_s = L^2/A \geq 1$
  For a sq watershed $B_s = 1$

RUN OFF VOLUME ESTIMATION BY CURVE NUMBER METHOD

LECTURE-21

Learning objective

5.3 curve number CN. **SCS-CN Method**

i.e., curve number CN. **SCS-CN Method**

The SCS curve-number (SCS-CN) method was developed by the Soil Conservation Service for estimating runoff volume (SCS, 1969). It is widely used to estimate runoff from small-to medium-sized watersheds. It relies on only one parameter,

5.3.1Basic Concepts

Runoff volume V_q is the total volume of runoff water occurring over a period of time expressed as

$$V_q = \int_0^t Q(t)\,dt \qquad (6.1)$$

Where Q_t is the discharge at time t.

This runoff volume resulted due to the precipitation occurred on a drainage basin. The Curve Number Method is based on two phenomena. The fundamental hypotheses of this method are:

1. Runoff starts after an initial abstraction I_a(mainly consists of interception, surface/depression storage, and infiltration) has been satisfied,
2. The ratio of actual retention of rainfall to the potential maximum retention S is equal to the ratio of direct runoff to rainfall minus initial abstraction.

To describe the phenomena, mathematically the relationship can be expressed as:

$$\frac{F}{S} = \frac{V_q}{P-I_a} \qquad (6.2)$$

Where F is the actual retention, S is the potential maximum retention, P is the accumulated rainfall depth, I_a is the initial abstraction.

Fig. 1(a) and (b) shows the above relationship for certain values of the initial abstraction and potential maximum retention. After runoff has started, the actual retention equals to rainfall minus initial abstraction and runoff.

Thus,

$$F = P - I_a - V_q \qquad (6.3)$$

Putting Eq. (6.3) in (6.2) gives

$$\frac{P-I_a-V_q}{S} = \frac{V_q}{P-I_a} \qquad (6.4)$$

Thus,

$$V_q = \frac{(P - I_a)^2}{P - I_a + S} \qquad (6.5)$$

To eliminate the need to estimate the two variables I_a and S in Eq. (6.5), a regression analysis was made on the basis of recorded rainfall and runoff data from small drainage basins (SCS 1972). The following average relationship was found

$$I_a = 0.2S \qquad (6.6)$$

Physically it means that for a given storm, 20% is the initial abstraction before the start of runoff. For Indian conditions,

$$I_a = 0.3S \qquad (6.7)$$

The value of I_a is subjected to corrections based on different AMC conditions and soil type and can vary from 0.1S to 0.4S. For red soil (Alfisol) and black soil (Vertisol), I_a value is taken as 0.15S and 0.3S respectively (Dhruvanarayana, 1993).

Combining Eqns. (5) and (6) gives

$$V_q = \frac{(P - 0.2\,S)^2}{P + 0.8\,S} \text{ for } P > 0.2\,S \qquad (6.8)$$

The Eq. (6.8) is the rainfall-runoff relationship used in the CN Method. It allows the runoff depth to be estimated from rainfall depth, given the value of the potential maximum retention S.

5.3.2Estimation of S

Estimation of the potential maximum retention, S in a watershed is very difficult as it depends on the characteristics of soil-vegetation-land use (SVL) complex and antecedent soil-moisture conditions. The Soil Conservation Service (SCS) expressed S as a function of curve number as:

$$CN = \frac{1000}{S + 10} \qquad (6.9)$$

or

$$S = \frac{1000}{CN} - 10 \qquad (6.10)$$

Where CN is a dimensionless number ranging from 0-100 as shown in Fig. (2), S is in inches. For SI unitof S (mm) the Eq. (6.9) is modified to

$$CN = \frac{25400}{S+254} \qquad (6.11)$$

The usual practice to compute runoff, V_q, first compute S for given CN values (using Eq.6.10) and then substitute S in the (Eq. 6.8).

For example: For paved areas, when CN equals 100, S becomes zero (Eq.6.10) and all rainfall will become runoff (Eq.6.8). In contrasts, for highly permeable, flat lying soils, when CN equals zero, S will go to infinity, (Eq. 6.10), hence, all rainfall will infiltrate and there will be no runoff. In drainage basins, the reality will be in between these two conditions.

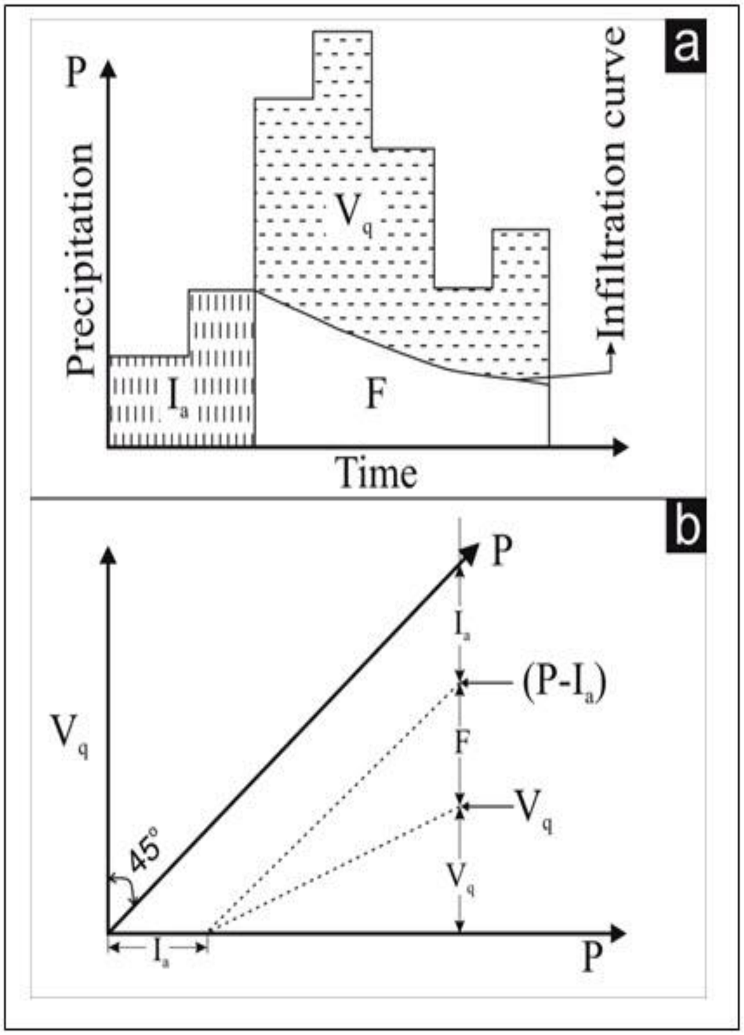


Fig. 6.1. (a). SCS relation between precipitation, runoff, and retention. (b) A mass curve representation of the SCS relation between precipitation, runoff, and retention. (Source: Singh, 1992)

To estimate the volume of direct runoff Eq. (6.8) and (6.10) can be used for the known amount of precipitation and curve number. The SCS (1969) developed a graphical solution as shown in Fig. 6.2 of these equations. Either of these approaches can be made to estimate the volume of surface runoff.

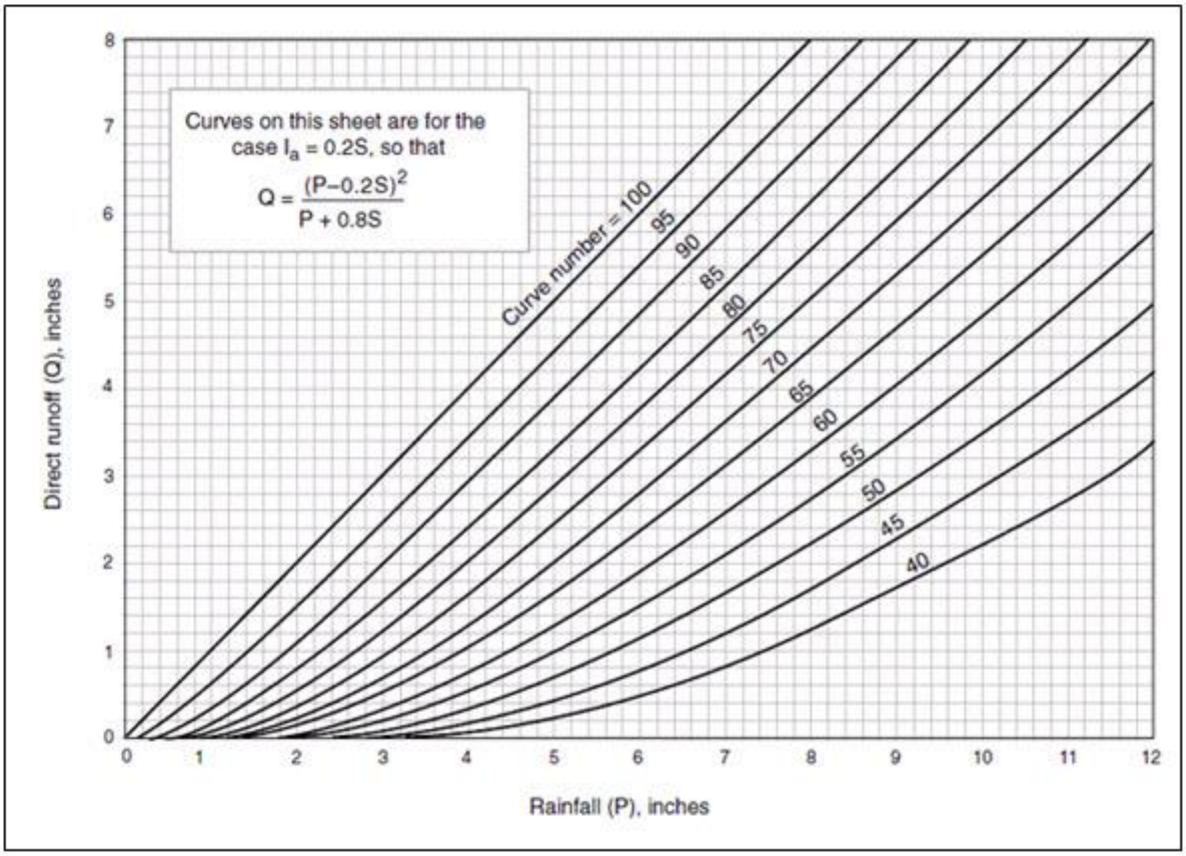


Fig. 6.2. Volume of direct runoff as a function of rainfall and curve number. (Source: Soil Conservation Service, 1969)

5.3.3 Limitations of SCS CN Method

The followings are the limitations of SCS curve number method:

(i) The soil group of the basin should have uniform hydrologic characteristics.

(ii) Rainfall should be uniform and distributed uniformly over the basin area.

(iii) All other hydrologic characteristics should be uniform.

As most of the drainage basins do not satisfy the above assumptions, this curve number method over-predicts by a large magnitude.

5.3.4 Peak Flow Rate Determination using SCS-CN

The SCS-CN estimates the peak runoff rate by using the following equation developed by Ogrosky and Mockus (1957) by using the 6-hour rainfall as the design frequency of small watersheds.

$$Q_p = \frac{0.0208 \times Q \times A}{t_p}$$

Where Q_p is peak rate of runoff in m^3/s, Q is the runoff depth in cm, A is area of watershed in ha, t_p is the time to peak in hour. Time to peak, t_p, is estimated from time of concentration, t_c, in hour, using the following equation:

$$t_p = 0.6 \times t_c + \sqrt{t_c} \quad (6.13)$$

The time of concentration, t_c can be determined by the CN Method using the following equation (Schwab et al., 1993):

$$t_c = \frac{L^{0.8}[(\frac{1000}{CN}) - 9]^{0.7}}{4407\ (S_g)^{0.5}} \quad (6.14)$$

Where L is the longest flow length in metre, CN is the curve number, S_g is the average slope of the watershed in percent.

Hydrologic Soil Group

The CN values are highly dependent on the soil surface. The soil surfaces are grouped into 4 classes which are known as hydrologic soil groups. These are classified into 4 classes on the basis of runoff potential of the surface and are described below:

1. **Group-A:** (Lowest Runoff Potential): Soils in this group have the lowest runoff potential(high infiltration rates) even when thoroughly wetted and consist chiefly of deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission.
2. **Group-B:** (Moderately Low Runoff Potential): Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, well drained to moderately well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
3. **Group-C:** (Moderately high Runoff Potential): Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.
4. **Group-D:** (Highest Runoff Potential): Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

LECTURE-22

Learning objective
5.4 Reservoir Management

RESERVOIR MANAGEMENT

->when a barrier s constructed across some river in the form of a dam , water gets stored on the upper stream side of the barrier, forming a pool of water ,generally called a dam reservoir or an impounding reservoir or a river reservoir or a storage reservoir .

- Depending upon the purpose of by a given reservoir they may be classified as:
    1. Storage or conservation reservoirs
    2. Flood control reservoirs
    3. Multipurpose reservoir
    4. Distribution reservoir

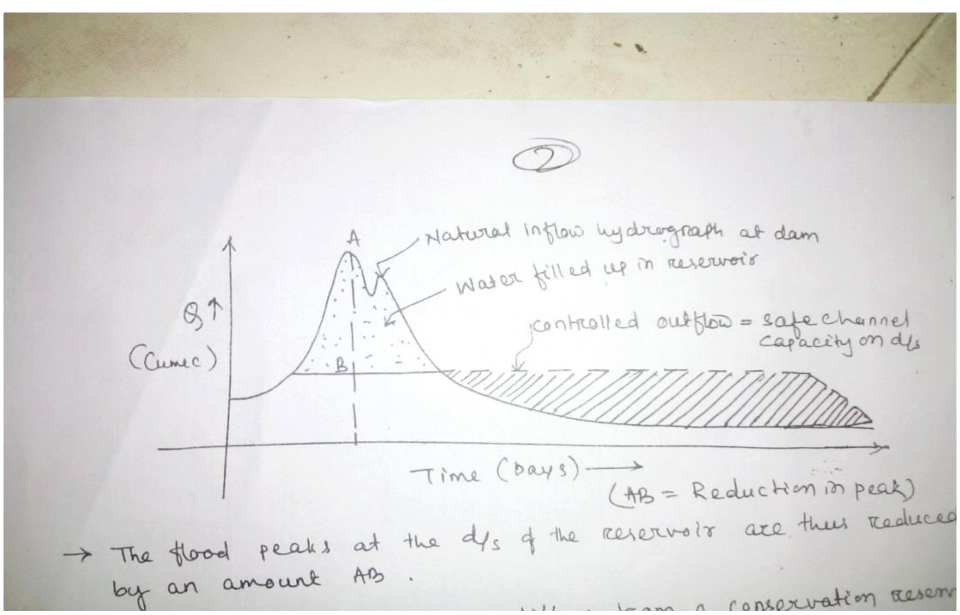
- Storage or conservation reservoirs:-
    - ✓ It can be retain excess supplies during periods of peak flow and canrelease them gradually during low flows and when the need arises
- Flood control reservoir
    - ✓ Otherwise known as flood mitigation reservoir.

It stores a portion of the flood flows in such a way as to minimize theflood peaks at the area to be protected downstream

- ✓ The inflows in access is stored in the reservoir, which is thengradually released so as to cover the storage capacity for next flood

The flood peaks at the downstream of the reservoir are thus reduced by an amount AB

- ✓ A flood control reservoir differs from a conservation reservoir only in its need for a large sluice way capacity to permit rapid draw down before or after flood
- ✓ FLOOD CONTROL RESERVOIRS:



1. Storage reservoir/detention basin
2. Retarding basin

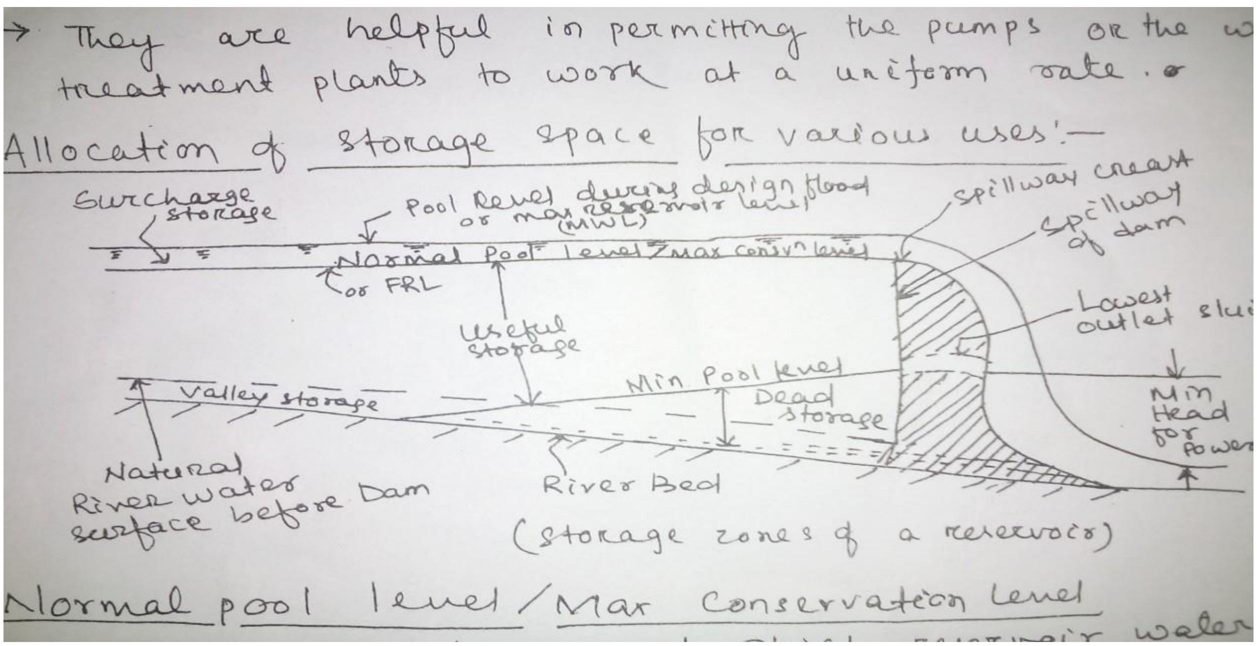
✓ A reservoir having gates and valves installation at its spillway and at its sluice outlet is storage reservoir while a reservoir with uncontrolled and ungated outlets is retarding basin

- MULTIPURPOSE RESERVOIR
  - ✓ A reservoir planned for and constructed to solve more than one problem together is called multipurpose reservoir
  - ✓ A reservoir is designed to protect downstream areas from flood and also to conserve water for water supply,irrigation ,industrial needs , hydroelectric purposes etc shall be called a multipurpose reservoir Eg:bhakra nangal dam ,nagarjun sagar yojna

DISTRIBUTION RESERVOIR

- ✓ It is a small storage reservoir constructed within a city water supplysystem
- ✓ Such a reservoir can supply at higher rates than inflow in critical demand periods
- ✓ They are helpful in permitting the pumps or the water treatment plantto work at a uniform rate

- ALLOCATION OF STORAGE SPACE FOR VARIOUS USES:-



- NORMAL POOL LEVEL/MAXIMUM CONSERVATION LEVEL
  - ✓ It is the maximum elevation to which reservoir water surfaces willraise during normal operating conditions.
  - ✓ It is equivalent to the elevation of the spillway crest or the top of the spillway gates

✓ MINIMUM POOL LEVEL

- ✓ The lowest water surface elevation, which has to be maintained under normal operated conditions in a reservoir
- ✓ This level may be fixed by the elevation of the lowest outlet in the dam or may be guided by the minimum head required for the efficient functioning of turbines

- ✓ USEFUL AND DEAD STORAGE
  - ✓ The volume of water stored in a reservoir between the minimum and normal pool level is called the useful storage
  - ✓ Water stored in the reservoir below the minimum pool level is known as dead storage in a multipurpose reservoir useful storage is composed of conservation storage and flood mitigation storage

- ✓ MAXIMUM POOL LEEL OR FULL RESERVOIR LEVEL:-
  - ✓ During high floods ,water is discharge over the spillway but will cause the water level to rise in the reservoir above the normal pool level
  - ✓ The maximum level to which the water rises during the worst design flood is known as the maximum pool level
- ✓ SURCHARGE STORAGE
  - ✓ THE volume of water stored between the normal pool level and the maximum pool level is called surcharge storage
  - ✓ It is an uncontrolled and temporary because it exist till the flood is in progress and cant be retained for later use .
- ✓ BANK STORAGE

  - ✓ When the reservoir is filled up , certain amount of water seeps into the permeable reservoir banks .this water comes out as soon as the reservoir gets depleted .This volume of water is known as bank storage .
  - ✓ The bank storage increases the reservoir capacity above indicated by the elevation capacity curve of the reservoir

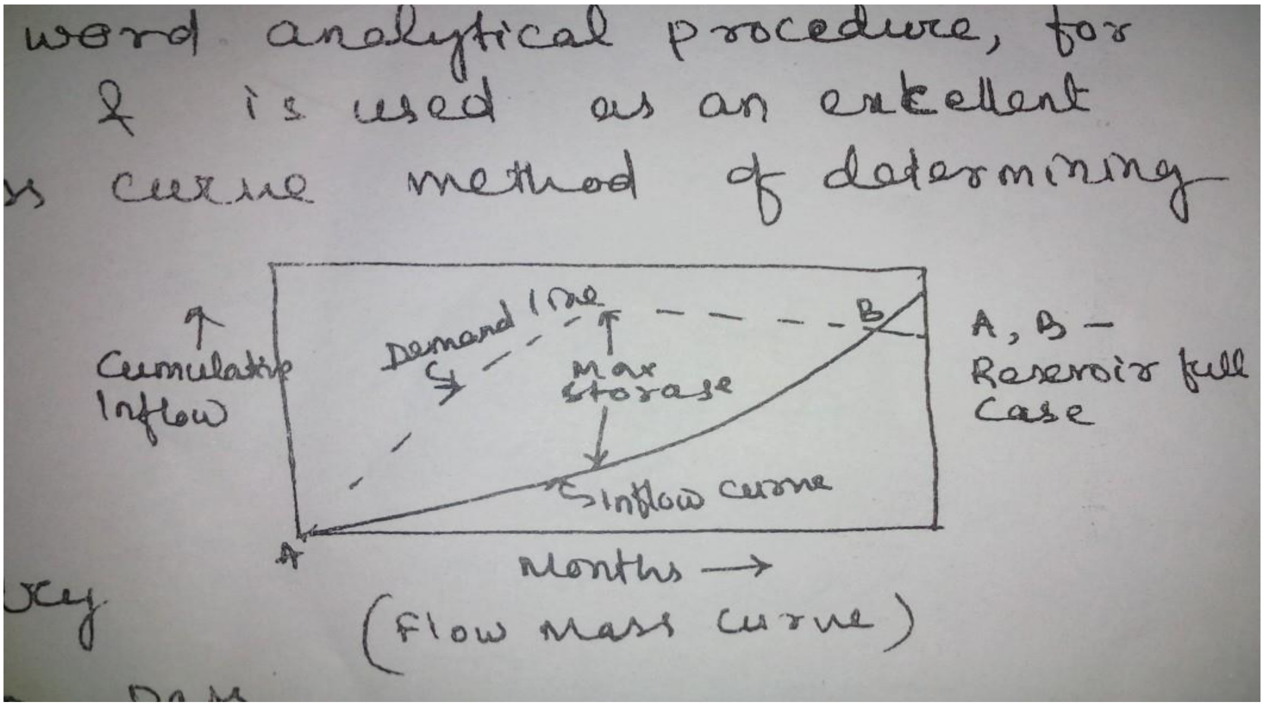
- ✓ VALLEY STORAGE
  - ✓ Before the construction of dam certain variable amount of water is stored in the stream channel called valley storage.
  - ✓ After the reservoir is formed the storage increases and the actual net increase in the storage is equal to the storage capacity of the reservoir is called natural valley storage
  - ✓ EFFECTIVE STORAGE=USEFUL STORAGE +SURCHARGE STORAGE –VALLEY STORAGE
- ✓ FIXATION OF RESERVOIR CAPACITY
  - ✓ Storage Capacity of a reservoir is the maximum difference between the cumulative supply and demand during the period of the driest year of the available records.
  - ✓ Two popular methods for calculation of reservoir capacity are:
    - (a) Flow Mass Curve/ Ripple Mass Curve
    - (b) Sequent Peak Algorithm

- ✓ SEUENT PEAK ALGORITHM
- ✓ It is a simple and straightforward analytical procedure, for computing reservoir capacity & is used as an excellent alternative to the flow mass curve method of determining reservoir capacity.

