WATER RESOURCES ENGINEERING

Course code:ACE014

III. B.Tech II semester

Regulation: IARE R-16

BY

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CO's	Course outcomes
CO1	Understand the basic knowledge of hydrology, hydrological cycle, precipitation and movement of water on earth and below the earth surface in addition to importance and estimation of runoff
CO2	Determining the importance of different types of hydrographs.
CO3	Importance and occurrence of Ground water, estimation of discharge through various types of aquifers, wells development

COs	Course Outcome
CO4	Analyze the importance of irrigation and their types, methods of application of irrigation water, duty and delta, irrigation efficiencies, water logging.
CO5	Understand the classification of canals, design of irrigation canals, IS standards for a canal design canal lining, SCS curve number method, flood frequency analysis of stream flow.

UNIT– I
INTRODUCTION TO ENGINEERING HYDROLOGY AND ITS APPLICATIONS

CLOs	Course Learning Outcome
CLO1	Understand the basic concepts of Hydrology and its applications. And also understand different forms and types of precipitation.
CLO2	Understand the basic concepts of Hydrology and its applications. And also understand different forms and
CLO3	Compute the average rainfall over a basin, processing of rainfall data, and adjustment of rainfall record and usage of double mass curve.
CLO4	Understand the concepts of runoff, factors affecting runoff, runoff over a catchment, empirical and rational formulae.

CLOs	Course Learning Outcome
CLO5	Understand the abstraction from rainfall, evaporation, factors affecting evaporation, measurement of evaporation, evapo-transpiration,penman and Blaney-Criddle methods and infilteration

Definition of hydrology:

- The study of water in all its forms (rain, snow and water on the earth's surface), and from its origins to all its destinations on the earth is called hydrology.

Scope of Hydrology

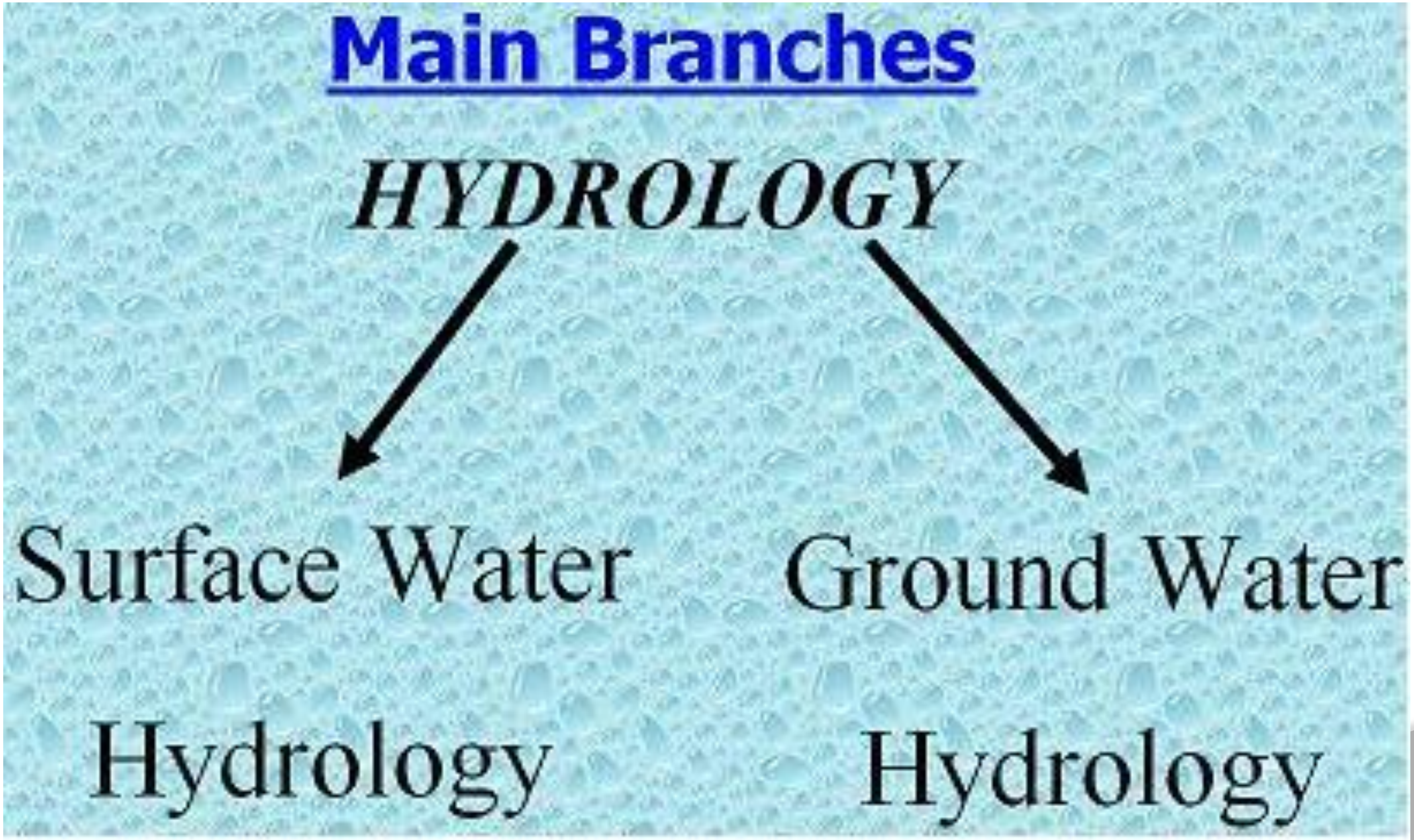
- Water is one the most valuable natural resources essential for human and animal life, industry and agriculture.
- It is also used for Power generation, navigation and fisheries.
- Tremendous importance is given to the hydrology all over the world in the development and management of water resources for irrigation, water supply, flood control, water-logging and salinity control, Hydro power and navigation.