LECTURE-23

Learning objective
5.5 Demerits of Mass curve
5.6 sequent peak Algorithm

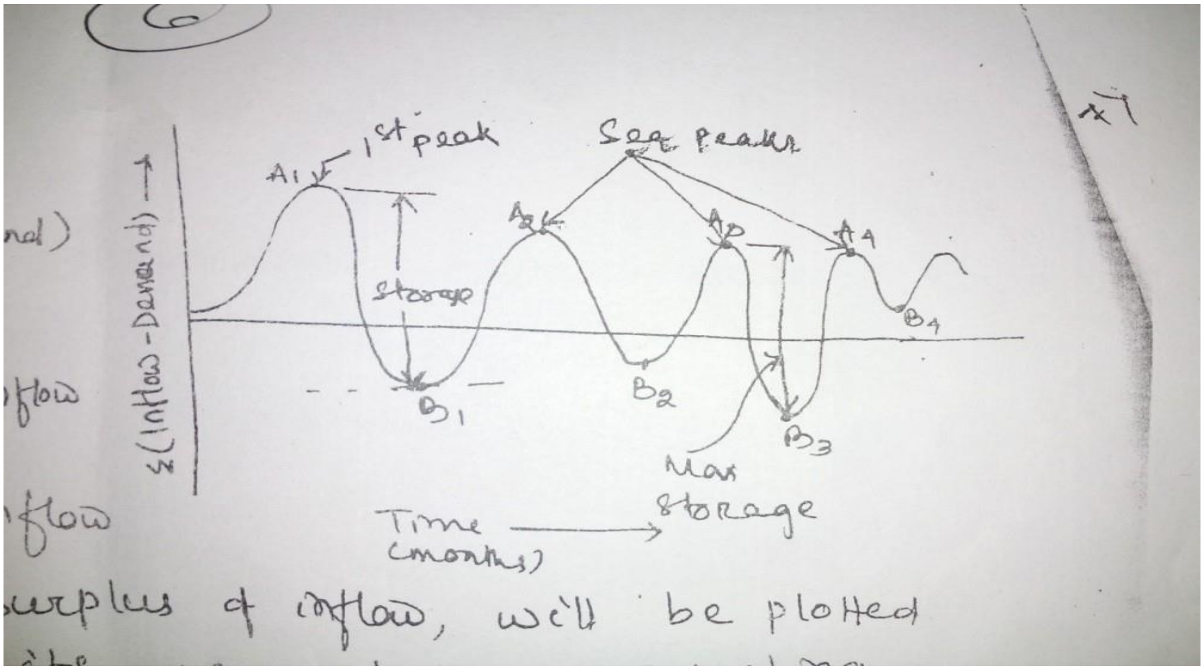
DEMERITS OF MASS CURVE



- ✓ In the mass curve analysis, the reservoir is assumed to be full at the beginning of the dry period and storage required to pass the dry period is estimated.
- ✓ If the mass curve contains only one ridge point and there are no well defined subsequent trough points, it may become necessary to repeat the given data for one more cycle.
- ✓ Also the demand line is usually not a straight line (but assumed as straight) because, it is generally non uniform due to seasonal variation in demand.

The sequent peak algorithm technique helps us to device simple mathematicalsolution to the problem of computing reservoir capacity.

SEQUENT PEAK ALGORITHM



- ✓ It is a plot between time in X- axis and sum of (inflow- demand) in Y-axis.
  ∑(Inflow- Demand)=∑Net Inflow
- ✓ The positive values of net inflow representing cumulative surplus of inflow, will be plotted above X-axis while its negative values representing cumulative deficit of inflow, will be plotted below X-axis.
- ✓ The first ridge point A1 is the first peak in the figure shown above while subsequent ridges A2, A3, A4 etc are called sequent peak.
- ✓ Similarly B1 is the first trough but B2, B3 etc are sequent troughs.
- ✓ The difference between first peak= Normal storage in reservoir under normal inflows. But the maximum difference between any sequent peak and following trough = Maximum Storage.
- ✓ The Normal and Maximum storage through sequent peak algorithm is calculated as:
  1. Convert the monthly inflows into the volume units for the period ofavailable data.
  2. Estimate the monthly volume of all the outflows from the reservoir. Thisshould include losses from evaporation, seepage and others.
  3. Compute the cumulative inflow and cumulative outflows.

4. Compute (∑Inflows-∑Outflows).
5. Plot a graph by taking time (months) in X-axis and (∑Inflow-∑Outflow)on Y-axis.
6. The data will plot peaks and troughs. The 2nd and subsequent peaks arecalled sequent peaks.
7. The max difference between any sequent peak and the just followingthrough is the max storage required for the reservoir .
   The difference between 1st pick and following through =Normal storage

- RESERVOIR SEDIMENTATION:
  - ✓ The sediment particles try to settle down to the river bottom due to the gravitational force , but may be kept in suspension due to the upstream current in the turbulent flow which may overcome the gravity force .Due to these reasons, the river carries fine sedimentation in suspension load and larger solids along the river bedas bed load.
- SEDIMENT YEILD :
  - ✓ It is the total flow of sediment from a watershed measured at a location in a riverat a specified time.
- EROSION:
  - ✓ It is the process of detachment and transportation of sediment by erosive agent.
- SEDIMENT DELIVERY RATIO:
  - ✓ Ratio of sediment delivered at a gauging site in a river to a total erosion from the entire area upstream it.
- BED LOAD:
  - ✓ The coarse sediment material moving close to the river bed by rolling or sliding is called bed load.
  - ✓ E.g. material moving within 10-15 cm from bed.
- SUSPENDED LOAD :
  - ✓ Relatively finer particle which mix and move with river water in suspension and are found throughout the channel water in the downstream is called suspended load.
- WASH LOAD:
  - ✓ Fine , very fine ,and electrochemically charged soil particle carried by river water are called wash load and don't ordinarily settle down at the bottom of the container even after keeping it undisturbed for hours.
- RESERVOIR SEDIMENTATION CONTROL :
  - ✓ The deposition of sediment in reservoir is known as reservoir setting or reservoir sedimentation.

- ✓ The total volume of silt deposited during the design period of dam is estimated and approx that much volume is left unused to allow the silting and is known as dead storage.
- ✓ TOTAL CAPACITY OF RESERVOIR –DEAD STORAGE =LIVE STORAGE/EFFECTIVE STORAGE
- ✓ The dead storage generally varies between 15-20% of the total capacity.

- TRAP EFFICINCY:
  - ✓ It is defined as the % of the sedimentation deposited in the reservoir even in spite of taking precautions and measures to control its deposition.
  - ✓ ἠ =Total sediment deposited in the reservoir /total sediment flowing inthe river
- CAPACITY INFLOW RATIO:
  - ✓ It is the ratio of reservoir capacity to the total inflow of water in it ἠ=f(capacity/inflow)
  - ✓ In order to increase the time of the reservoir it is necessary to controlthe deposition of sediment.
  - ✓ Methods are
    Pre constructing measures Post
    constructing measures
- PRE CONSTUCTING MEASURES:
  - ✓ These are the methods which are adopted before and during theexecution of the project
  1. Selection of dam site
  2. Construction of dam in stages
  3. Construction of check dam
  4. Vegetation screens
  5. Construction of under sluice in the dam

- POST CONSTRUCTION MEASURES:
  - ✓ These measures are to be taken during the operation of project.
    1. Removal of post flood water
    2. Mechanical stirring of the project
    3. Erosion control and soil conservation.

##

Learning objective

5.7 Flow duration curve

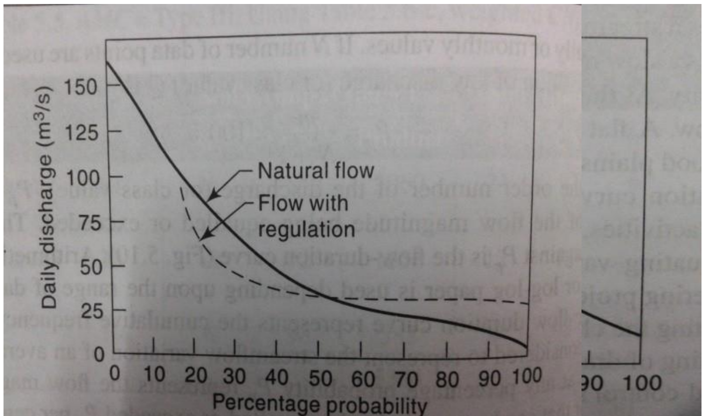


Fig. 5.11 *Reservoir Regulation Effect*

FLOW DURATION CURVE

It is well known that the stream flow varies over a water year. One of the popular methods of studying this stream flow variability is through flow duration curves. A flow duration curve of a stream is a plot of discharge against the percent of time the flow was equaled or exceeded. The curve is also known as discharge-frequency curve.

The stream flow data is arranged in a descending order of discharges, using class intervals if the number of individual values is very large. The data used can be daily weekly, ten daily or monthly values. If N number of data points are used in this listing the plotting position of any discharge (or class value)Q is

P_p = m/N+1 x 100%

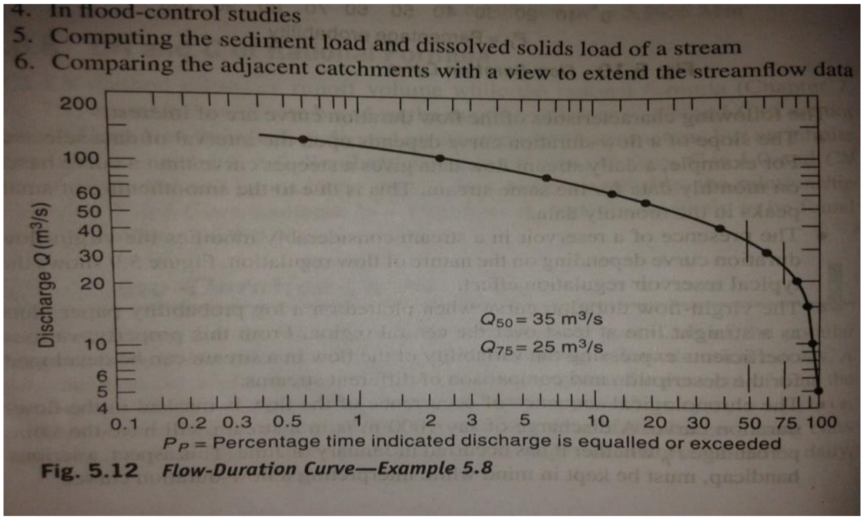
Where m is the order number of the discharge (or class value) Pp = percentage probability of the flow magnitude being equaled or exceeded. The plot of the discharge Q against P_p is the flow duration curve (Fig 5.10). Arithmetic scale paper or semi-log or log- log paper is used depending upon the range of data and use of the plot. The flow duration curve represents the cumulative frequency distribution and can be considered to represent the stream flow variation of an average year. The ordinate Q_p at any percentage probability Pp represents the flow magnitude in an average year that can be expected to be equaled or exceeded Pp percent of time and is termed as P_p & dependable flow. In a perennial river Q_{100} = 100% dependable flow is a finite value. On the other hand, in an intermittent or ephemeral river the stream flow is zero for a finite part of the year and as such Q_{100} is equal to zero.

The following characteristics of the flow duration curve are of interest.

- The slope of a flow duration curve depends upon the interval of data selected. For example, a daily stream flow data gives steeper curve than a curve based on monthly data for the same stream. This is due to the smoothening of small peaks in the monthly data.
- The presence of a reservoir in a stream considerably modifies the virgin-flow duration curve depending on the nature of flow regulation. Figure 5.9 shows the typical reservoir regulation effect.
- The virgin-flow duration curve when plotted on a log probability paper plots as a

straight line at least over the central region. Form this property, various coefficients expressing the variability of the flow in a stream can be developed for the description and comparison.

- The chronological sequence of occurrence of the flow is masked in the flow duration curve. A discharge of say 1000 m^3/s in a stream will have the same percentage Pp whether it has occurred in January or June. This aspect a serious



handicap, must be kept in mind while interpreting a flow duration curve.

- The flow duration curve plotted on a log-log paper (fig 5.12) is useful in comparing the flow characteristic of different streams. A steps slope of the curve indicates a stream with a highly variable discharge. On the other hand, a flat slope indicates a slow response of the catchment to the rainfall and also indicates small variability. At the lower end of the curve, a flat portion indicates considerable base flow. A flat curve on the upper portion is typical of river basins having large flood plains and also or rivers having large snowfall during a wet season.

Flow – duration curves and considerable use in water resources planning and development activities.

Some of the important uses are

1) In evaluating various dependable flows in the planning of water resourcesengineering projects.
2) Evaluating the characteristics of the hydropower potential of a river
3) Designing of drainage systems
4) In flood-control studies
5) Computing the sediment load and dissolved solids load of stream
6) Comparing the adjacent catchments with a view to extend the stream flow data.

Excepted questions

1.List the factors affecting the seasonal annual yield (annual runoff) of a catchments.

2.Describe briefly the SCS-CN method of estimation of yield of a catchment through use of daily rain fall reco

-rd.

3.What is a flow-duration curve?

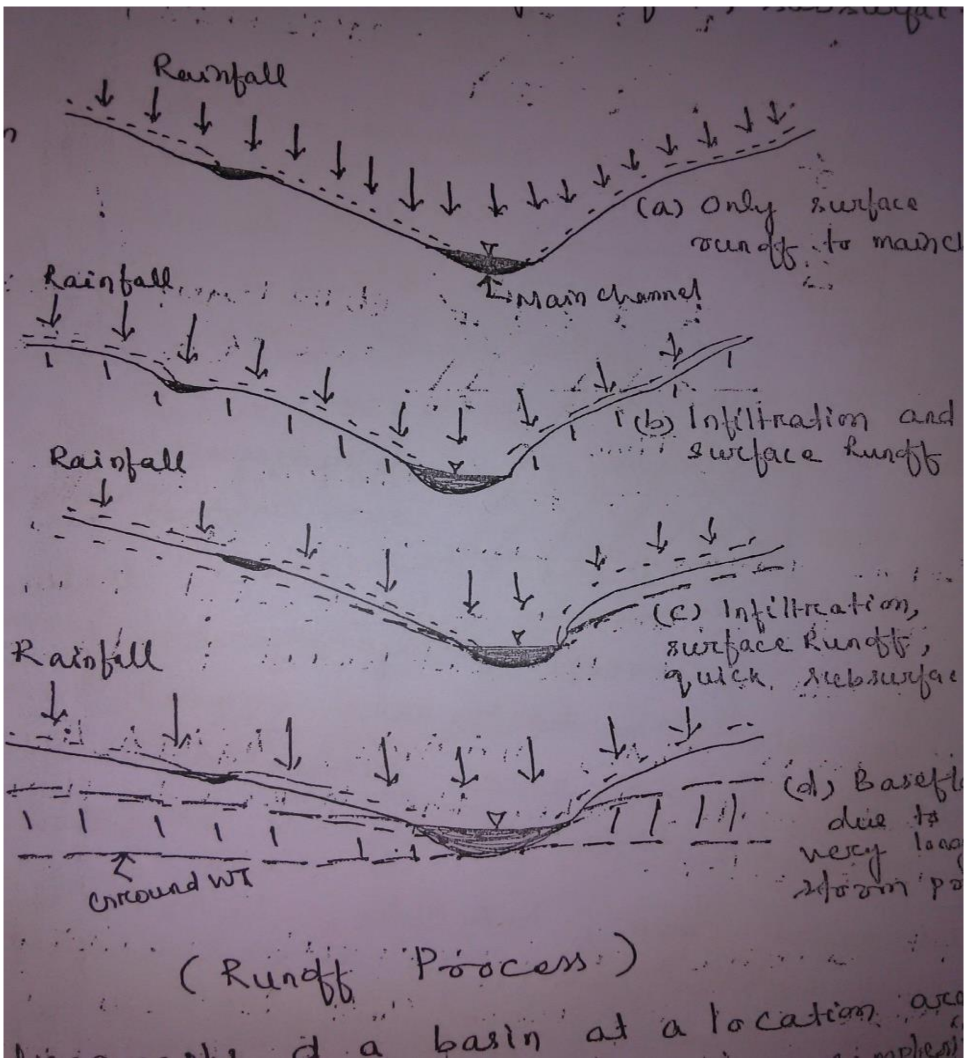
4.What are the limitations of flow mass curve?

MODULE-2 CHAPTER 6
LECTURE-25
Learning objective
6.1 Hydrograph

HYDROGRAPH

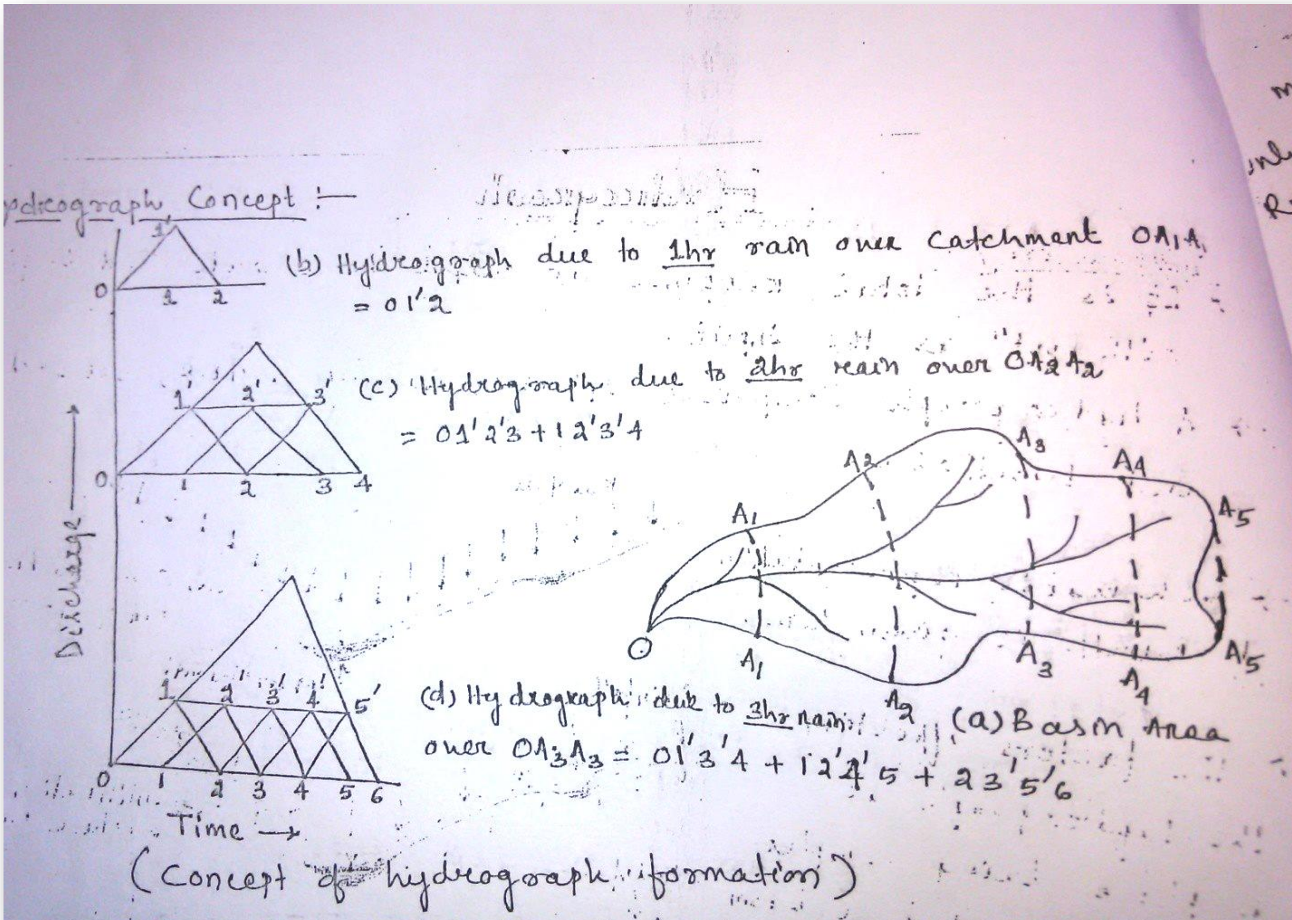
INTRODUCTION

- It is the total response or output of a watershed being with precipitation asinput.
- A hydrograph comprises three phases namely surface, subsurface, and baseflow .
- Schematic representation of runoff is given below:



- The factors affecting the hydrograph at a place being complex and interrelated a basin may not produce two exact flood hydrographs with two similar precipitations as input, nor can two basin of the same drainage area produce the same flood hydrographs with similar precipitation.
- When large number of hydrographs of a basin at a location is analyzed, their irregular shapes representing completely of the storm and the catchment character can be noticed.
- To being with a hydrograph resulting from a single storm is taken and its components are studied.

HYROGRAPH CONCEPT:



- Let us assume a basin area having uniform basin character with the entire area subjected to uniform rainfall and the condition of the catchment producing runoff are also uniform.

- The areas OA1A1,A1A1A2A2, A2A2A3A3,……….. are so divided that water takes one hour to reach from one boundary to the next below.
- First examine the hydrograph resulting from the first hour of the storm.
- Rainfall over the area OA1A1 is occurring for first hour. The runoff from line A1A1 takes one hour to reach at O . The hydrograph from the catchment area OA1A1 is shown as triangle 01'2. At the end of first hour when the runoff from the point O is still continuing at the catchment outlet, contribution from the boundary line A1A1 has started arriving. At this time all the area lying in boundary OA1A1 is contributing at O due to one hour rainfall. So the peak runoff resulting from the area OA1A1due to one hour rainfall occurs at the end of the one hour storm from the line A1A1takes one more hour to reach the at outlet O, that is at the end of second hour , when the last drop of the water from the boundary line A1A1 reaches at O ,the runoff hydrograph becomes zero .

- It may be noted that the whole area contributed for one hour only at the outlet due to one hour rainfall.
- Runoff from the boundary area A1A1contributed at O from the end first hour to end of second hour and runoff from Oat O is available for one beginning and ending with storm period from zero to one hour
- Next imagine that rainfall for one hour occur only in the area A1A1A2A2 which has started contributing to the outlet O after end of one hour and continued till the end of third hour .The resulting hydrograph is a triangle 12'3 as shown in the fig. with peak of flow at the second hour . Similarly if a second hour rainfall is imagined to have occurred in the area OA2A2 then the resulting hydrograph at O is the large triangle in fig(c).
- Similarly a three hour rainfall concentration over the area OA3A3 will produce a hydrograph of shape shown in fig (d) .
- Thus the hydrograph produced by one hour rainfall in the area are triangle at lags shown in figure. The combined effect will be when the total area is subjected to an uniform rainfall.
- The resulting hydrograph is the observed discharge from the catchment at outlet O . Any rainfall exceeding this time with the same intensity will produce a larger time base hydrograph. However the peak of the hydrograph will be of same magnitude and of longer time equal to the total rainfall period minus the time of travel of the drop of the water fromextreme boundary point to the basin outlet.
- LECTURE-26
  Learning objective
  6.2 Factor affecting Hydrograph

FACTORS AFFECTING FLOOD HYDROGRAPH

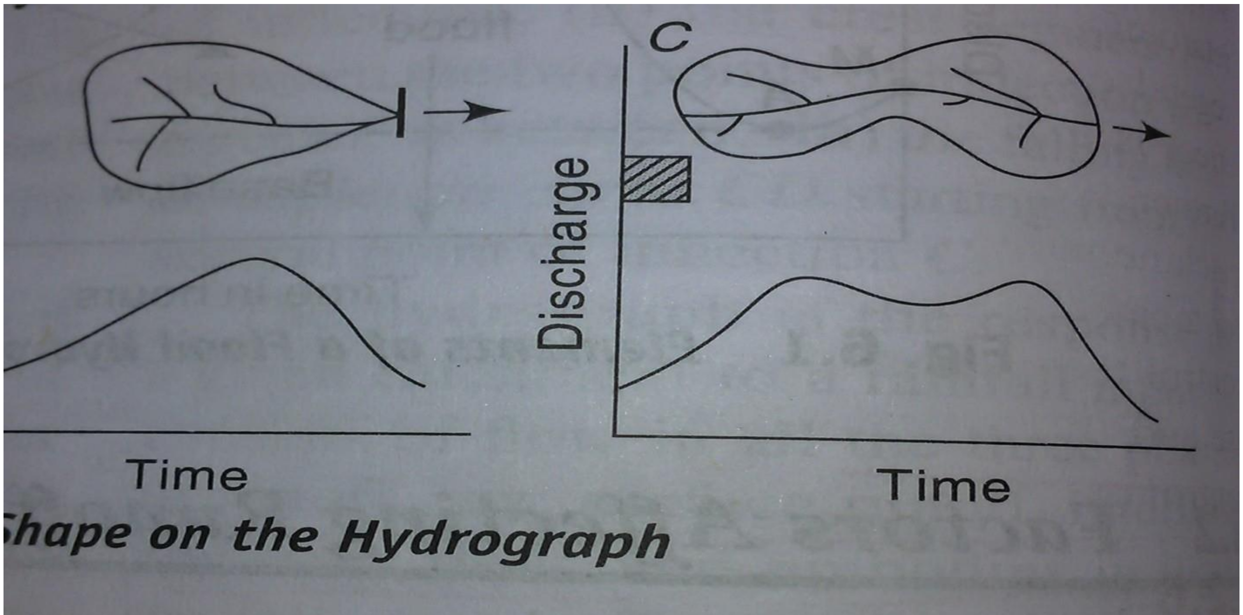
Two types of factors

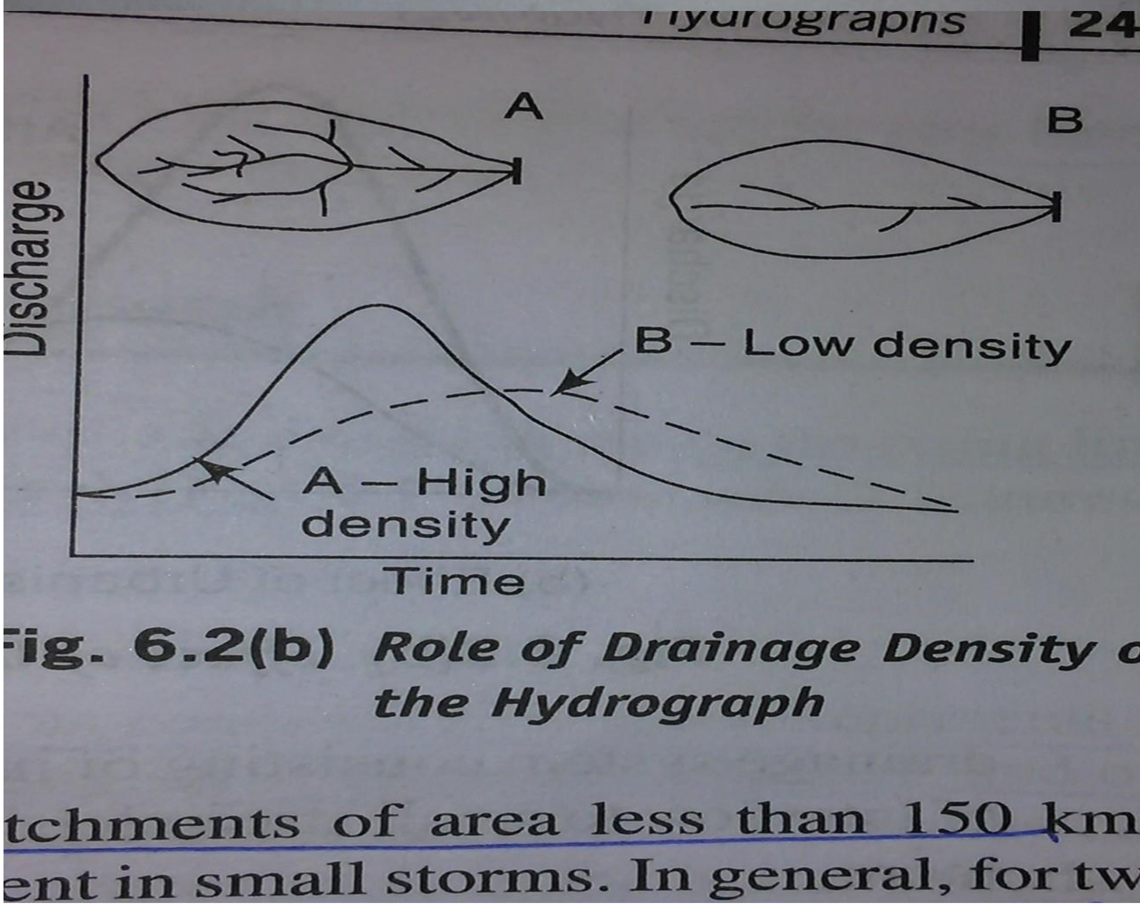
1. Physiographic
2. Climatic

- Climatic factors control the risking limb and recession limb is independent of storm character, only determined by catchment character.

1. Shape of the basin

- Shape of the basin influences the time taken for water from the remote part of the catchment to arrive at the outlet. So the occurrence of the peak and hence the shape of the hydrograph are affected.
- For semi circular shaped basin – high peak and narrow hydrograph.
- Elongated catchment – Broad and low peaked hydrograph.





2. Size of the basin

- In small catchment overland flow phase dominates channel flow. Hence landuse and intensity of rainfall have important role on the peak flood.

- In large basin, these effects are suppressed as channel flow is dominant. Peak discharge is directly proportional to the A^ n ,where A=area of the basin , n=exponent <1 (0.5 taken)
- Time base for large basin is greater than that of the smaller basin.
- Duration of the surface runoff from the time of occurrence of the peak is directly proportional to the A^ m ,where m=0.2

3. Slope
   - The slope of the main stream controls the velocity of the velocity ofthe flow in the channel.
   - Recession limb represents the depletion of storage, hence slope has pronounced effect on it.
   - Large stream slope – Quicker depletion – Steeper recession limb –Smaller time base

4. Drainage density
   - Drainage density = (total channel length) / (total drainage area)
   - Large drainage density – Quick disposal of runoff – Pronounced peak
   - Small drainage density – Squat hydrograph with slowly rising limb

5. Land use

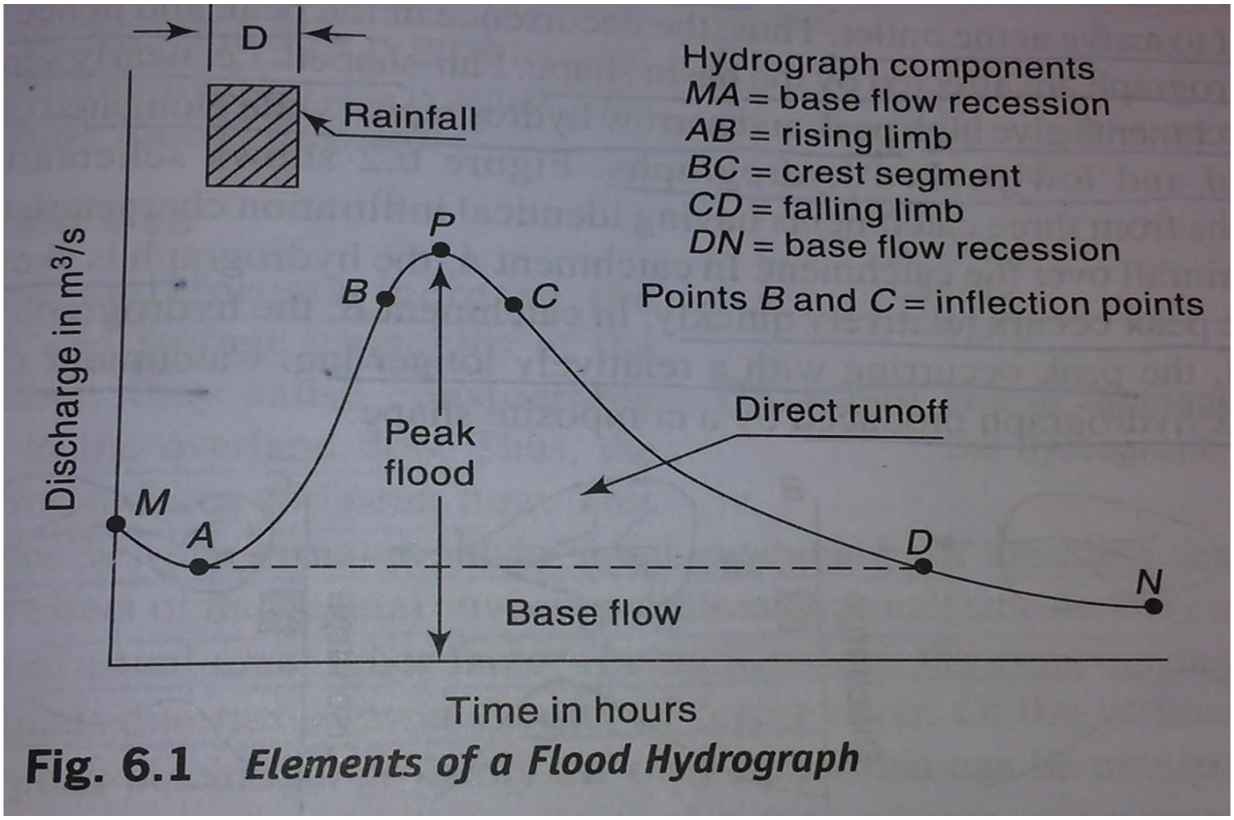
- Vegetation – increase infiltration – retards overland flow – reduces peak flow
- The effect is more pronounced in small catchment (<150Km^2) and smallstorms.
- This is the only factor which can be manipulated.

6. CLIMATIC FACTOR

- Three types 1.Intensity , 2.Duration , 3.Direction
- For a given duration, peak and volume of the surface runoff is directly proportional to the intensity.
- For small catchments shape of the hydrograph can also be affected byintensity.
- For a given intensity, duration of the storm is directly proportional to the volume of the run-off , effect of duration is reflected in the rising limb and peak. If rainfall of given intensity “i” lasts sufficiently long enough; “Q” is directly proportional to the “iA” will be reached.
  - If the storm direction is u/s to d/s =Quicker concentration at outlet basin = Peaked hydrograph results

- If the storm direction is d/s to u/s = lower peak and larger timebase
- Long and narrow catchment = hydrographs are most sensitiveto storm movement direction.

COMPONENTS OF HYDROGRAPH



- Component of a hydrograph are
  1. Rising limb
  2. Creast segment
  3. Recession limb

Rising limb (A to B)

- Also known as concentration curve and represents the increase in discharge due to gradual increase in channels and over the catchment.
- It mainly influenced by storm and basin character.
- Generally it is concave, rising slowly in the early stage of the flood , but more rapidly to the end of the portion and this is due to high and variable initial losses at early stage.

- The rising limb is attributed due to contribution of more and more area at the gauging site over time, and also due to decrease in losses over time.
- It gradually reaches the peak when maximum area contributes their runoff atgiven outlet.

Creast segment (B to C)

- Most important portion as it contains peak flow.
- This is the portion between two inflection points of rising and falling limb.
- Peak occurs when various part of basin contribute simultaneously to the outletat maximum rate.
- Generally peak flow occurs after cessation of rainfall.
- Multiple peaked complex hydrographs in a basin occur when two or more stormoccurs in succession.

Recession limb (C to D)

- This limb is the convex curve representing the withdrawal of water from the storage build up in the basin up in the basin with max at "C".
- Since the depletion of the storage takes place after the recession of rainfall , the shape of the hydrograph is independent of the storm character and depends entirely on the basin character.
- Point "D" represents where the contribution to the channel is purely from ground water.
- When he storm concentrates more near to the outlet , then the length of this curve is shorter where as if rainfall concentrates at the far end of the catchment the recession limb is channel storage.
- The curve is mathematically represents as : $Q_t = Q_o (K_r ^ t)$

{Where, Q_t =discharge at time t Q_o = discharge at time t=0

K_r =recession constant <1 }

Otherwise ,

$Q_t = Q_o (e^{-at})$ where $a = -\ln K_r$

- This equation is good for the lower portion of the curve where the contribution is mainly from ground water.
- In the upper part of the curve, contribution from surface storage,subsurface storage and ground water.

$$K_r = K_{rs} \cdot K_{ri} \cdot K_{rb}$$

K_{rs} =recession constant for surface storage K_{ri} =recession constant for interflow

K_{rb} =recession constant for base flow

When time in days,

K_{rs} =0.05 to 0.2

K_{ri} =0.5 to 0.85

K_{rb} =0.85 to 0.99

When interflow is not significant, K_{ri} =1

If at 2time instances t1 &t2

(Q1/Q2) = Kr ^ (t1 – t2)

(Q1/Q2) = e ^ -a(t1-t2)

- Time to peak (t_p)

- It is the time lapse between the starting points of the rising limb (A) tothe peak of the hydrograph (P).
- It is represented in days for large basins for and hours for small basins.
- Factor affecting "tp" are rainfall distribution over the basin , stormduration , travel time of water and other catchment character

- Time lag (t_l)

- It is the interval between center of mass of rainfall hyetograph to thecentre of mass of runoff hydrograph, measured from the same axis.
- Otherwise it can be taken as time lapse between the centre of mass of theeffective rainfall hyetograph and peak of hydrograph.

- Time of concentration (t_c)

- It is the time taken by the raindrop at farthest point of the catchment to reach at outlet.
- It can estimated by Kirpich formula

  (tc)=0.000323*L^0.77*S^-0.385

  (tc) =time of concentration (hr)

  L =max length of travel of water (m)S

  =sloe of channel =H/L

  H =elevation diff bet^ remote point in the channel andoutlet point
- Basically time to peak +storm duration =tc =tp+tr
- (tc) =1.42*tl

- Time base of hydrograph (T_b)

- It is considered as the time bet^ the starting of the runoff hydrograph (A) to the end of direct runoff (D) due to storm.
- Tb = tc +tr

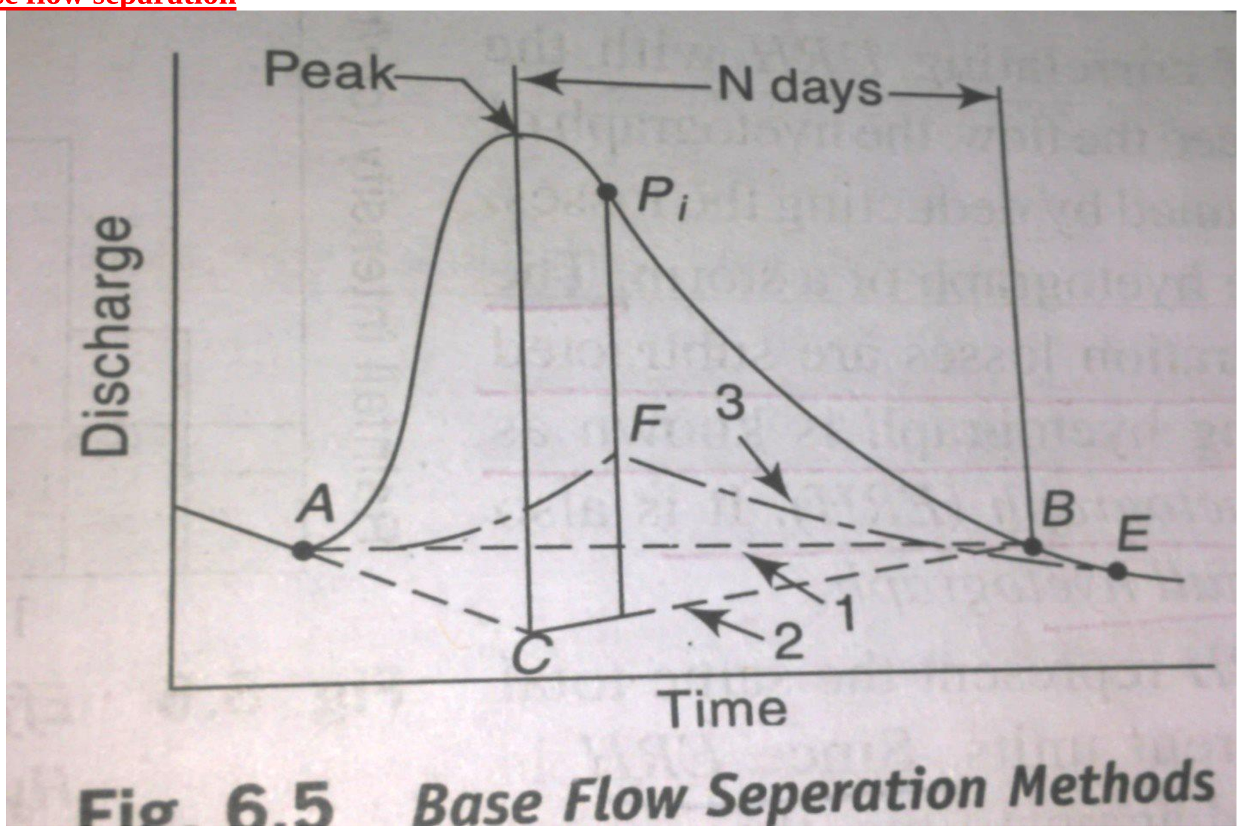
❖ Direct runoff

- It is the part of precipitation which appears quickly as flow in theriver.
- DR = surface runoff +sub surface runoff

❖ Base flow

- The part of runoff represented by a hydrograph which receives water fromthe ground water storage is called as base flow.
- Natural springs and river banks contribute to base flow in non rainy periods.
- Total Runoff = Direct runoff + base flow
- When a storm hydrograph is available , after separation the base flow , theresidual left is DRH.