Applications:

- Hydrology is used to find out maximum probable flood at proposed sites . E.g. Dams.
- The variation of water production from catchments can be calculated and described by hydrology.
- Engineering hydrology enables us to find out the relationship between a catchments' surface water and groundwater resources
- The expected flood flows over a spillway, at a highway Culvert or in an urban storm drainage system can be known by this very subject.
- It helps us to know the required reservoir capacity to assure adequate water for irrigation or municipal water supply in droughts condition.

- It tells us what hydrologic hardware (e.g. rain gauges, stream gauges etc) and software (computer models) are needed for real-time flood forecasting.
- Used in connection with design and operations of hydraulic structure and also used in prediction of flood over a spillway, at highway culvert or in urban storm drainage.
- Used to assess the reservoir capacity required to assure adequate water for irrigation or municipal water supply during drought.
- Hydrology is an indispensable tool in planning and building hydraulic structures. Hydrology is used for city water supply design which is based on catchments area, amount of rainfall, dry period, storage capacity, runoff evaporation and transpiration.
- Dam construction, reservoir capacity, spillway capacity, sizes of water supply pipelines and affect of afforest on water supply schemes, all are designed on basis of hydrological equations.

BRANCHES OF HYDROLOGY



HYDROLOGICAL CYCLE

- The hydrologic cycle describes the **continuous re-circulating** transport of the waters of the earth, linking atmosphere, land and oceans.
- Hydrological cycle is the cyclic movement of water containing basic continuous processes like evaporation, precipitation and runoff as Runoff –> Evaporation –> Precipitation –> Runoff. This is a continuous cycle which starts with evaporation from the water bodies such as oceans.
- Water evaporates from the ocean surface, driven by energy from the **Sun**, and joins the atmosphere, moving inland as clouds. Once inland, atmospheric conditions act to condense and precipitate water onto the land surface, where, driven by **gravitational forces**, it returns to the ocean through river and streams.
- The process is quite **complex**, containing many sub-cycles.
- Engineering Hydrology takes a **quantitative** view of the hydrologic cycle.