Base flow separation



- The relationship bet^ the surface flow hydrograph and the effect rainfall is tobe established.
- The surface flow hydrograph is established by deducting the base flow fromthe storm hydrograph.

Method:1 (Straight Line Method)

- It is the simplest method of base flow separation which is obtained by joining the beginning point of DRH (A) to the end of DRH (D) through a straight line.
- Point "A" is easily identified by noticing the sharp charge in the runoff rate at that point.
- Point "D" is located empirically as "N" days from peak.
- N=0.83*A^0.2 ; where A=Drainage area N=time in days

Method:2

- Here base flow curve existing prior to the commencement of surface runoff (A'A)is extended till it intersects the ordinate drawn from peak at Pi.
- Join Pi to D by a straight line.
- This method is most widely used.

Method:3

- In this method , the base flow recession curve after the depletion of the flood water (ED) is extended back word till it intersects the ordinate at the point of the inflection.
- Point A and F are joined by an arbitrary smooth curve.
- This method is realistic when ground water contribution is significant and the stream quickly.
- The surface runoff hydrograph after the separation of base flow is known as runoff hydrograph (DRH).

LECTURE-27

Learning objective

6.3 Unit hydrograph

Unit hydrograph:

- An unit hydrograph or unit graph is the hydrograph of direct runoff resulting from unit depth of 1cm rainfall excess generated uniformly over the basin for a specified duration (D hrs) at a uniformly rate.
- The "unit depth of rainfall excess" mean excess rainfall over and above all losses in the basin under consideration.
- The "duration" is the period of the rainfall excess which is assumed to be uniformly distributed over the basin.
- The specified duration is important as the shape and the peak of hydrograph of a basin depends on it. e.g.- 3hr rainfall excess means 3h-UH

- An UH of D hr means, it is the duration of rainfall excess giving rise to theUH,but not duration of occurrence of UH.

Assumptions and conditions in UH:

1. Time Invariance:
   - This is the first basic assumption which says that direct runoff response to agiven effective rainfall in a catchment is time invariant.
   - The DRH for a given ER in a catchment is always
   - Same irrespective of the time when it occurs.

2.Linear Response :
   - The direct runoff response to the rainfall excess is assumed to be linear.
   - Most important assumption of UH theory.
   - It means if an input X1(t)causes output Y1(t) and X2(t) – Y2(t) , then X1(t) +X2(t) gives Y1(t)+Y2(t) Consequently if X2(t) = r*X1(t) ; Y2(t)=r*Y1(t)
   - Thus, if a rainfall excess in a duration D is r times the unit depth , the resulting DRH will have ordinates bearing ratio "r" to those of the corresponding D-hr . The base will same but the area of DRH will beincreased r times that of UH.

Application of UH:

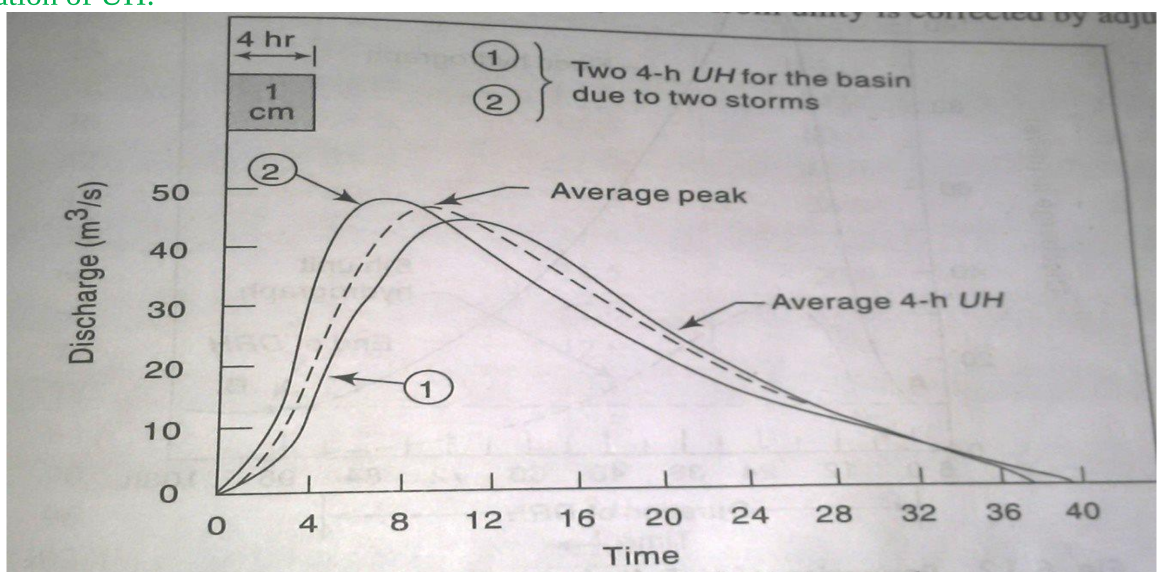


Fig. 6.12 *Derivation of an Average Unit Hydrograph*

- The number of isolated storm hydrographs caused by short spellsrainfall excess, each of approx same duration (0.9 to 1.1 Dh) are selected.
- For each storm hydrographs, the base flow is separated.
- The area under each DRH is evaluated and the volume of the directrunoff obtained is divided by catchment area to obtained the depth of ER.
- The ordinate of various DRH are divided by the respective ER valueto obtain the ordinate of the UH.
- Flood hydrograph used in the analysis should have the followingfeatures:
    - Storm should be isolated i.e occurring individually
    - Rainfall should be fairly uniform during the duration andshould cover the entire catchment area.
    - The duration of rainfall should be 1/5 to ½ of the basinlag.
    - The rainfall excess of the selected storm should be high.(Range :1to 4 cm preferred)
- A number of UH of a given duration are derived by above method andplotted on a common pair of axes.
- Mean of such curves as the UH is adopted.
- While deriving the mean curve, the average of peak flows and time topeaks are first calculated.
- Then a mean curve of best fit is drawn through the average peak on anaverage base length.
- The volume of DRH is calculated and any departure from unity iscorrected by adjusting the value of the peak.
- The average ERH is drawn of unit depth to indicate the type andduration of rainfall causing the UH.

LECTURE-28

Learning objective
6.4 UH from a complex storm

UH from a complex storm :

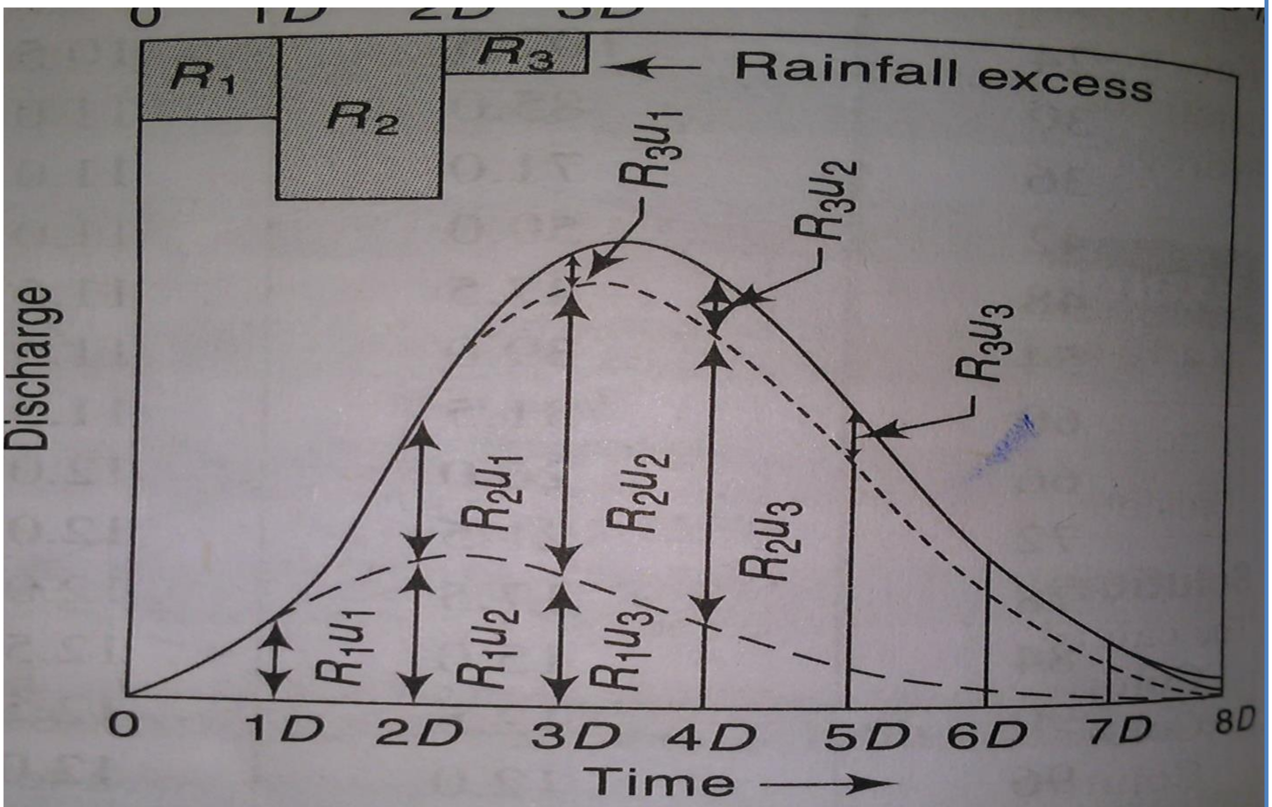


Fig. 6.14 *Unit Hydrograph from a Complex Storm*

- When simple isolated storms are not available, data from complexstorms of long duration are used for UH.
- 1st to decompose a measured composite flood hydrograph into its components DRH and base flow.
- A common UH of appropriate duration is assumed to exist.
- Let a rainfall excess of 3 duration of D-h and ER of R1 , R2 , and R3interval 1D ,2D ,3D ……… from the short of ERH.
- Let the ordinates of UH be U1,U2 ,U3 ……. And ordinates ofcomposite DRH be Q1, Q2, Q3………

Then

Q1=R1u1

Q2=R1u2+R2u1

Q3=R1u3+R2u2+R3u1

Q4=R1u4+R2u3+R3u2

………………………………

From the above equations u1, u2, u3 can be determined. In this method, errorpropagate and huge calculation.

Distribution Graph:

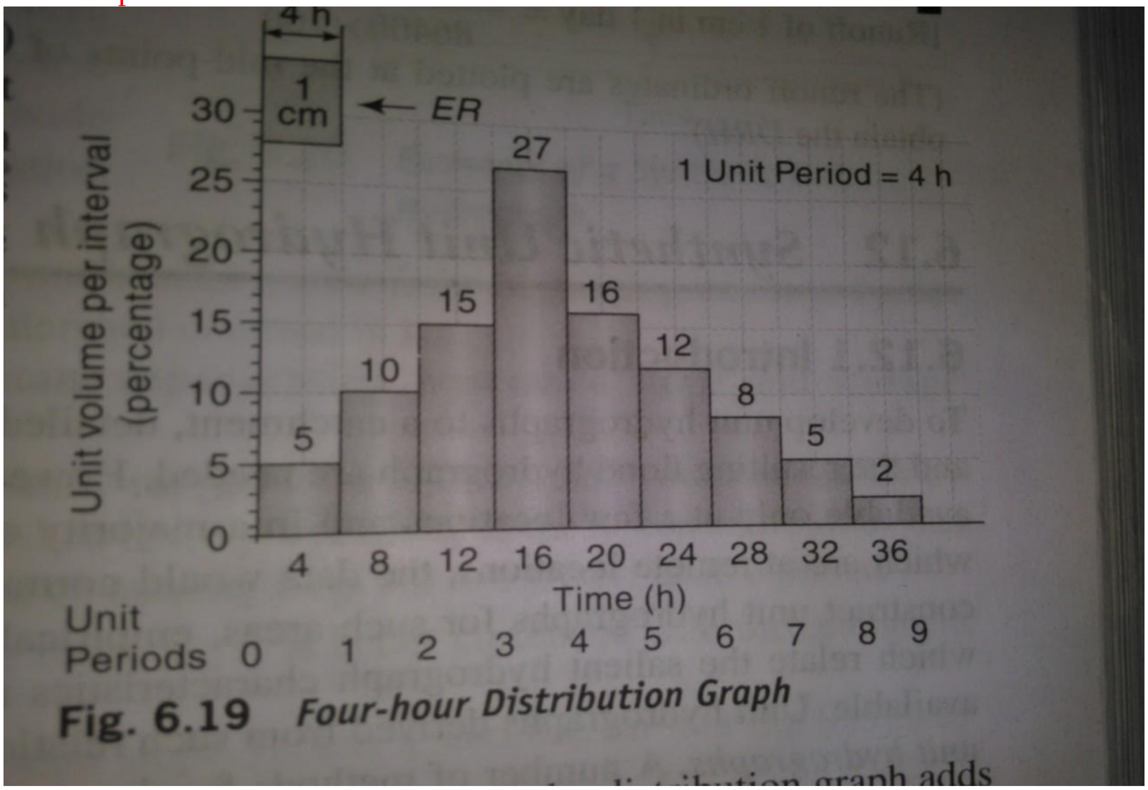


Fig. 6.19 Four-hour Distribution Graph

- Introduced by Bernard (1935)
- Shows variation if the UH.
- It is a D hr with ordinates showing the % of the surface runoff occurring insuccessive periods of equal time intervals of D hr.
- The duration ER is taken as unit interval and distribution graph ordinates areindicated at successive such intervals.
- In fig. interval =4 hr

  Total area under the distribution graph =100%
- The use of distribution graph is to generate a DRH for a known ERH isexactly the same as that of UH.
- These are used to compare the runoff character of different catchment.

Instantaneous Unit Hydrograph (IUH):

- UH are named as per their duration of rainfall excess.
- With decrease in duration, peak will shifted towards left axis.
- In a limiting case , when the duration of rainfall excess becomes infinitesimally small e.g 1cm of ER is spread over the catchment uniformly and instantaneously , the resulting DRH is know is known as 1UH.(D-0)
- The notation of 1UH is U(0,t) where as for UH is U(D,t).

- Since it is impossible for a basin to get 1 cm ER in 0 time so 1UH concept is purely theoretical and defined as a fictitious UH representing the surface hydrograph from a basin resulting from instantaneous rainfall excess volume of 1cm over the basin.
- The advantages of 1UH is the eliminated of a major parameter “the duration of effective rainfall” from the UH.
- The ordinate of DRH at time t , derived from an 1UH is Qt= ∫

  U(t-T) I(T) dT

  U(t-T) = IUH ordinate at time T

  I(T) = rainfall excess function of duration to at the time T dT =

  extreme small element of ERH

  t’ =t when t<to t’

  =to when t>to
- This Eq^ is called convolution integral or Duhamel integral in which the IUH , U(t-T)is called Kernel function
- Convolution of IUH and I(T) is shown in fig. where the shape of the IUH resembles a single peaked hydrograph.
- Here an instantaneous rainfall function I(t) of duration to get DRH from a catchment whose discharge at any time t is given by the integral.
- If UH is represented by U(D,t) where D is the unit duration or simply the duration of ER and t represents the time , then the ordinate of UH is representedas U or U(D,t)
- For an IUH , D=0 the ordinate of IUH at time t is U(0,t) or simply U(t)
- Properties of IUH are :
  - U(t)>0 ,when t>0
  - U(t)=0 ,when t<0
  - U(t)---0 when t---∞
  - ∫U(t) dt =unit depth of catchment
  - ∫U(t) t dt = the time lag of IUH (tl)
  - tp of IUH <time of the centroid of the curve

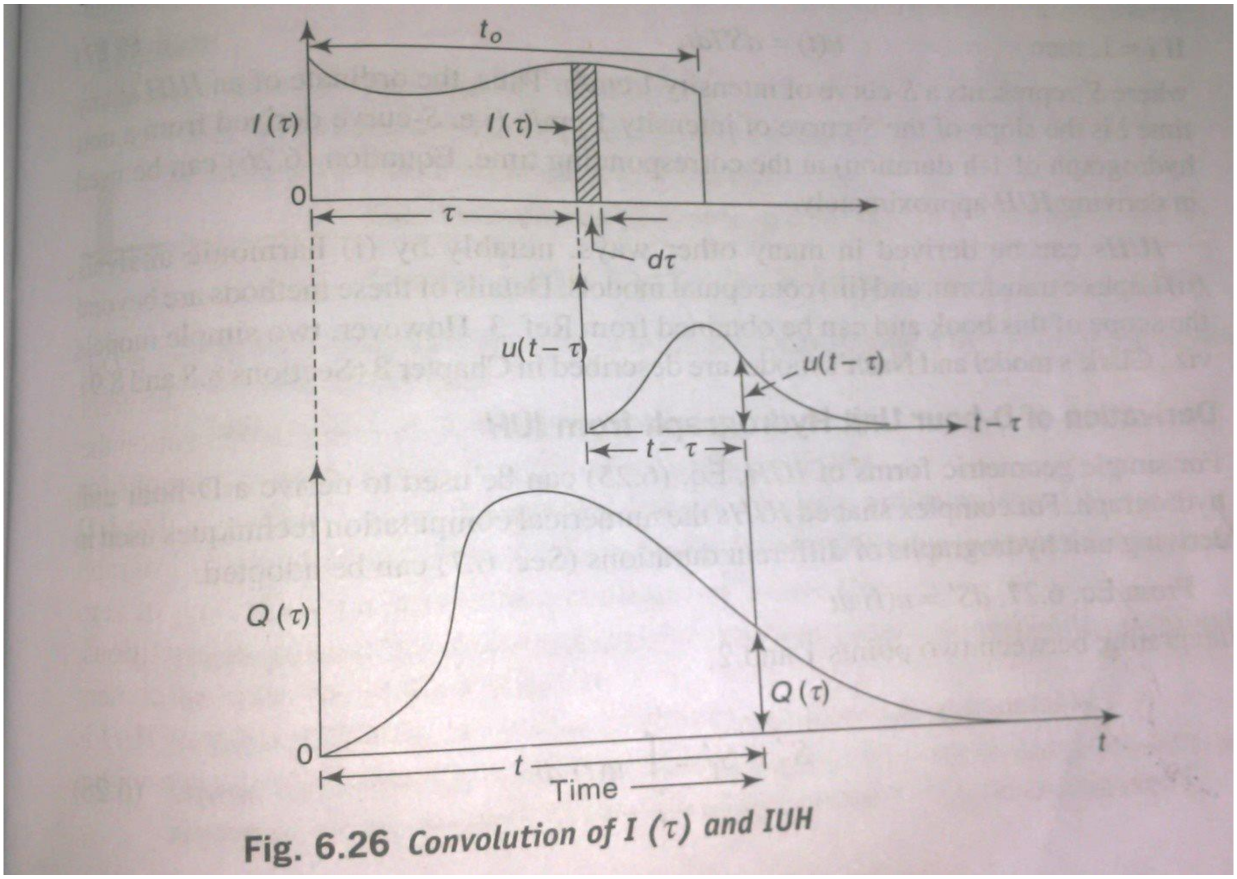


Fig. 6.26 *Convolution of* $I(\tau)$ *and IUH*

Derivation of IUH :

- IUH can be derived by :
    1. From S-Hydrograph
    2. From conceptual models
    3. By fitting harmonic series to DRH and ERH
    4. Theorytically from Laplace transform functionFrom S

– hydrograph:

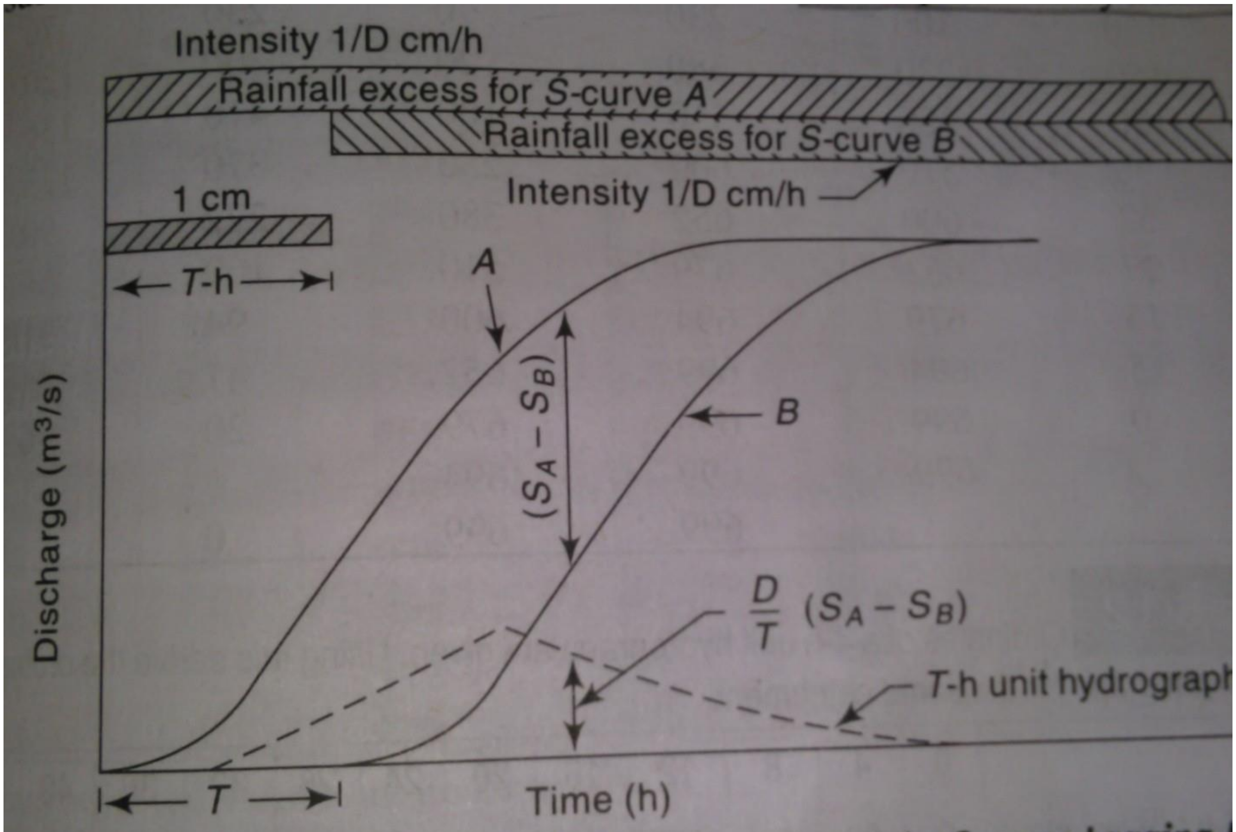


Fig. 6.18 *Derivation of a T-h Unit Hydrograph by S-curve Lagging*

- When 2S hydrographs are separated by dt hr , then dt hr ordinate =(S1-S2)/(dt/D) =(S1-S2)/(i*dt) ,i=1/D cm/hr
- In a limiting case where case where dt—0, then the time of ER is infinitesimally small and the result will be IUH.
- So the IUH ordinate at any instant "t" is given as:
- U(t)= ΔS/(i*Δt) =ΔS/Δt =ds/dt
- This means that when a S-hydrograph derived from an UH of 1 hr ER i.e 1cm/hr , then the slope of the S-hydrograph gives IUH ordinate at anytime t from the origin of the S-hydrograph.

Derivation of UH from IUH :

- IUH is derived from any conceptual model then it can be used for UHderivation in the following steps:
- Prepare a table in which col (1) contains and col (2) contains IUH ordinates
- In col(3) enter the IUH ordinates of step(2) by lagging D hr , the requiredduration of UH.
- Col(4)= col(2) + col(3)
- Col(5)=col(4)/2 (this col shows UH of D hr duration)

- It is to be noted that the D hr UH obtained by the above process should not be >3hr
- If larger duration is required, then the process of S-hydrograph or method of superposition may be adopted.
- The ordinate of UH at any instant (t) is (S1-S2)/(i*dt)
- If the intensity of rainfall for the UH from which S-hydrograph is derived is i=1cm/hr i.e S hydrograph his derived from a 1hr UH ,then U(t)=Δs/Δt ,is approx the slope of S-hydrograph is derived .Ina limiting case where dt—0,thenER time will be small.
- As ΔS becomes very small, the slope of S-curve at any instant "t" is the ordinate of IUH.

U(t)=ds/dt as dt—0

ds=U(t) dt

=∫ds=∫U(t) dt

=S2-S1=∫U(t) dt

=1/2 [u(t2)+u(t1)](t2-t1)

As bet^ 1&2 we can always take

U(t)=1/2[U(t2)+U(t1)]

(S2-S1)/(t2-t1)=1/2 [U(t2)+U(t1)]

- Thus by taking average of IUH ordinate at dt =(t2-t1) gives a dt hr UH. Dt<1hr because bet^ t2 and t1, the profile of hydrograph is curvilinear and for large diff of time it may error in its average value.

Excepted questions

1.List the factors affecting a flood hydrograph.

2.Explain the term Rainfall Excess (ER).How is ERH of a stroam obtained?

3.What is a unit hydrograph?List the assumptions involved in the unit hydrograph theory.

4.Distingush between Hyetograph and hydrograph.

Learning objective
7.1 Rational method

Peak flood estimation by Rational Method

RATIONAL METHOD

- It is used for calculating peak discharge for small catchments (<50 km^2)
- The formula is called rational because of the units of the quantities considered being numerically consistent.
- Original formula was in FPS unit. (Rainfall-inch, Area-Acre)
- The runoff gradually increases form zero to peak when rainfall duration reaches the time of concentration 't_c' and thereafter it becomes const. for the remaining period of rainfall excess ($t-t_c$) i.e. from time t_c onwards. After the cessation of rain, the runoff recedes gradually to become zero at time t_c from the end of the peak. In rational formula a certain % of rainfall is considered as runoff.
- In FPS unit, $Q_p = CIA$ (1) where Q_p = peak discharge
- In SI units $Q_p = 0.278\ CIA$ C= Runoff Coefficient = runoff/Rainfall
  I = Rainfall intensity in mm/h
  A = Area of catchment in km^2
- C varies 0.05-0.95, it represents the cumulative effect of the watershed losses.

FACTORS AFFECTING VALUE OF C:

- Initial losses
- Depression storage
- Nature of the soil
- Surface slope
- Degree of saturation
- Rainfall intensity
- Geology of the catchment
- Geo-hydrological characteristics of basin
  $C_w = \sum (C_i A_i)/A$, Value can be used in equation (2)
  General form correlating intensity duration-return period is
  $I = K.T^a/(t_c+b)^n$

  I = intensity of rainfall (cm/h)

  T = Return period (yrs)

  T_c = time of concentration (hr)
  K,a,b,n = const

TIME OF CONCENTRATION (T_C)

No. of empirical equation available for the estimation of t_c

1) US practice
   For small basins, $t_c = t_p = C_{tl}\ ((LL_{ca})/\sqrt{s})^n$
   Where C_{tl}, n = Basin Const

   S = Basin slope

   $(LL_{ca})/\sqrt{s})$ = Catchment parameter

   L = Basin length measured along the water course from the basin divide to the gauging stn.

   L_{ca} = dist along the main water course from the gauging station to a point app to the watershed controlled (Km)

2) KIRPICH Equation
   The formula relates the t_c of the length of travel and slope of the catchment as
   $t_c = 0.01947 L^{0.77} S^{-0.385}$ L = max length of travel of water

   S = slope of catchment $\Delta H/L$
   This equation can easily be written as $t_c = 0.01947\ K_1^{\ 0.77}$

   Where $K1 = \sqrt{(L^3/\Delta H)}$

RAINFALL INTENSITY (I OR $I_{TC,P}$)

The rainfall intensity corresponding to a duration t_c and the desired probability of exceedence P, (Return period T=1/P)

$i_{tc,p} = kT^x/(t+a)^n$

k,x,a,n = Area specific co-efficient

RUNOFF CO-EFFICIENT (C)

'C' Represents the integrated effect of the catchment losses and depends upon the nature of the surface, surface slope and rainfall intensity.

Equation (2) assumes a homogenous catchment surface. If it is non homogenoous, then it can be divided into subareas each having diff. runoff coefficients & then each coefficient is calculated separately & then merged.

If the non-homogenous sub areas can't be separated, then equivalent C_e is used

C_i = R.C. for subarea i having area A_i

EMPERIAL FORMULAE

Flood Peak area relationship

The simplest relationship is those which relate the flood peak to the drainage area.
The max flood discharge Q_p from a catchment area A is given by $Q_p = f(A)$

Dickens formula

Where $Q_p = C_d A^{3/4}$

Q_p= Max flood discharge (m^3/s)
C_d = Dickens const (6-30)

A = Catchment area (km^2)

Dickens formula is used in the central and northern parts of the country.

Ryves formula

$Q_p = C_R A^{2/3}$

where Cr = Ryves coefficient

used in Tamilnadu and parts of Karnataka & Andhra Pradesh
CR = 6.8 for areas within 80 Km from the east loc.

8.5 for areas which are 80-160 Km

= 10.2 for limited areas near hills

INGLIS FORMULA

Based on flood data of catchments in Western Ghats in Maharashtra
$Q_p = 124A/ (\sqrt{(A+10.4)})$

OTHER FORMULAE

Some other formulae are these which relate the Q_p with A along with flood frequency
Fuller's formula ($Q_{TP} = C_f A^{0.8} (1+0.8\log T)$)

Where Q_{TP} = Max 24 h flood with a frequency of Tyr in m^2/s
C_f = Const with values between 0.18-1.88

ENVELOPE CURVES

$Q_{mp} = 3025A/(278+A)^{0.78}$

Q_{mp} = max flood discharge (m^3/s)
A = Catchment Area (km^2)

LECTURE-30

Learning objective

7.2 Gumbels Method

Gumbel's Methods: Gumbel's distribution is a probabilistic theory of statistics. It is used as a model of maximum number distribution among the various samples.[17] It is useful to predict the future natural disaster like flood, earthquake, drought etc.[9] The Gumbel's distribution method of frequency analysis needs minimum ten years annual maximum historical data to assume the probabilistic future prediction. It is also known as the generalized extreme value distribution method. In this study, the Gumbel frequency distribution method was applied to predict the flood frequency of lower Ganga River basin[3].

The 72 years annual maximum Peak discharge data was used to execute the flood frequency analysis. In flood frequency curve "X" axis represents the return period and "Y" axis represents annual maximum peak discharge value. The Gumbel's distribution flood frequency analysis was completed based on the equation number (1) and return period was calculated using the equation number (6).

MODULE – 3

IRRIGATION, WATER REQUIREMENT OF CROPS

IRRIGATION:

Definition of Irrigation:

Irrigation is defined as the systematic process of artificially supplying water to land for raising crops. It is the profession, science of planning and designing an efficient, economic system to fit natural conditions.

NECESSITY OF IRRIGATION IN INDIA:

India being an agricultural country, as such all the resources depends on the agricultural output. The yield of an agricultural land depends on number of factors, however moist vital need is adequate quantities of water at various stages of the growth of the plants, but such conditions are rarely satisfied by natural rains. Hence the necessity of irrigation are as follows:

Less Rainfall:

- When the rainfall is less than 100cm i.e. less than needed for the crop, artificial supply is necessary.
- Hence irrigation work may be constructed at places where adequate quantities of water is available and convey the same to places of necessity.

Non – Uniformity of Rainfall:

- The rainfall over a particular area may be sufficient but not uniform over the crop period.
- In other words more water is supplied during the monsoon months, there is acute requirement of irrigation in other periods.

Commercial Crops with addition Water:

- The rainfall in a particular area may be sufficient to raise the regular crops, but large quantities of water may be necessary for raising commercial and cash crops like sugar cane etc.

Controlled Water Supply:

- By constructing a proper distribution system, crop yield can be substantially increased.

BENEFITS AND ILL EFFECT OF IRRIGATION:

Irrigation project are designed in such a way that, they give both direct and indirect benefits.

Direct Benefits or Advantages:

Increase in Food Production: this is achieved by controlled and timely supply of optimum quantity of water to the crop.

Protection from Famine: irrigation projects can save the places of famine in two ways: during construction employment opportunities are provided to the local people and after construction continuous supply is assured even during drought period.

Cultivation of Cash Crops: due to irrigation, it is possible to grow cash crops such as sugarcane, tobacco, cotton etc.

Addition to the Wealth of the Country: irrigation projects are so designed that they bring some revenue to the country in the form of tax, bumper crops and hence saves importing of food crops from other countries.

Increase in Prosperity of People: as continuous water supply is assured from an irrigation project, two or more superior crops can be grown, plus the value of the agricultural lands increases, thereby increasing the prosperity of people.

Hydro – Electric Power Generation: major project are designed in such a way that power generation can be done together with irrigation.

Domestic and Industrial Water Supply: water from irrigation canals can be used for domestic and industrial water supply.

Improvements of Communication: as all the canals are provided with inspection roads, which can be metalled and hence can be used as means of communication.

Canal Plantation: the area along the canal is always damp and hence canal plantation is possible, which in turn increases the wealth of the country and also minimizes soil erosion.

Improvement in the Ground Water Storage: due to constant percolation and seepage of water, the ground water table raises, which is beneficial for better growth of the crop.

Aid in Civilization: due to the improvement of irrigation projects there will be increase in the yield, the standard of living of the framer gets improved and becomes more civilized.

Indirect Benefits or Disadvantages:

- Climate becomes damp and cold, giving rise to malaria.
- Excess irrigation with poor drainage may results in water logging and causes salt efflorescence, resulting in drastic reduction of crop yield.
- Land revenue decreases in places where irrigation is extended as a protective measure.
- Excessive seepage from unlined canals would lead water logging of adjacent lands.

ENVIRONMENTAL IMPACTS OF IRRIGATION:

- Introduction to irrigation results in extensive changes in vegetation, flora and fauna, there by altering the ecology of the command area of the project.
- These improvements have a chain of advantages for a more prosperous life for the people.
- Barren, unfertile lands are turned into green pastures, good forests and change of human environment too.
- However on the contrary the development of irrigation to meet the constantly increasing food demand has detrimental environmental hazards in the form of water logging and salinity.
- Proper care must be taken to drain the command areas in order to decrease the adverse environmental effects of irrigation.

SYSTEM OF IRRIGATION:

Various systems of irrigation are broadly classified as follows:

- **Flow Irrigation or Gravity Irrigation:** the water is supplied to the fields by gravity only, through a network of canals. This system is further subdivided into perennial irrigation and flood or inundation irrigation.
- **Lift Irrigation or Pumped Irrigation:** water is lifted with the help of pumps and discharged into lift canal. The source of supply can be from a river or canal and from ground surface.

Flow Irrigation:

Flow irrigation is that type of irrigation in which the irrigation water is supplied to a field by gravity. Flow irrigation is divided into two classes:

Perennial Irrigation System: the water necessary for irrigation is supplied in accordance with the crop requirements throughout the crop period. Hence, for such a system some storage works such as dams, weirs or barrages are necessary to store excess water during floods and release it to the crops at the time of necessity.

Inundation or Flood Irrigation System: water is flooded, till the land gets thoroughly saturated. Irrigation is carried out after draining the water.

Direct Irrigation and Storage Irrigation:

Direct Irrigation:

- A weir or barrage is constructed across a river, so that the water can be diverted into the canal, such a system is also known as river canal irrigation.
- In this method water is not stored.
- Hence water level in the canal varies according to the water level in the river.
- Sarda canal system and Ganga canal system of UP are examples of this system of irrigation.

Storage Irrigation:

- In this system water is impounded in the form of a reservoir by the construction of a dam or a weir and this water is used for irrigation through a network of canals.
- Generally in order to achieve economy the project may be multipurpose, meaning the water can be used for number of purposes.
- This system is used when the monsoon are heavy during part of the year, but for most of the months in the year the discharge is not sufficient to meet the demand of the canals.

Bandhara Irrigation System:

- Bandhara irrigation is a special type of irrigation and is essentially a diversion irrigation scheme on non – perennial streams.
- This system is practiced in some parts of Maharashtra and Karnataka.
- The bandhara system was developed by late Sir M Visvesvaraya.
- A bandhara is a masonry diversion weir of small height of about 1.2m to 4.5m, constructed across the stream and the water from the upstream side of such a structure being diverted into small canals.
- It is the cheapest and most economical type of irrigation.

- Bandharas can be constructed in series and irrigation can be carried out on both the sides of the canals.
- The capacity of each bandhara can vary from few hectares to few hundred of hectares, depending on the volume of water available.
- Generally the length of a bandhara canal should not be more than 8km.

Location of Bandharas:

- The rivers should preferably be perennial in nature.
- Good foundation should be available for constructing the bandhara.
- The section at the site should be straight, narrow and well defined.
- The command of the canal should be fairly good and fertile.
- The natural banks on both sides of the site should be high so that no land is wasted on the upstream side.
- The cost of construction should be less or economical.

Advantages:

- The system of irrigation has a low initial cost.
- Losses in the canal are less, therefore duty of water is more.
- Small quantities of water which would have otherwise gone water is utilized to maximum in this system.
- As the lengths of the main canal and the distribution system being small, seepage and evaporation losses are very less.

Disadvantages:

- When excess water is available, it goes waste, since the area to be irrigated is small and fixed.
- Water supply in the canal depends on the nature of the river.
- As the water resources upstream of the bandhara depends on the nature of the stream, water may not be available for domestic purposes during dry seasons.

Tank Irrigation:

- Tank irrigation is a storage on the upstream which utilizes the water stored on the upstream side of a smaller (less than 12m height) earth dam or a bund.
- The reservoir or storage so formed upstream of such a bund is known as a tank.

- Tank irrigation method is very much popular in South India.
- Generally tank bunds are provided with sluices or outlets for discharging water from the tank for the tank for the purpose of irrigation.
- Excess water can be discharged from a surplus escape weir provided in the body or at one end of the tank bund.
- When a tank neither receives water from an upper tank nor discharges its own surplus into a lower tank, it is called an isolated tank.
- When a number of tanks are connected in series, such that any tank either receives the surplus water into the lower tank or do both, they are known as tanks in series or group of tanks.
- The storage capacity of a tank can be computed by using the contour plan of the area of the water spread, the total capacity will be sum of the capacities between successive contours.
- When the contour plan is not available and if only the area of the tank at full tank level FTL multiplied by one third of the vertical distance between the FTL and the deepest bed level of the tank or the level of the silt of the lowest sluice whichever is higher of the two.

Failure of Tank Bunds:

A tank bund may fail due to any of the following reasons:

Hydraulic Failures: may be due to overtopping, erosion of the upstream face, cracking due to fast action, erosion of downstream face by gully formation, erosion of the downstream toe.

Seepage Failures: may be due to piping through the foundations, piping through the body of the dam, sloughing of downstream toe.

Structural Failures: may be due to foundation slide, slide in embankments.

Lift Irrigation:

This system is also known as the pumped irrigation, which can be further classified into:

Lift Irrigation from Surface Source: the water is lifted with the help of pump and discharged into lift canals. The water source may be river or gravity canal. The water so lifted flows to the fields through a network of gravity canals.

Lift Irrigation from Ground Source: the water is lifted by means of tube wells or open wells. The water from such wells are pumped into the network of canals, leading to the place of necessity.

Methods of Lifting Water from Shallow Wells:

Following methods are generally used for lifting water from open wells for the purpose of irrigation.

Persian Wheel:

- This method is used for lifting water from wells which are 10 to 20 m deep.
- This is very common in western UP and Punjab.
- It consists of a big framed wooden wheel fixed in a vertical position above the top of the well.
- At the end of the axel of this wheel, another vertical wooden wheel of smaller diameter is fitted, this smaller wheel is rotated by a gear mechanism, which in turn is driven by a pair of bullock.
- As the bullocks move round all the wheels rotate and the metallic buckets filled with water start coming to the upstream end of the field canal, through which water flows to the land.

Doon:

- This method is used to lift waters up to 1.2m closed at upstream end and open on the downstream side.
- This chute is supported at its centre on a horizontal rod on which it rocks.
- The closed upstream end of the chute is connected by a rope on one side and a counter weight mechanism to the other side.
- A wooden platform is fixed in the channel near its berm such that the top of platform is above the water level in the channel.
- The farmer stands on the platform who can operate the chute to lift the irrigation water from the channel to the irrigation fields.

Wind Lass:

- This methods is employed for lifting small quantity of water for irrigation or for drinking.
- In this method two wheels each having four or six projecting arms are joined together to from a cylindrical wooden frame.
- This cylinder is rested on top of the well.
- The bucket is tied to one of the rope while the other end of it is fixed to the axle of the frame.
- For lifting the water the wooden cylinder is rotated in one direction so that the bucket is lowered into the well and when it is full the cylinder is rotated in the opposite direction till the bucket rises to the top of the well so that the water can be discharged into the canal.
- This process is repeated as per requirements.

Advantages of Well:

- Water is under the sole control of the farmer hence it can be used according to the necessity in the field.
- Isolated areas, not served by any other irrigation scheme can be irrigated by wells.
- Pumping or lifting of water from well depresses the water table, this reduces the chances of water logging.
- The maintenance cost is low.
- Due to minimum conveyance losses, duty of water will be quite high.
- Overall cost of the project is small.
- In tube well irrigation, water can be supplied to the irrigator on volumetric basis, thus there is more scope for economic use of water.