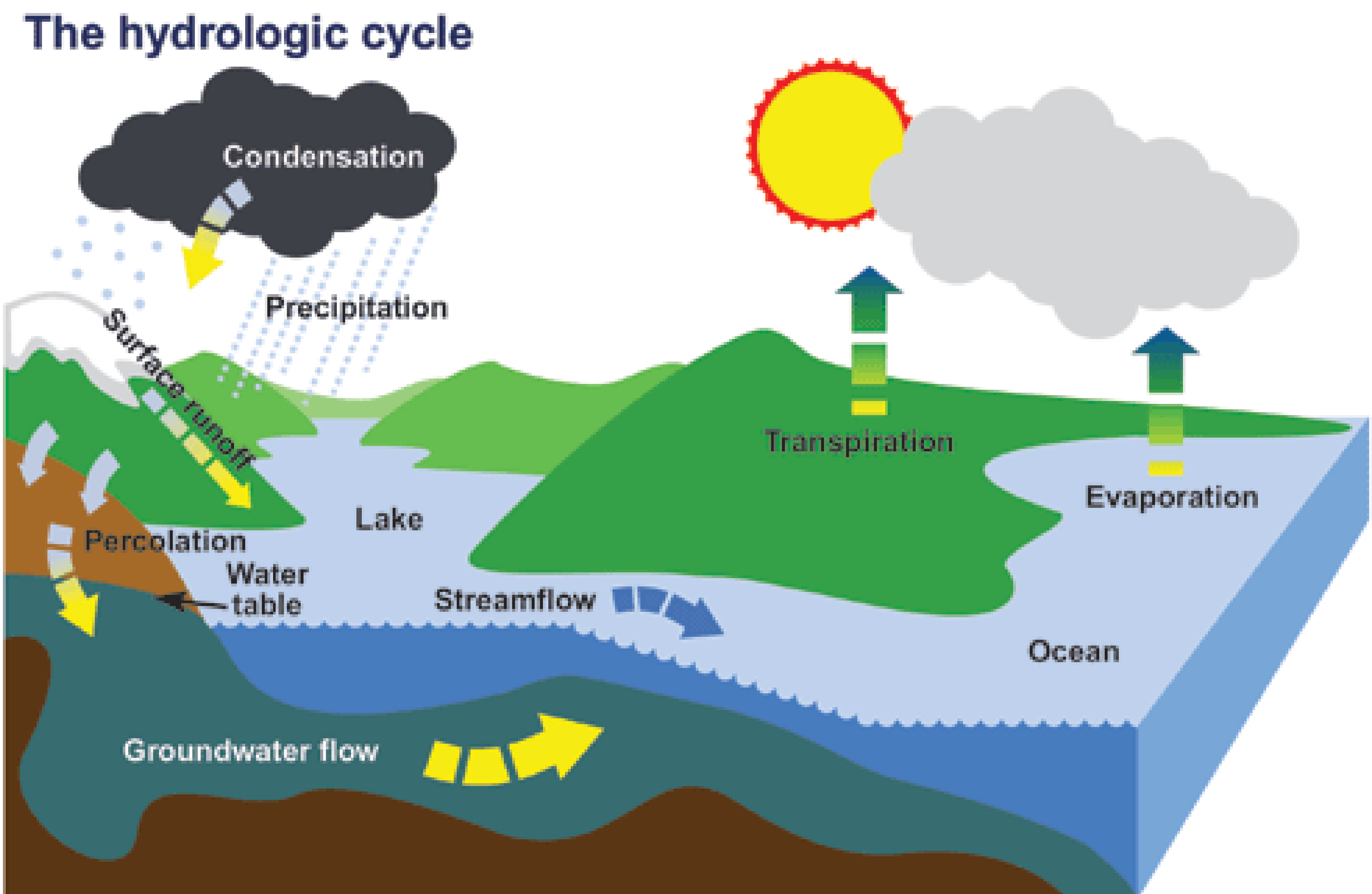
HYDROLOGICAL CYCLE

✓ The quantification of the hydrologic cycle which is an open system can be represented by a **mass balance equation**, where inputs minus outputs are equal to the change in storage.

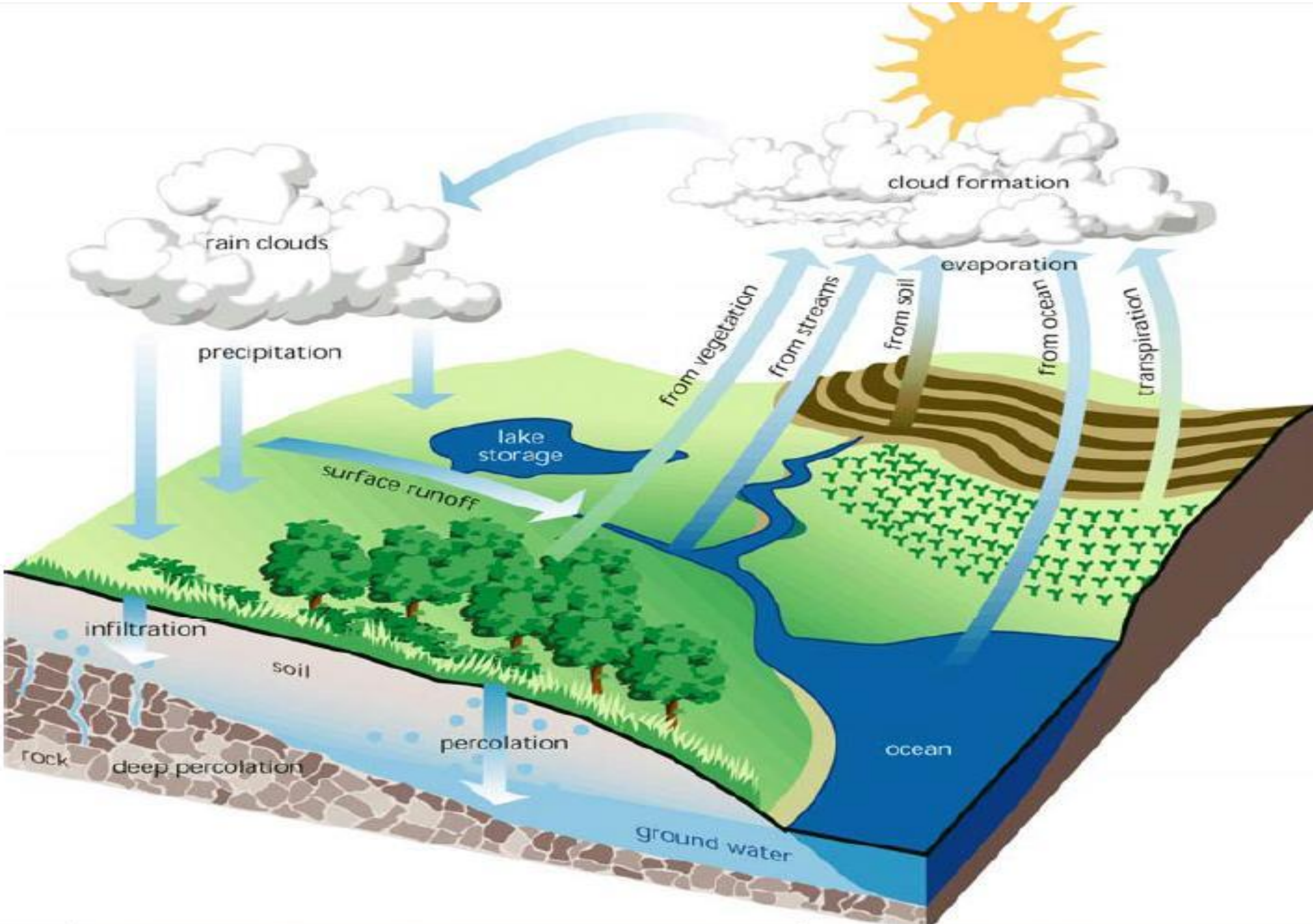
The water holding elements of the hydrological cycle are:

- Atmosphere
- Vegetation
- Snow packs
- Land surface
- Soil
- Streams, lakes and rivers
- Aquifers
- Oceans