Disadvantages of Well:

- Any defect in the lifting mechanism, leads to interruption in the water supply.
- Since the well water is free from silt contents, it has minimum manure value.
- The cost of irrigation with well is high.
- The quantity of well water and its yield depends on the ground water storage, if it is less, the irrigation capacity will also be less.

Comparison of Lift Irrigation and Canal Irrigation:

- In lift irrigation, pumping device are essential, while in the canal irrigation no such devices are required.
- In the case of lift irrigation, the farmer can irrigate his fields as per his requirements, while in the canal irrigation he has to wait for his turn.
- In lift irrigation pumping of water reduces the possibility of water logging, but in the case of canal irrigation water logging is possible.
- In the case of lift irrigation, water supply gets disrupted due to repair or due to power failure.
- Lift irrigation can be implemented anywhere and everywhere, but canal irrigation is possible in places where water can flow by gravity only.
- Due to the absence of slit in well water, its manorial value will be low, but in case of canal water, silt content is more meaning relatively high manorial value. This is an added advantage of canal irrigation.

- The area under irrigation in the case of lift irrigation will be relatively small compared to the canal irrigation.
- Lift irrigation water is used economically when compared to the canal irrigation.
- Lift irrigation is possible at all times even in draughts, but irrigation becomes more difficult when the rains fail.
- Staff requirement for lift irrigation is small compared to the canal irrigation.

Tube Well Irrigation:

- The maximum discharge from ordinary open well vary between 4 to 5 liters/sec, hence their usage is limited to small locality or dwellings, also it may not be economical to install pumps in such wells.
- In order to get more yield, tube wells are commonly used.
- These wells consist of blind pipes and strainer pipes driven into water bearing strata.
- The maximum yield of such a well will be about 200 lps and the depth may vary from 50 to 500m.

Following types of tube wells are usually constructed:

- Strainer type tube wells.
- Cavity type tube wells.
- Slotted type tube wells.
- Perforated type tube wells.

DEFINITIONS:

Delta (Δ): it may be defined as the total volume of water delivered by the area over which it hasbeen spread.

or

It is the total depth of water in centimetres required by a crop to come to its maturity.

Duty: it denotes the irrigating capacity of a unit water. It is usually defined as the area of land in hectares which can be irrigated for growing any crop if one cumec or 1 m^3/sec of water is continuously supplied to the land for the entire base period of the crop.

Gross Duty: it is the duty of water measured at the source of diversion of irrigation supplies.

Nominal Duty: it is the duty sanctioned as per schedule of the irrigation department.

Economic Water Duty: it is the duty of water which results in the maximum yield.

Designed Duty: it is the duty of water assumed in an irrigation project for designing the capacity of a channel.

Farm Duty or Net Duty: it is the duty measured in the farm.

Flow Duty: it is the duty determined at the head of a channel.

Quantity Duty: it is the duty expressed in terms of the volume of water stored, and is expressed as hectares/million cubic meters of water available.

High Duty: when small amounts of water matures comparatively small area under crop the duty is said to be high.

Low Duty: when large amounts of water matures comparatively small areas under a crop the duty is said to be low.

Base of Duty of Water: it is defined as the period to which the stated duty of water has reference. When the duty of water is expressed for the entire base period and if the base is not mentioned it isevident that the duty refers to the entire base period.

Base Period: it is the period from the first to the last watering of the crop just before its maturity.It is expressed in number of days.

Outlet Factor: the duty of water at the outlet or at the head of a field channel is known as the outlet factor.

Cumec Day: the total quantity of water flowing continuously for one day at the rate of one cumec is known as cumec day.

1 cumec day = $1 \times 24 \times 60 \times 60 = 8.64 \times 10^4$ m^3 = 8.64 Hectare – meters.

Consumptive Use of Evapo Transpiration: it is defined as the total quantity of water used by the vegetative growth of a given area in transpiration and buildings of plant tissue and that evaporated from the adjacent soil in the area in any specified time.

Effective Rainfall: it is that part of the precipitation falling during the growing period of a crop that is available to meet the evapo transpiration needs of the crop.

Water Conveyance Efficiency [η_a]: it is defined as the ratio of the quantity of water delivered tothe filed to the quantity of water diverted into the canal system from the storage.

Water Application Efficiency [η_u]: it is defined as the ratio of the quantity of water stored in theroot zone of the plant to the quantity of water delivered to the field.

Water Use Efficiency [η_s]: it is defined as the quantity of water beneficially used including thewater required for leaching to the quantity of water delivered.

Water Storage Efficiency [η_c]: it is defined as the ratio of the quantity of water stored in the irrigation to the quantity of water needed to bring the moisture content of the soil to the field capacity.

Consumptive Use Efficiency [η_{cu}]: it is defined as the ratio of the normal consumptive use of water to the net amount of water depleted from the root zone.

Consumptive Irrigation Requirement [CIR]: it is defined as the amount of irrigation water thatis required to meet the evapo transpiration needs of a crop during its full growth.

Consumptive Irrigation Requirement = Consumptive Use – Effective Rainfall

Net Irrigation Requirement [NIR]: it is defined as the amount of irrigation water required to be delivered at the field to meet the evapo transpiration needs of a crop as well as other needs such a leaching etc.

Net Irrigation Requirement = Consumptive Use – Effective Rainfall + Amount of Water required for Leaching

Field Irrigation Requirement [FIR]: it is defined as the amount of water required to meet the net irrigation plus the amount of water lost as surface runoff and through deep percolation.

Gross Irrigation Requirement [GIR]: it is defined as the amount of water required to meet the field irrigation requirements plus the amount of irrigation water lost in conveyance through the canal system.

Paleo: it is first watering before sowing the crop. Paleo watering is done to provide sufficient quantities of water to the unsaturated zone of the soil.

Full Supply Coefficient: it is defined as the area estimated to be irrigated during the base period divided by the design full supply discharge of the channel at its head during maximum demand.

RELATION BETWEEN DUTY, DELTA AND BASE PERIOD:

Let

D = Duty of water in hectares/cumec

B = Base period of the crop in days

Δ = Delta of water in meters

Volume of water applied to D Hectares of the field corresponding to a depth of Δ meters in B days

= D x Δ Hectares – meter

$= D \times \Delta \times 10^4$ $meter^3$ – [1]

Volume of one cubic meter of water flowing for B days = 1 x 24 x 60 x 60 x B

$= 8.64 \times 10^4 \times B$ $meter^3$ – [2]

Equating 1 and 2 equations

$$D \times \Delta \times 10^4 = 8.64 \times 10^4 \times B$$

$$D = 8.64 \{B / \Delta\} \quad \text{– [3]}$$

In equation 3

D = hectares / cumec

B = days

Δ = meters

Values of Duty, Delta and Base periods for some of the common Rabi and Kharif Crops:

No. Crop	Base Period (B) Days	Delta (Δ) meters	Average Duty D (Hectares/cumec)
RABI CROPS			
Wheat	150 to 180	0.3 to 0.35	1800
Potato	135 to 165	0.6 to 0.80	1600
Gram	150 to 195	0.15	2000

Peas	150 to 195	0.55	1500
Barley	150 to 180	0.3 to 0.35	1800
KHARIF CROPS			
Rice	90 to 135	0.8 to 1.40	900
Bajra	120 to 150	0.30	2000
Maize	120 to 135	0.35 to 0.45	1800
Dals	120 to 150	0.30	2000

FACTORS AFFECTING CROP WATER REQUIREMENTS:

The water requirements of crop are affected by the following parameters:

- Depth of the ground water table.
- Slope of the ground surface.
- Climatic conditions of the region.
- Intensity of irrigation.
- Texture and structure of soil.
- Moisture storage capacity of the soil.
- Type and quantity of manure applied to the fields.
- System of irrigation used.

OPTIMUM USE OF IRRIGATION WATER:

- Optimum requirements of water is defined as the quantity of water supplied to a crop, giving maximum yield of the crop.
- This requirement can be satisfied by irrigation water as well as by rainwater.
- Hence it is essential to know the optimum water requirement for a particular crop.
- Supply of less water may result in the plant to spend extra energy to get moisture from the soil which otherwise would have been used in its growth.
- Supply of excess water will expel the air from the soil pores and will prevent free circulation of fresh air, essential for food preparation of the paint.

IMPORTANCE OF DUTY:

Knowledge of duty of water for crops serves the following purposes:

- It helps in the design of irrigation channel in an irrigation project.
- Also knowing the amount of water available in the head of the main canal and overall duty, we can get an idea regarding the extent of area that can be irrigated from the available water.
- It helps to check the efficiency of the working of a canal system.
- From the area actually matured by canals in existence, it is possible to know whether the area actually matured is as proposed in the project or not.

FACTORS AFFECTING DUTY OF IRRIGATION WATER:

The duty of irrigation water depends upon the following factors:

Soil Characteristics: the duty of water directly depends on the soil characteristics, if the soil is pervious and coarse grained, losses are more, thereby there will be reduction in duty.

Sub – Soil Conditions: seepage losses depends on the sub – soil condition. If the water table is close to the normal supply level, seepage losses will be minimum and the duty of water will be high.

Climate Conditions: evaporation of water will be high when the temperature is high and the humidity is less this results in severe reduction of the duty of water.

Rainfall: if the irrigated area receives sufficient rainfall at the right time, then the quantity of irrigation supplied reduces, thereby the duty will be more.

Type of Crop: it is a fact that different crops require different amounts of water and hence the duties would be different for different crops. This means that a crop requiring more water would have lessduty and vice versa.

Crop Period: the crop period/base period varies from crop to crop. This means that a crop with longer base period has lesser duty and vice versa.

Unevenness of the Irrigation Fields: even fields have better duty compared to uneven fields as more water is lost in the latter case.

Preparation of Fields: properly deep ploughed fields require overall less quantity of water, hence the duty will be more.

Longitudinal Slope of Fields: fields having little longitudinal downward slope towards the furtherend, requires less water and hence duty of water will be high.

Field Position in Relation to Canal: duty of water depends on the distance of the field from the canal outlet, which means if the distance of the field is more than the water losses will be more, or the duty will be less.

Use of Irrigation Water: when the irrigation water is assessed volumetrically, water will be more economically used, meaning that the duty will be more.

Skill of the Farmer: skilled farmer will make proper use of water, thereby the duty of water ill be high at such places.

Chemical Composition of Water: when the water quality is good, lesser quantities are required for irrigation, compared with water having chemicals. Hence duty for good quality water will be high.

Method of Irrigation: duty of water is more in case of perennial irrigation.

Mode of Applying Water: the flood irrigation system has lesser duty than the furrow system.

Time and Frequency of Cultivation: frequent cultivation reduces the loss of moisture through weeds. Also when the soil is in good tilth, evaporation losses are less, hence better duty.

Canal Conditions: lined canals have higher duties compared to unlined canals as losses are minimum in the former case.

METHODS OF IMPROVING DUTY:

Following are the various methods of improving duty:

- By adopting suitable methods of applying water, conveyance losses can be minimized thereby duty of water can be increased.
- By properly ploughing and levelling off the field before sowing the crop and also giving good tilth, duty can be improved.
- By frequent cultivation of the land moisture loss is reduced, thereby duty can be increased.
- By lining the network of canals, percolation and evaporation losses are reduced and hence duty can be increased.
- By reducing the idle length of the canal, duty can be increased.
- By practicing the rotation of crops, duty can be increased.

- By adopting the volumetric method of assessing the irrigation water, duty can be increased.
- By selecting the source, yielding good quality water, duty can be increased.
- By avoiding the canal route through sandy or porous reaches, losses can be minimized, thereby duty can be increased.
- By properly training farmers, to use water economically, duty can be increased.
- By establishing research stations the study of soil and conservation of moisture, duty can be increased.

CROP ROTATION:

- Crop rotation means that nature of the crop sown in a particular field is changed year after year.
- It is a fact that all crops require similar type of nutrient salts, but quantities may vary.
- Hence if different crops are grown there would be more balanced fooding and the soil deficient in one particular type of nutrient is allowed to build up.
- Insects and crop diseases will multiply if the same crop is grown continuously.
- Rotation will check the disease.
- There could be deep rooted and shallow rooted crops in rotation and if they are allowed to draw their food from different depths, the soil will be better utilized.

For examples of crop rotation are:

- Groundnut rotation with cotton.
- Bajra rotation with cotton.
- Cotton after gram.
- Wheat after sugarcane.
- Rice gram.

FREQUENCY OF IRRIGATION:

- Irrigation frequency refers to the number of days between irrigation during periods without rainfall.
- It depends on consumptive use of rate of a crop and on the amount of available moisture in the crop root zone.
- It is function of crop, soil and climate.
- Sandy soils must be irrigated more often the fine texture deep soils.

- A moisture use ratio varies with the kind of crop and climate conditions and increases as crop grows larger and days become longer and hotter.
- In general, irrigation should start when about 50 percent and not over 60 percent of the available moisture has been used from the root zone in which most of the roots are concentrated.
- The stage of crop growth with reference to critical periods of growth is also kept in view while designing irrigation frequency.
- The interval that can be safely allowed between two successive irrigation is known as frequency of irrigation.
- Irrigation Interval = {Allowable soil moisture depletion / Daily water use}

Factors Affecting Frequency of Irrigation:

Humidity:

- In rainy season, the humidity is high and rains may be received just when the crop is in need of water.
- In such case, some irrigation turns could be stopped and frequency may be extended to 20 days.
- During winter season, also the frequency will be longer than in summer because of less evapo transpiration, dew fall, night time humidity and less sunshine.
- The frequency may therefore be 15 to 20 days in winter and 6 to 8 days in summer.
- In summer irrigation, water is given more frequently and hence more frequency of irrigation in summer, medium in winter and less in rainy season.

Stage of Growth of Crops:

- During certain stages particularly at flowering and fruit formation stages of crop requires much larger quantities of water then earlier stages.
- In earlier stages, even if a little less water than estimated daily use is provided, the crop will stand without any harm, perhaps a slight moisture stress may encourage better root growth.

Type of Crop:

- The frequency of irrigation will also depend up on the crop.
- A succulent leaf vegetable will require irrigation more often than cereal crop like Jowar.
- Crops which are doses of fertilizers need more water than those with little or no fertilizers.

Soil Type:

- Light soil requires more frequent irrigation than the loamy soils.
- Sandy loam soil need to be irrigated every fifth day while clay loam may be irrigated every tenth day.
- Time required to irrigate an area.
- The time required to irrigate an area depends up on magnitude of discharge, quantity of water applied, irrigation efficiency and area.
- The time required to irrigate an area is calculated by the formula.

$$IQT = Ad$$

Where

I = irrigation efficiency

Q = discharge in cusec

T = time in hours

A = area in acres

d = moisture deficit in soil

MODULE – 4

CANALS, RESERVOIRS

CANALS :

Introduction:

Canals one as old as irrigation and they date back to many centuries, particularly in India and Egypt. However, during these periods irrigation was restricted to smaller areas and these areas were fed by **Inundation Canals** of short length from a river. During 19^{th} century canal design more scientific with the use of Chezy, Kutter and Buzin formulate and in India Kennedy and Lacey's equation more popular presently advanced equations and methods are being used in designing both unlined and lined canals. It is a fact that net error of canals play a vital role in any irrigation factor. Therefore, proper design of canals is of great importance. Usually canals suffer from selling and scouring problems in addition to weed growth, heavy seepage losses leading to extensive water logging on its sides, throughout the length. The velocity of water in a canal shall neither by selling nor scouring. Also it is most essential to select a most economical section of the canal.

Definition of Canal:

A canal is a passage for the flow of water, mainly under gravitational force. It is generally trapezoidal in shape constructed on the ground to carry water to the fields from a storage system like a tank or reservoir.

TYPES OF CANALS:

Alluvial and Non – Alluvial Canals:

- **Alluvial canals** are those constructed through alluvial soils, their bed and banks comprise of the same material that is being transported by the canal.
- Such a canal can be readily silted or scoured.
- These canals are designed using the Lacey's Regime Theory.
- Alluvial canals generally take off from a barrage or a weir.
- Such soils are available in Indo – Gang etic plains of North India.
- **Non – alluvial canals** are those constructed through hard soils or fresh rocks.
- These types of canals are stable, usually designed for higher velocities and can withstand erosion.
- They are designed using Manning's, Chezy's and Kutter's equations.

- Non – alluvial canals take off from reservoirs. Such soils are usually found in central and South India.

Permanent and Inundation Canals:

- **Permanent canals** are the canals fed by a permanent source of supply.
- They are also known as perennial canals.
- They are well graded channels and are provided with permanent regulation and distribution works.
- **Inundation canals** are the canals which usually draw their supplies during monsoon.
- These canals are not provided with any head works for diverting the water but are provided with canal head regulators.
- Inundation canals are non – perennial in nature.

Lined and Unlined Canals:

- A **lined canal** is on which is provided with a protective covering on the bed and sides, in order to prevent seepage of water and also to minimize the erosion.
- An **unlined canal** is one which has its bed and sides made up of soil through which it is constructed and no protective covering is provided.
- The velocity in such a canal is maintained low to overcome the risk of erosion.

Productive and Protective Canals:

- A **productive canal** is one which when completed fully yields enough revenue for its running and maintenance.
- A **protective canal** is constructed as a relief work against famine to provide employment to the people of that area.
- The revenue from such a canal does not cover its running charges and also does not repay its initial capital expenditure.

CLASSIFICATION OF CANALS BASED ON DISCHARGE:

The irrigation canals can be classified on the basis of their discharge carrying capacity and relative importance in the network into the following categories:

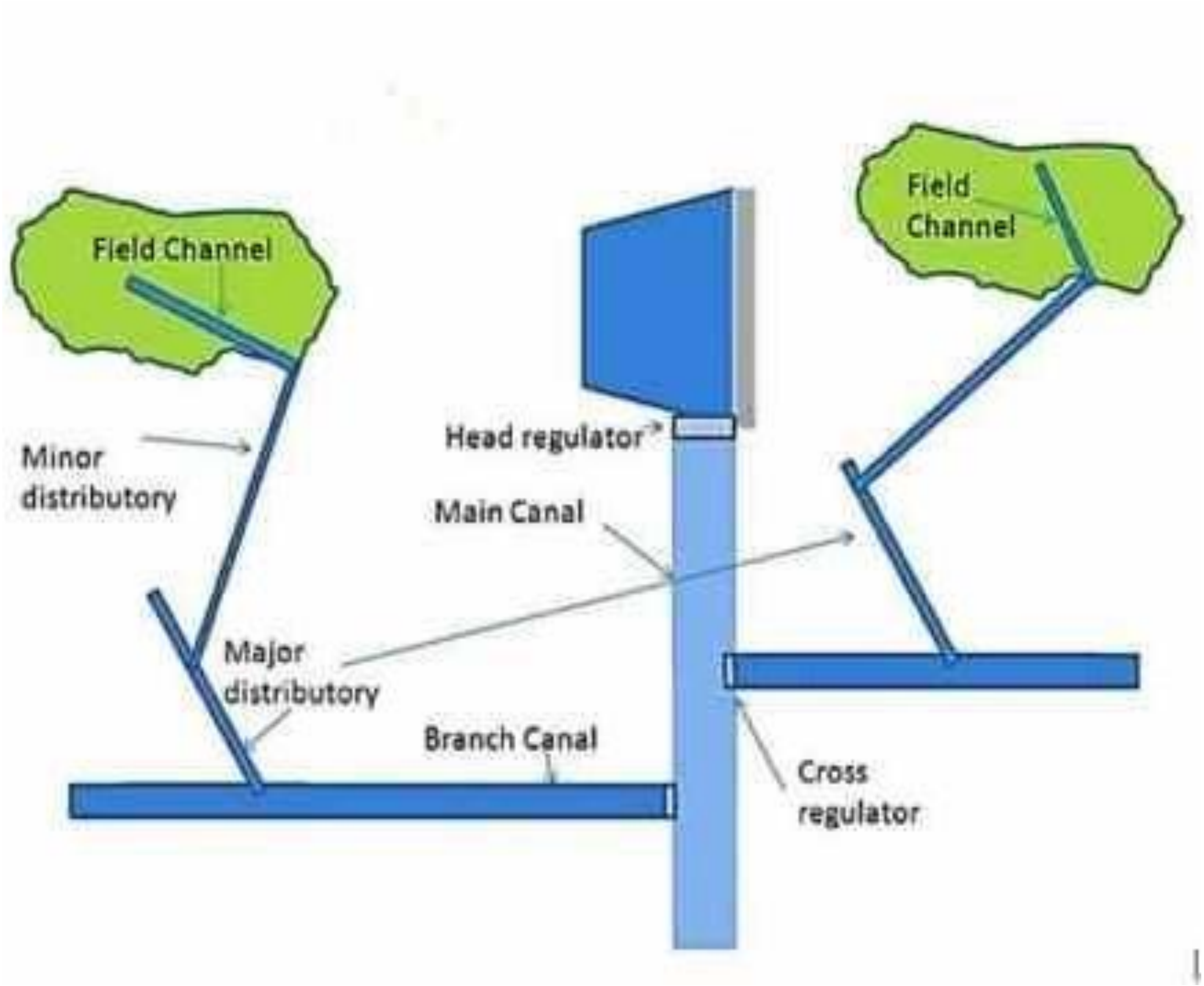
Main Canal: it is the principal canal of the network, it generally takes off from the reservoir. Such acanal carries heavy discharge and is not used for direct irrigation. Main canal is intended to supply water to the branch canal and major distributary.

Branch Canal: these are canals branching off from the main canal in either direction taking off at regular intervals. The discharge in such canals will be more than 5 cumecs. The main function of a branchcanal is to supply water to the major and minor distributaries.

Major Distributary: takes off from branch canal. It supplies water for irrigation to the fields through the outlets provided along its length. The discharge inn such a canal varies from 0.25 to 5 cumecs.