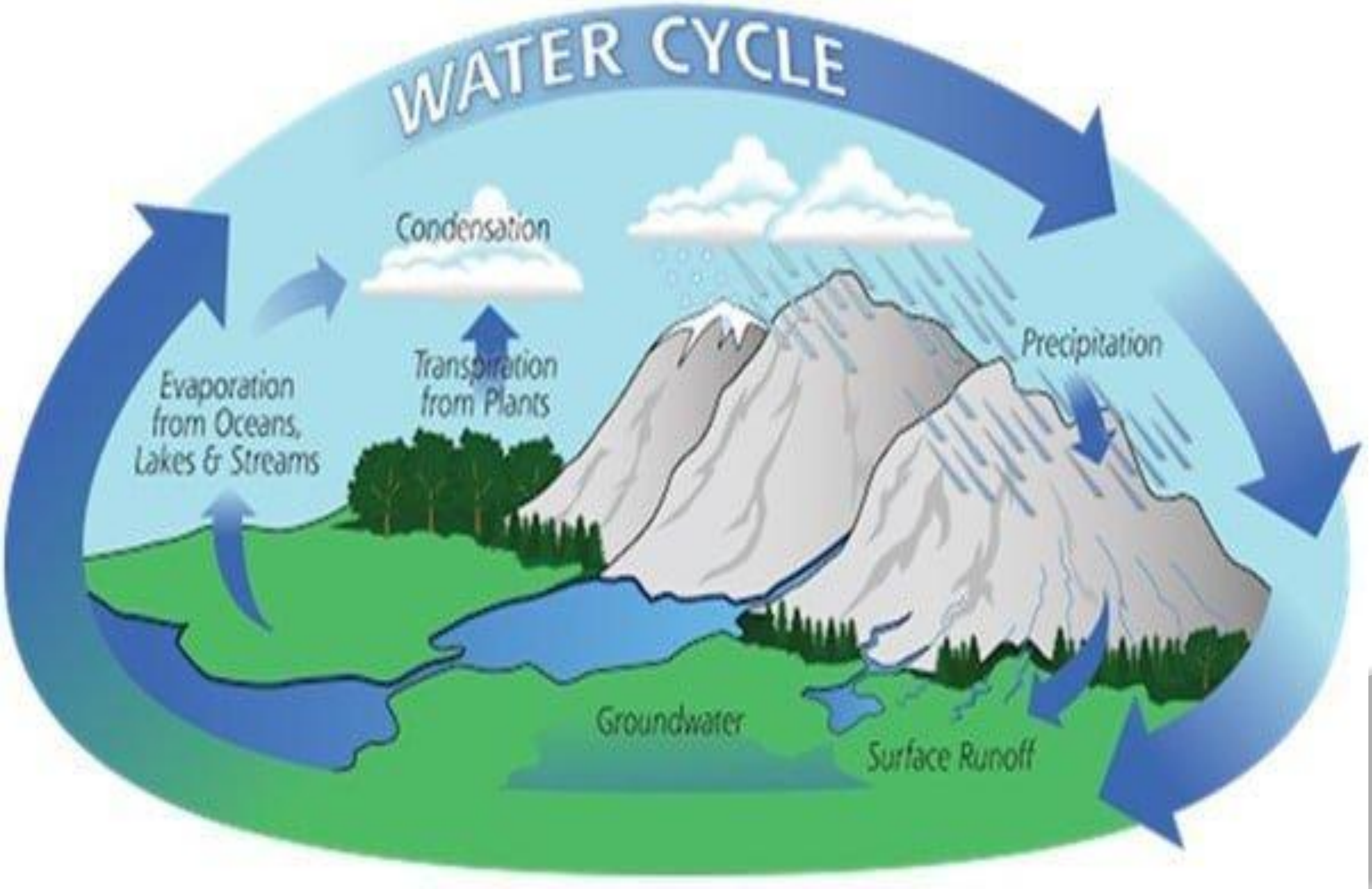
HYDROLOGICAL CYCLE



HYDROLOGICAL CYCLE



HYDROLOGICAL CYCLE



COMPONENTS OF HYDROLOGICAL CYCLE

1. **Runoff:** It is the water flowing over the land making its way towards rivers, lakes, oceans etc. as surface or subsurface flow.
   - **Surface runoff**: it is the running water over the land and which ultimately discharge water to the sea.
   - **Subsurface runoff**: The water getting infiltrated into pervious soil mass, making its way towards rivers and lakes can be termed as subsurface runoff.
2. **Precipitation**

   It is the fall of moisture from atmosphere to the earth's surface in any form. Example: rain, hail, snow, sleet, glaze, drizzle, snowflakes.
3. **Evaporation**

   It is the conversion of natural liquids like water into gaseous form like air.
4. **Condensation**

   It is the conversion of a vapor or gas to a liquid.

COMPONENTS OF HYDROLOGICAL CYCLE

5. **Transpiration:**

It is the evaporation taking place from any plant or greenery. Example, water droplet on a leaf getting evaporated into atmosphere.