Minor Distributary: it is a canal taking off from the major distributary or a branch canal. The discharge carrying capacity of such a channel will be less than 0.25 cumec.

Field Channel or Minor: it is a canal supplying water to the fields directly. It takes of from a majoror a minor distributary. These canals even though constructed by the irrigation department, have to be maintained and regulated by the framer. The discharge in this canal will be less than 0.1 cumec.

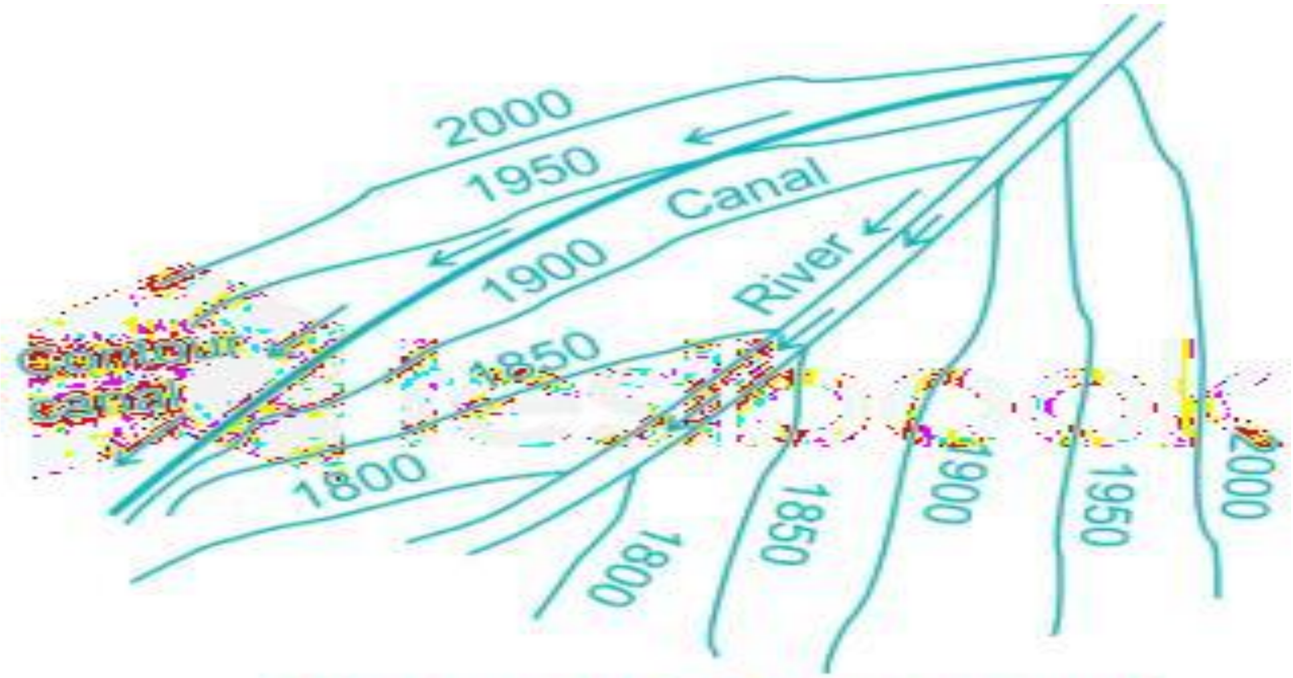


CLASSIFICATION OF CANALS BASED ON THEIR ALIGNMENT:

Based on alignment canals can be classified as:

Contour Canal:

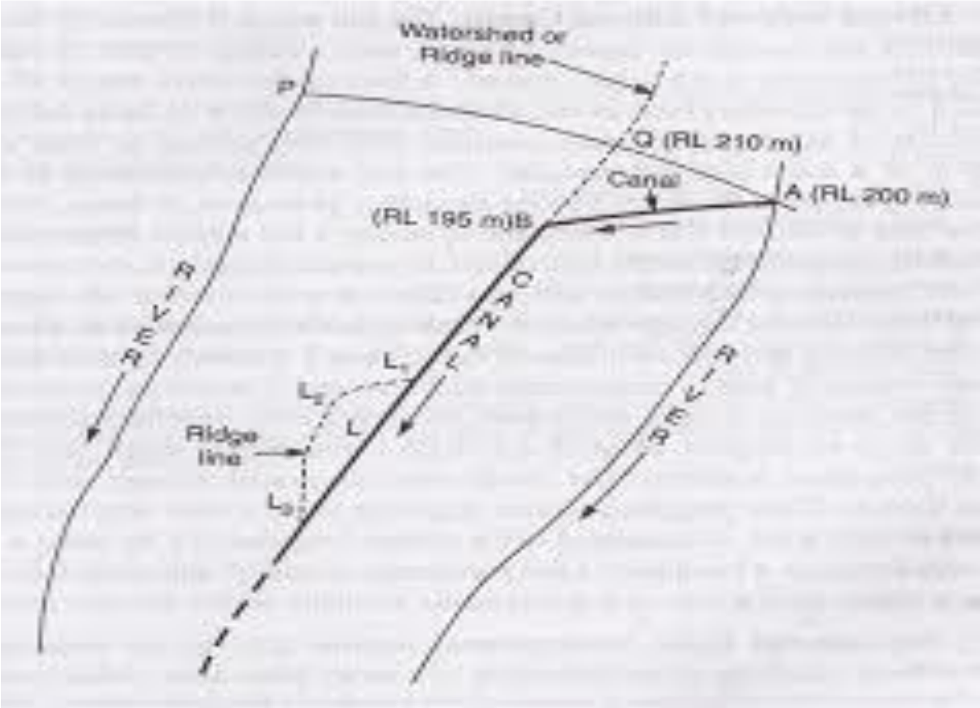
- It is a canal aligned nearly parallel to the contours of the country as shown in figure.
- It is also known as a single bank canal.
- A contour canal can irrigate only on one side.
- The contour canal does not follow the same contour all along its length due to the fact that some bed slope is necessary for the flow of water under gravity.
- A contour canal has to cross drainage and hence needs canal cross drainage works.



Alignment of a contour canal

Water Shed Canal or Ridge Canal:

- It is a canal which is aligned along the ridge or the natural water shed line as shown in figure.
- Such a canal does not need any cross drainage works.
- Cost analysis reveals that the ridge canals are most economical.
- Sometimes it may be necessary to abandon the ridge line in order to bypass habitations such as villages, towns etc. situated on the water shed.



Side Slope Canal:

- This type of a canal is aligned roughly at right angles to the contours of the country.
- Hence it runs approximately parallel to the natural drainage, thereby cross drainage works are avoided.
- The main disadvantages of such a canal is that it has very steep bed slope of the ground is at right angles to the contours of the country.
- Figure shows a side slope canal.

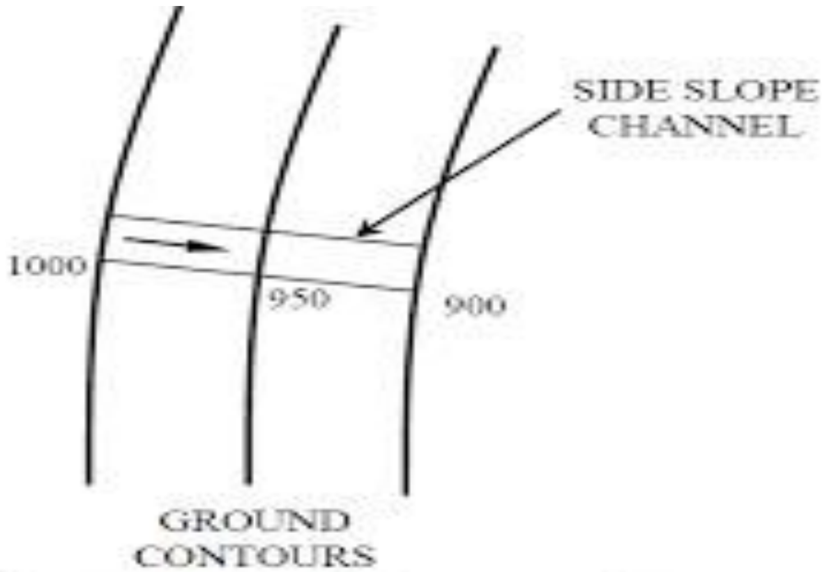


Fig: Alignment of a side slope canal

Detour Canal:

- A contour canal may have to cross number of C D works.
- A detour canal envisages adoption of a lengthy alignment so that the cost of construction of the canal and its related hydraulic structures are a minimum.
- However, the lengthy alignment of a detour canal may result in loss of command and increased number of C D works.

CONSIDERATION FOR ALIGNMENT OF A CANAL:

Following are the various consideration for the alignment of a canal.

- The alignment should be such that it ensures the most economical way of distributing water to the land, has the maximum commanded area and minimum number of drainage work.
- The alignment on a watershed being the most economical is preferred.
- The length of the main canal from the point, where it takes off from river to a point where it mounts on a watershed should be minimum.
- The contour alignment should be changed in order to reduce the number of cross drainage works.
- The alignment should avoid villages, roads, places of worship etc.
- The alignment should pass through the balanced depth of cut.
- The number of kinks and acute curve must be minimum.
- Idle length of the canal should be minimum.
- The alignment of the canal should be avoided in rocky, brackish or cracked strata.

DEFINITIONS:

Water Requirement of a Crop: it can be defined as the quantity of water required by a crop in a given period of time for normal growth under field conditions.

Total Water Requirement: it can be defined as the quantity of water needed for potential production per unit of land for sustained production and is then sum of consumptive use, application conveyance losses and other special needs.

Unit Water Requirement: it is defined as the weight of water actually used by the plants or crops in producing unit weight of dry matter.

Optimum Moisture Percentage: it is that moisture corresponding to which optimum growth of plant takes place.

Readily available Moisture: it is that moisture which is easily extracted by the plants and is approximately equal to 75% of the available moisture.

Available Moisture: it is the difference in water content of the soil between field capacity and permanent wilting.

Soil Moisture Deficiency or Field Moisture Deficiency: it is the water required to bring the soil moisture content of the soil to its field capacity.

Frequency of Irrigation: it depends on the amount of readily available moisture in the root zone of the plant and the rate of consumptive use, If C_u is the rate of consumptive use expressed in terms of depth of moisture lost from the soil per day, then frequency of irrigation.

$$f_w = \{d_w / C_w\}, \ f_w \text{ is expressed in days}$$

Arid and Semi-Arid Region: the area where irrigation is a must for agriculture is known as arid region. The area in which inferior crops can be grown without irrigation is known as semi-arid region.

Gross Commanded Area (GCA): it is the total area enclosed between the imaginary boundaries line up to which certain irrigation channel is capable of supplying water for irrigation purposes. It includes unculturable areas like small drainages, ponds, forests, buildings, roads, barren land plus the fields on which the crops are grown or can be grown.

Culturable Commanded Area (CCA): it is the land on which crops can be grown satisfactorily. CCA can be:

> **Culturable Cultivated Area:** it is the area of the land on which cultivation practices are performed in the present time.
>
> **Culturable Uncultivated Area:** it is the area on which cultivation can be done if thought of it, but presently not cultivated for various reasons.

$$CCA = \{GCA - \text{Unculturable Area of GCA}\}$$

Intensity of Irrigation: it is the ratio of irrigated land at a time in one crop season to the culturable command area.

Rotation of Crops: it means that nature of the crop sown in a particular field is changed year afteryear.

Crop Ratio: it is the ratio of the areas under the crops of two main seasons.

Crop Season: it is part of the year during which a particular crop is grown.

Rabi Crop Season: are also known as winter crops. Normally these crops are sown in the monthof October and are harvested by the end of March.

Kharif Crop Season: are also known as monsoon crops. Normally these crops are sown in themonth of April and are harvested by the end of September.

Hot Weather Crops: these are the crops sown in February and harvested in May or June.

Dry Crops: these are the crops which are ordinarily grown without irrigation, but utilizing the moisture stored in the soil during rainy season.

Wet Crops: these are the crops which are grown with irrigation.

Cash Crops: these are the crops that can be encashed in the market.

Crop Period: it is the total time in days that has elapsed between the sowing of the crop and its harvesting. Hence crop period is the total time during which the crop remains in the field.

Base period: it is the total time in days between the first watering done for the preparation of the land sowing of a crop and the last watering done before its harvesting.

Overlap Allowance: it is possible that crops of one season may extend into the other season. Hence both the crops need water simultaneously. This extra discharge of water provided for this reason is known as overlap allowance.

Time Factor: it is the ratio of the number of days the canal has actually run to the number of days the canal was supposed to run for a particular period of watering as per calculations in the design.

Capacity Factor: it is the ratio of the average discharge of a canal at any point to the full supply discharge of the canal at the same point.

Berms: they are narrow strip of land left at the ground level between the inner toe of the bank and top edge of cutting.

Free Board: is the gap or the margin of height between FSL and top of the bank.

KENNEDY’S THEORY:

- The salient features of Kennedy’s theory for the design of earthen channels based on the critical velocity concept and its limitations.
- Kennedy selected a number of sites in upper Bari Doab canal system for carrying out investigations about velocity and depth of the channel.
- As the sites selected by him were more than thirty years old channel.
- As the sites selected by him were more than thirty years old they were assumed to be flowing with non-silting, non-scouring velocity.

Kennedy’s investigation revealed the following:

- The silt is kept in suspension due to eddies, also the silt supporting power is therefore proportional to the bed width of the stream and not it’s wetted perimeter.
- A velocity sufficient to generate these eddies keeps the sediment in suspension, thereby avoiding sitting up of the channel.
- He designated this velocity as the critical velocity [V_o] defined as the mean velocity which just keeps the channel free from silting and scouring.
- Hence established a relation between critical velocity to the depth of flowing water [y] as,

$$V_o = 0.55\, y^{0.64}$$

- However, Kennedy realized the importance of silt grade on critical velocity and introduce a factors m known as critical velocity ratio in equation there by it can be rewritten as,

$$V = 0.55\, m\, y^{0.64}$$

Where m = critical velocity = {V / V_o}

- Kennedy and Kutter’s equation for finding the mean velocity of flow (V).

$$V = \left\{\frac{23+\frac{1}{N}+\frac{0.00155}{S}}{1+\left[23+\frac{0.00155}{S}\right]+\frac{N}{\sqrt{R}}}\right\} \sqrt{RS}$$

Where

- N = Manning’s Rugosity Coefficient
- R = Hydraulic Radius = [Area / Wetted Perimeter]
- S = Longitudinal slope of the channel bed

Limitations of Kennedy’s Theory are:

- Limitations of Kutter’s equation become incorporated in Kennedy’s design procedure.
- Kennedy did not give any equation for the bed slope of the channel, it is decided and based on the slope of the ground available.

Design Procedure:

Case 1: given, discharge (Q), water surface slope (S), coefficient of rugosity (N) and critical velocity ratio (V_o).

Procedure:

- Assume a trail depth y.
- Calculate the velocity V_o for the formula, $V_o = 0.55\ y^{0.64}$.
- Calculate the area of cross section (A) from the continuity equation, $A = \{Q / V_o\}$.
- Calculate the bed width B from the relation, $A = By + ny^2$. Where the side slopes n is assumed as 0.5.
- Calculate the wetted perimeter P from the relation, $P = B + 2y \sqrt{(1 + n^2)}$ and hence calculate the hydraulic radius $R = \{A/P\}$.
- Calculate the mean velocity V from the Kutter’s formula.

$$V = \left\{\frac{23+\frac{1}{N}+\frac{0.00155}{S}}{1+\left[23+\frac{0.00155}{S}\right]+\frac{N}{\sqrt{R}}}\right\} \sqrt{RS}$$

- If the values of the velocities as given by equations are identical, then the assumed depth [y] is correct, otherwise the procedure has to be repeated.

Case 2: given, Q, N, m and B/y ratio form wood’s table.

Procedure:

- Calculate A in terms of y.

$$\text{Let } \{B/y\} = x \text{ therefore, } B = xy$$

$$A = By + ny^2 = xy^2 + \{y^2 / 2\}$$

$$A = y^2 (x + 0.5)$$

- Calculate the velocity V from the Kennedy’s equation, $V = 0.55\ m\ y^{0.64}$.
- Substituting the values of A and V in the continuity equation, calculate the value of y i.e.

$$Q = AV = y^2 (x + 0.5) \times 0.55\ m\ y^{0.64}$$

$$y = \left\{\frac{Q}{0.55\ m\ (x+0.5)}\right\}^{\frac{1}{2.64}}$$

- Knowing Y calculate the bed width B and the hydraulic radius R from the relations B = n y and R = {A / P}.
- Calculate the velocity from the Kennedy's equation, $V = 0.55\ m\ y^{0.64}$.
- Knowing V and R, determine the slope S from the Kutter's equation by trial and error.

$$V = \left\{\frac{23+\frac{1}{N}+\frac{0.00155}{S}}{1+[23+\frac{0.00155}{S}]+\frac{N}{\sqrt{R}}}\right\} \sqrt{RS}$$

Draw Backs of Kennedy's Theory:

Following are the draw backs of Kennedy's theory.

- It ignores the importance of bed width and depth ratio.
- The draw backs of Kutter's equation are reflected in the Kennedy's theory.
- Adaptation of an arbitrary N value of 0.0225 is incorrect.
- Kennedys' theory aims at the design of average regime channel.
- Kennedy has not given an equation for the slope.
- Silt concentration and bed load are not considered.
- Silt grade and silt charge is not defined.
- Kennedy's procedure is by trial and error only, which means for any value of y there can be number values of B, i.e. the channel need not be an economical section.
- Kennedy simply mentioned the critical velocity ratio (CVR) m, but did not give a procedure to measure it.

LACEY'S THEORY:

Regime Channel: according to Lacey a regime channel is a stable channel transporting a regime silt charge. A channel is said to be in regime if it flows in incoherent unlimited alluvium of the same character as that transported and the silt grade and silt charge are all constant.

Incoherent Alluvium: it is a loosely composed granular soil which can be scoured with the same ease with which it is deposited.

Regime Silt Charge: it is the minimum transported load consistent with fully active bed.

Regime Silt Grade: this indicates the range between the small and big particles.

Regime Conditions: an irrigation channel is said to be in regime when the following conditions are satisfied:

- The channel is flowing in unlimited incoherent alluvium of the same character as that transported.
- Silt grade and silt charge is constant.
- Discharge is constant.

If all the above conditions are completely satisfied the channel is said to be in true regime. However, in practice this is not possible.

Initial Regime: it is the state of the channel that has formed its section only and not yet secured the longitudinal slope.

Final Regime: it is the state of the channel after attaining its section and the longitudinal slope.

Permanent Regime: this is stage when the channel is protected on the bed and sides with protecting material, so that neither the cross section changes nor its longitudinal slope.

Design Procedure:

- Calculate the silt factor F from the equation, $F = 1.76 \sqrt{m}$, m = mean particle size in mm.
- Calculate the average velocity from the equation, $V = \{\frac{Qf^2}{140}\}^{\frac{1}{6}}$
- Calculate the area of cross section of the channel from the continuity equation, $A = \{Q / V\}$.
- Calculate the wetted perimeters of the channel from the equation, $P = 4.75 \sqrt{Q}$.
- Knowing A and P and assuming the side slopes of the channel as 0.5H to 1V, calculate the bed with (B) and depth of flow (y) from the relations
- $A = By + ny^2$ and $P = B + 2y$, n = 0.5 side slope
- Calculate the hydraulic radius, $R = \{A / P\}$.
- Also calculate the hydraulic radius R from the equation, $R = \{5 /2\} \times \{V^2 / f\}$.
- Calculate the bed slope S from the equation, $S = \{f^{5/3} / 3340\ Q^{1/6}\}$.

From the above procedure it is very clear that Lacey's method does not involve any trial and error procedure as in the case of Kennedy's theory.

Draw Backs of Lacey’s Theory:

Following are the draw backs of Lacey’s theory.

- The characteristics of regime channel are not precisely defined.
- The true regime conditions as given by Lacey are just theoretical and may not be achieved in practice.
- The value of silt factor f may be different for the bed and sides, hence the derivation of various equations by considering f alone is not satisfactory.
- Lacey’s theory does not consider the concentration of silt.
- According to Lacey’s a regime channel is inherently free from external shock, however a regime channel carries sediment and will normally have a changing pattern of bed ripple transportations, this statement is unlikely to be correct.
- Silt charge and silt grade are not properly defined by Lacey.
- Lacey’s equations do not include silt charge.
- Lacey indicate that a true regime channel has a semi elliptical section but it is not supported by any equations.
- The values of f obtained from various equations of Lacey are often divergent.
- Lacey’s equations are empirical, hence the constants are to be determined for different conditions of the channel.

COMPARISON BETWEEN LACEY’S THEORY AND KENNEDY’S THEORY:

Kennedy’s Theory	Lacey’s Theory
There can be many sections for a given discharge.	Only one regime section is possible for a given discharge and silt factor.
Kennedy simply stated CVR but did not give any method to measure CVR.	Lacey introduce the silt factor f and correlated silt factor to the diameter of silt and rugosity coefficient.
Kennedy did not give any equation for regime velocity, he has adopted Kutter’s equation, and hence any limitations of these equations are reflected in the Kennedy’s theory.	Lacey has given a definite equation for calculating the velocity.
Kennedy considered depth as variable and gave critical velocity formula in terms of the depth y.	Lacey has considered hydraulic mean radius R as the variable and derived velocity formula in terms

	of R.
Kennedy did not specify regime slope.	Lacey specified regime slope for the given discharge and silt factor.
Basic theoretical conception of silt transportation is same as that of Lacey. The eddies generated from the sides are ignored.	Theoretical conception of silt transportation is that silt is kept in suspension by vertical components of eddies caused by friction against wetted perimeter.
Kennedy considered channel section as trapezoidal.	Lacey considered the channel to be semi elliptical.
Section is wider and shallower.	Section is tighter and deeper.
According to Kennedy channels are said to be in regime when they neither silt nor scour.	Lacey considered that channels cannot be in true regime and hence classified them into initial and final regime.
Kennedy did not consider the importance of bed width and depth ratio and has just selected these values from wood's table.	Lacey has given a definite formula for the wetter perimeter for a given discharge.
Kennedy's theory is applicable to irrigation channels only.	Lacey's theory is applicable to irrigation channels as well as rivers.

Lacey's theory has the following additional merits:

- It is more rational as it gives more quantitative relation between discharge, grain size and coefficient of rugosity.
- There is only one canal section, wetted perimeter and hydraulic radius for a given discharge slope and silt factor.
- It does not involve any trial and error procedure.
- Specified separate design equations for perfect regime.

RESERVOIRS:

Introduction:

Construction of a dam, barrage across a river results is the formation of a reservoir, which is nothing but huge storage of water. This water is stored during the period when the inflow is in excess of the demand on the downstream side. The water stored may be used for irrigation, hydroelectric power, domestic usage, industrial usage, recreation and so on. Apart from the said factors a reservoir helps in controlling the floods, improvement in climate, reduction in river pollution, check on spread of diseases due to improved water supply and sanitation. Finally reduction in the river section of river cross section thereby considerable area is made available for cultivation. On the other hand formation of a reservoir would have disadvantages like: submergence of fertile lands, displacement of large population, possible advice effects on the ecology of the area, entrapping of fertile sand and displacement of wild life.

Definition:

A reservoir is a large body of water stored on the upstream side of a dam constructed across a river. Therefore, a reservoir and a dam exist together.

CLASSIFICATION OF RESERVOIRS:

Depending upon the purpose served, reservoir may be classified as.

Storage Reservoir:

- A storage reservoir also known as conservation reservoir, mainly servers the purpose of conserving water.
- Essentially water is stored during monsoon and released gradually for intended purpose like irrigation, water supply or hydropower.
- Such a reservoir also helps in moderating the floods and reducing the flood damage to a certain extent.
- However, it is not designed as a flood control reservoir.

Flood Control Reservoir:

- A flood control reservoir serves the purpose of flood controlling by protecting the areas on the downstream side.
- It is also known as flood mitigation reservoir or flood mitigation or flood protection reservoir.
- Flood water from this type of reservoir is discharges or let out till the outflow reaches the safe capacity of the channel.
- When once the safe capacity is exceeded flood water is stored in the reservoir.
- This type of reservoir is therefore designed to moderate the flood and not to conserve water.

Multipurpose Reservoir:

- A multipurpose reservoir is designed and constructed to serve more than one purpose.
- Most of the reservoirs are multipurpose reservoirs.

Distribution Reservoir:

- A distribution reservoir is a small storage reservoir which helps in storing water during period of lean demand and supplies during the period of high demand.
- Such type of reservoir so as take care of water supply for irrigation.

Balancing Reservoir:

- A balancing reservoir is a small reservoir constructed downstream of the main reservoir so as to store water released from the main reservoir.

INVESTIGATION FOR RESERVOIR:

Following are the investigations that are usually conducted for reservoir planning.

Engineering Investigations / Surveys:

- Generally engineering surveys are conducted for the dam, the reservoir and their associated works.
- During this investigation topographic survey of the area is carried out and the contour plan is prepared.
- The horizontal control is usually provided by triangulation survey and vertical control by precise levelling.
- A the **dam site,** very accurate triangulation survey is conducted and a contour plan to a scale of 1:250 or 1:500 is generally prepared with contour intervals in the range of 1 to 2 m.
- Such a survey should cover an area up to 200m upstream, 400m downstream and for adequate width beyond the two abutments.
- For a **reservoir,** the contour plan is generally prepared to a scale of 1:15,000 with contour intervals between 2 to 3 m.
- The area – elevation and storage – elevation curves are prepared for different elevations up to an elevation of 3 to 5 m higher than the anticipated maximum water level.

Geological Investigations:

Following are the reasons for carrying out the geological investigations at a reservoir site.

- Suitability of foundation for the dam.
- Water tightness of the reservoir basis.
- Location of quarry sites for the construction.

Hydrological Investigations:

Following purpose demand the hydrological investigations.

- To study the runoff pattern and to estimate yield.
- To determine the maximum discharge at the site.

SELECTION OF SITE FOR A RESERVOIR:

A good site for a reservoir should have the following characteristics.

Large Storage Capacity: the topography of the proposed site should be such that the reservoir has large capacity for storing the water.

Suitable Site for the Dam: a suitable site for the proposed dam should be available on the downstream side of the reservoir, with very good foundation, narrow opening in the valley to provide minimum length of the dam and also the cost of construction should be minimum.

Water Tightness of the Reservoir: geology at the proposed reservoir site should be such that the entire reservoir basin is water tight. They should have granite, gneiss, schists, slates or shales etc.

Good Hydrological Conditions: the hydrological conditions of the river at the reservoir should give high yield. Evaporation, transpiration and percolation losses should be minimum.

Deep Reservoir: the proposed site should be such that a deep reservoir is formed after the dam construction. The reason being evaporation losses would be minimum, in addition to low cost of land acquisition and less weed growth.

Small Submerged Area: at the proposed site, the submerged area should be minimum and should not affect the ecology of the area. Important places, monuments, roads, railway lines should not submerge.

Minimum Silt Inflow: the life of reservoir is defined by the quantity of silt inflow, which menas that, if the silt inflow is large, the life would be less. Hence it is necessary to select the reservoir site at such a place, where the silt inflow is minimum.

No Objectionable Minerals: the proposed site should be free from soluble and objectionable salts, which may pollute the reservoir.

Minimum Acquisition and Construction Cost: the overall cost of the project should be minimum in terms of dam construction, land acquisition for reservoir, buildings, roads, railways etc.

STORAGE ZONES OF A RESERVOIR:

Based on relative water levels, the storage zones of a reservoir are represented in figure they are.

Live Storage or Useful Storage: is that amount of water available or stored between the minimum pool level (LWL) and the full reservoir level (FRL). Minimum pool level or low water level is fixed after considering the minimum working head required for the efficient working of turbines.

Surcharge Storage: is the volume of water stored above the full reservoir level (FRL) up to the maximum water level (MWL).

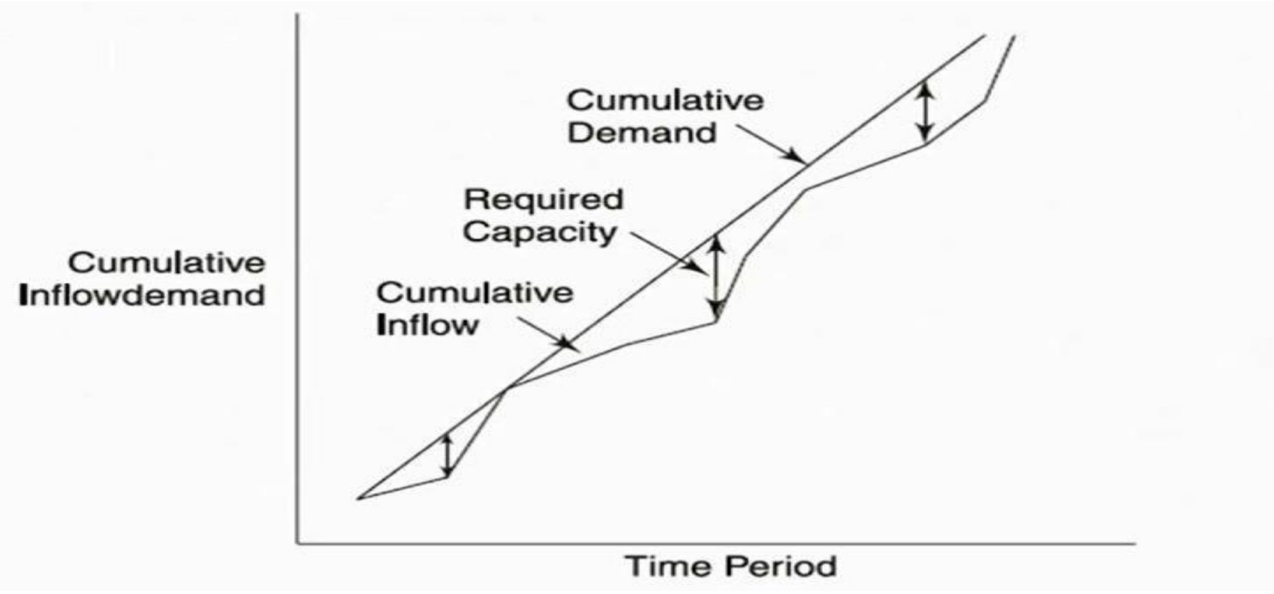
Dead Storage: is the volume of water held below the minimum pool level. This storage is not useful and hence cannot be used for any purpose under ordinary operating conditions.

Bank Storage: water stored in the banks of a river is known as bank storage. In most of the reservoirs the bank storage is small since the banks are generally impervious.

Valley Storage: is the volume of water held by the natural river channel in its valley up to the top of its banks before the construction of the reservoir.

MASS CURVE:

Mass curve is a graphical representation of cumulative volume of water in the reservoir versus cumulative time. It will be a continuously raising curve as shown in figure.



FIXING CAPACITY OF A RESERVOIR:

Capacity of a reservoir depends on the inflow and demand. It is fact that if the available inflow is more than the demand, there is no necessity of any storage. On the other hand, if the inflow is less and demand is high a large reservoir capacity is required. Capacity for a reservoir can be determined by the following methods:

Mass Curve or Graphical Method:

The procedure adopted will be as follows.

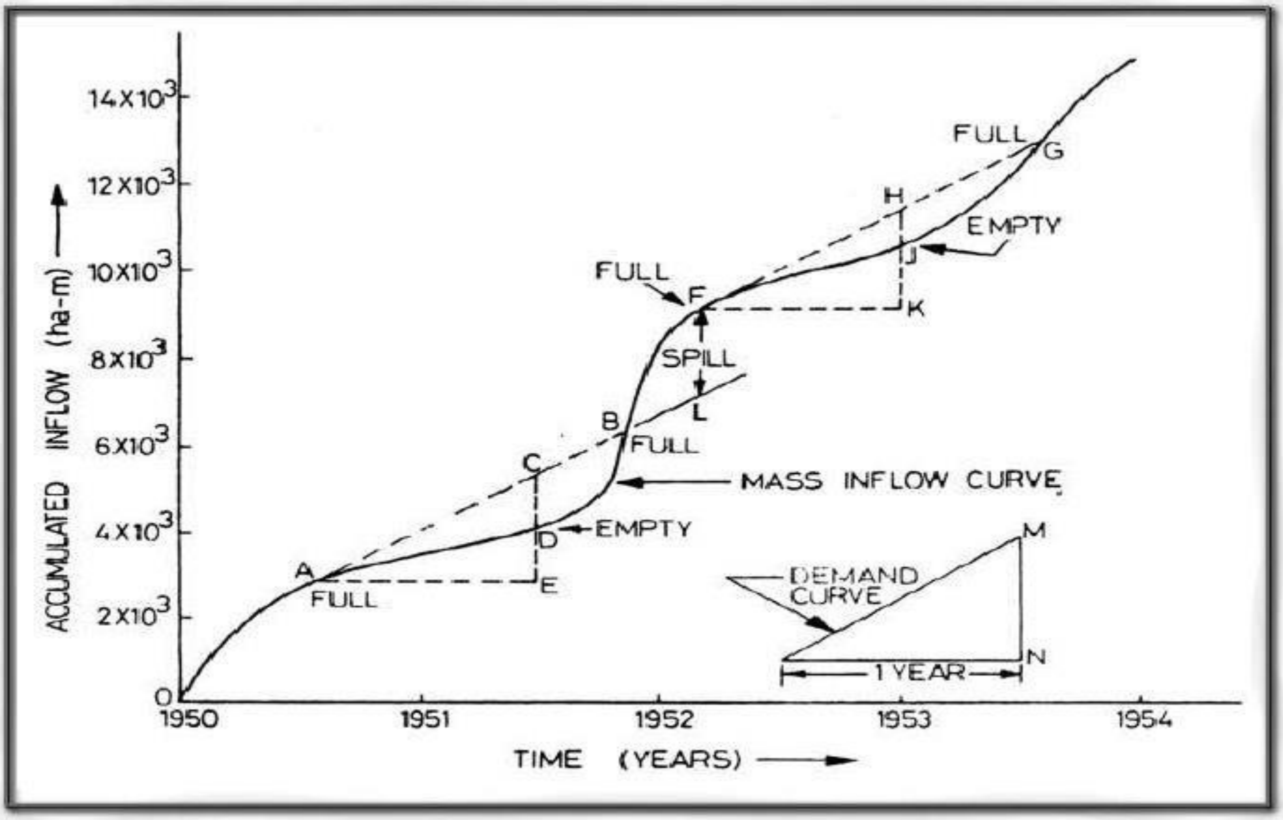
- Prepare the mass inflow curve for the flow hydrograph of the site for a number of consecutive years including the most critical years i.e., when the discharge is low. Figure shows the mass inflow curve.
- Prepare the mass demand curve corresponding to the given rate of demand. If the rate of demand is constant, the mass demand curve is a straight line as shown in figure. The scale selected for plotting of the mass inflow and mass demand curve should be the same.
- Draw the lines AB, FG etc. such that they are parallel to the mass demand curve and they are tangential to the peak points or crest at A, F etc. of the mass inflow curve points A, F etc. indicate the beginning of dry periods marked by the depressions.
- Determine the vertical intercepts CD, HJ etc. between the tangential lines and the mass inflow curve. These intercepts indicate the volumes by which the inflow volumes fall short of demand, which can be explained as follows:

  Assuming that the reservoirs is full at point A, the inflow volume during the period AE is equal to ordinate DE and the demand is equal to ordinate CE. Thus the storage required is equal to the volume intercepted by the intercept CD.
- Determine the largest of the vertical intercept determined in step 4. The largest vertical intercept represents the storage capacity required.

Following important points have to be noted:

- The capacity obtained in the net storage capacity which must be available to meet the demand. The gross capacity of the reservoir will be more than the net storage capacity. It is obtained by adding the evaporation and seepage losses to the net storage capacity.

- The tangential lines AB, FG etc. when extended forward must interest the inflow curve. This is necessary for the reservoir to get filled again. If these lines do not intersect the mass curve, the reservoir would not fall again. Many times very large reservoir may not get refilled every year.
- The vertical distance such as FL between the successive tangents represent the volume of water flowing over the spillway.

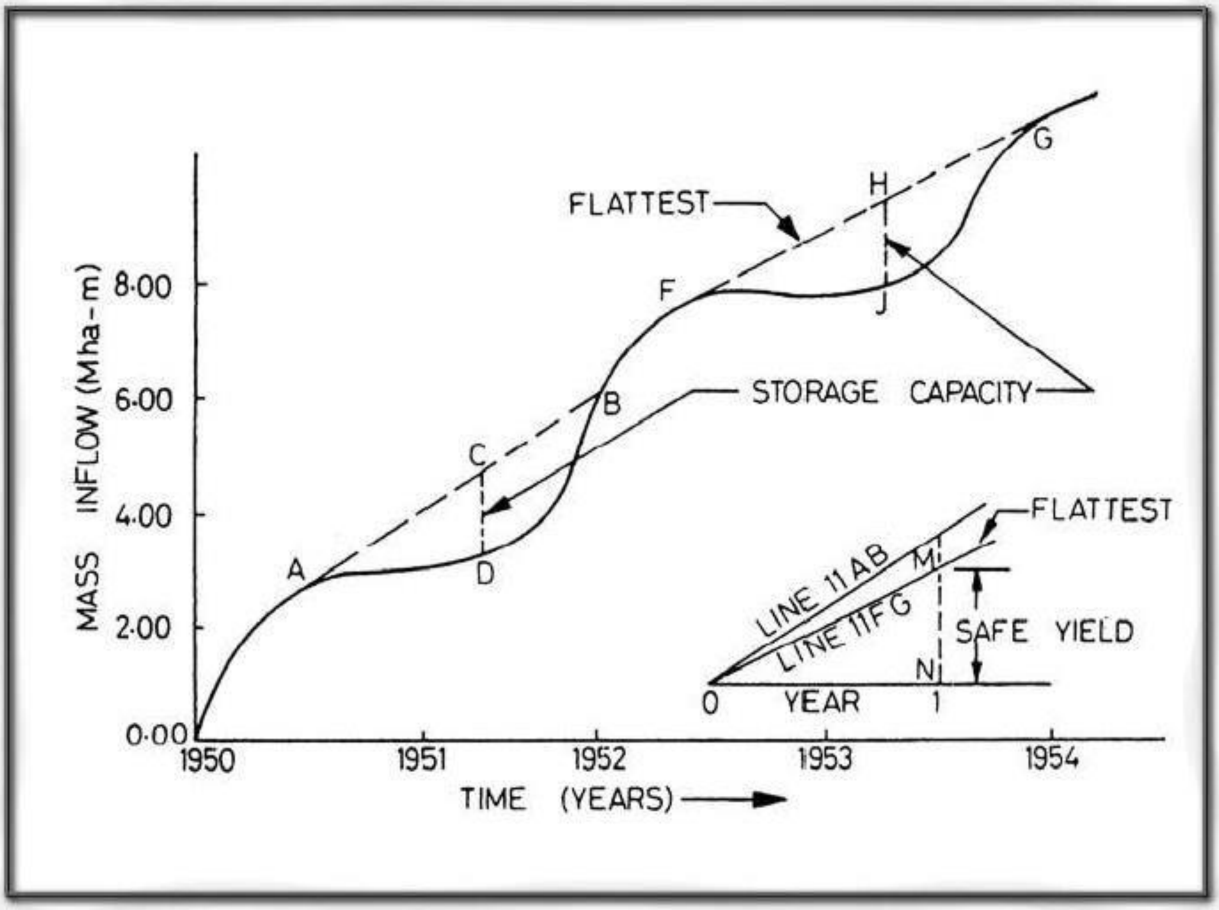


Determination of Yield of a Reservoir:

Determination of yield from a reservoir of known capacity can be done by using the mass inflow curve. This method is just the reverse of the method of determining the reservoir capacity. The procedure for determining the reservoir yield is as follows:

- Prepare the mass inflow curve from the flow hydrograph of the river and shown in figure.
- Draw tangents AB, FG etc. at the crest A, F etc. of the mass inflow curve in such a way that the maximum slope (intercept) of these tangents from the mass inflow curve is equal to the capacity of the reservoir.
- Measure slopes of all tangents drawn in the previous step and determine the slope of the flattest tangent.

- Draw the mass demand curve from the slope of the flattest tangent as shown in figure. The yield is equal to the slope of this line.



Analytical Method for Determination of Storage Capacity:

Following analytical procedure is adopted in determining the storage capacity of a reservoir.

- The stream flow data at the reservoir site is collected during dry period (month wise). In case of very large reservoir annual inflow rates may be used.
- The discharge to be released on to the downstream side in order to meet the water requirements is estimated.
- The direct precipitation falling on the reservoir is calculated month wise.
- The evaporation losses from the reservoir is estimated by a suitable method.
- The monthly demands are estimated.
- The adjustable inflow during different months are calculated as follows:

  Adjustable inflow = {Stream flow + Precipitation – Evaporation – Downstream Discharge}
- The monthly storage capacity is computed:

Storage required = {Adjustable Inflow – Demand}

- The storage capacity of the reservoir would be the sum of all the storages determined in the previous step.

ECONOMIC HEIGHT OF DAM:

- Economic height of a dam can be theoretically defined as that height for which the cost of the dam per million cubic meter of storage is minimum.
- The height of the dam is determined by preparing approximate estimate of cost of several heights of dam at a given site, somewhat above and below the level, where the elevation storage curve shows a fairly high rate of increase of storage per meter of elevation, while at the corresponding elevation the cross section of the dam site shows the length of the dam to be moderate.
- When once the approximate cost per million cubic meter of storage for about five or six alternatives, the cost per million cubic meter of storage is plotted against height to determine the most economical height of the dam.

RESERVOIR SEDIMENTATION:

Sedimentation of a reservoir is a major problem all over the world and no economical solution is proposed to overcome this problem, expect providing a dead storage for accommodating the sediments. The mean reason for sedimentation are disintegration, erosion, transpiration and sedimentation.

Mechanism of Reservoir Sedimentation:

- Reservoir sedimentation is almost similar to those in delta made by a river, before joining the sea or ocean.
- The bottom layers comprise of fine sediments, next layer of coarser sandy sediments with the top most layers consisting of coarser particles.
- Sediment is a product of erosion in the catchment area of the reservoir and hence the rate of erosion smaller would be the sediment load entering the reservoir.

Factors Affecting Sedimentation:

- Extent of catchment area.
- Amount of sediment load in the river.
- Type of rainfall and snow fall.
- Mean monthly and annual temperature.

- Monthly and annual rainfall from the catchment or sub catchment.
- Slope of catchment.
- Vegetation of catchment.
- Geological formations of the catchment.
- Presence of upstream reservoir and the extent of trapping of sediment there in.
- Quantity of sediment flushed through sluices.
- Degree of consolidation of the accumulated sediment due to weathering.
- Operation schedule of the reservoir.