6. Evapotranspiration

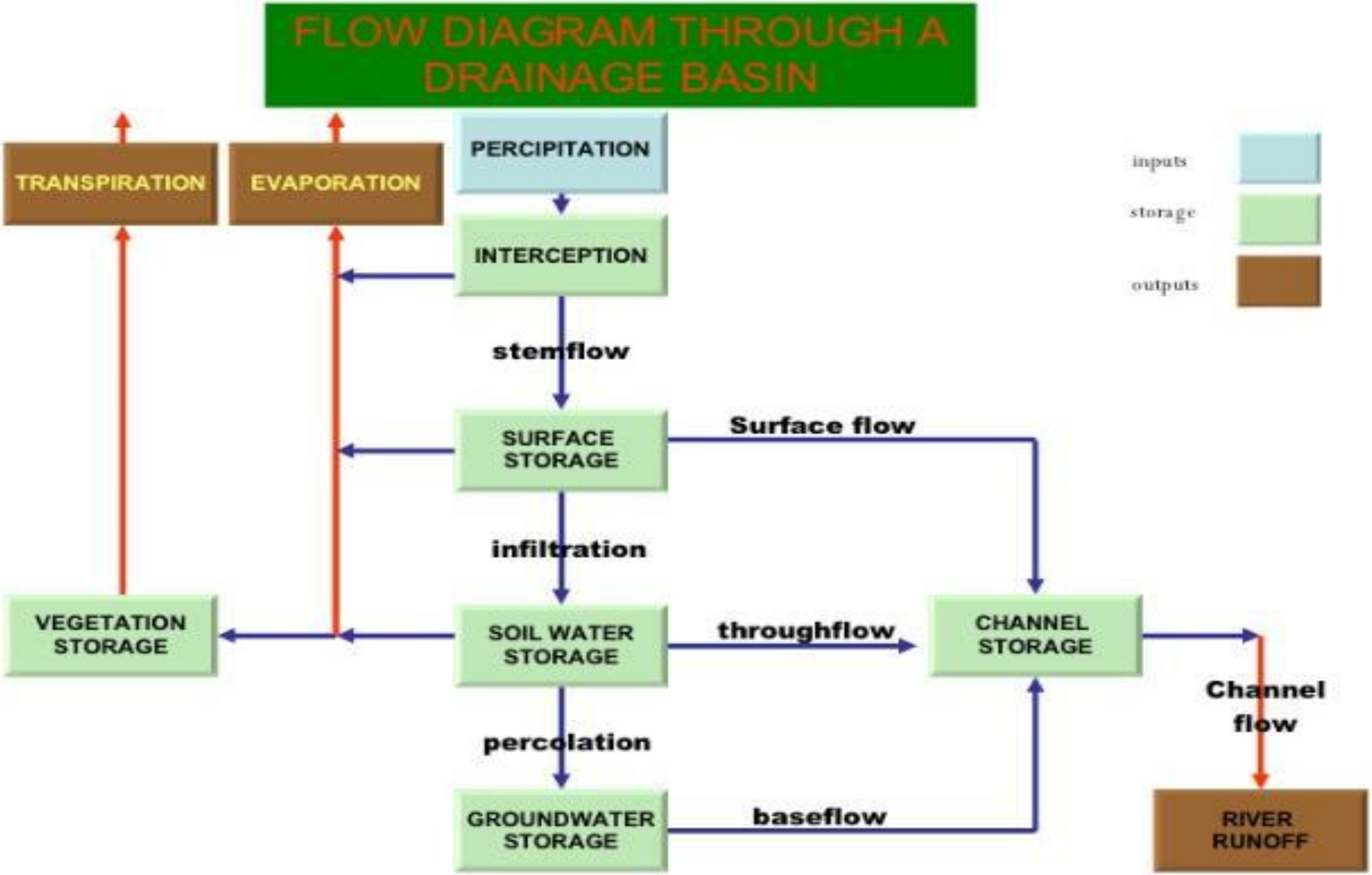
It is the combination of evaporation and transpiration.

7. Infiltration

It is the process of filtration of water to the inner layers of soil based on its structure and nature.

Pervious soils go through more infiltration than impervious. Infiltration in soils like sand, gravel and coarser material is more and for finer soil particles like clay and silt, infiltration is less.

HYDROLOGICAL CYCLE



PRECIPITATION

Definition:

Any form of moisture reaching the earths surface from the atmosphere is called precipitation. The types of precipitation are described below.It is one of major part in the hydrology cycle. There are three classification of rain based on the intensity of rain.

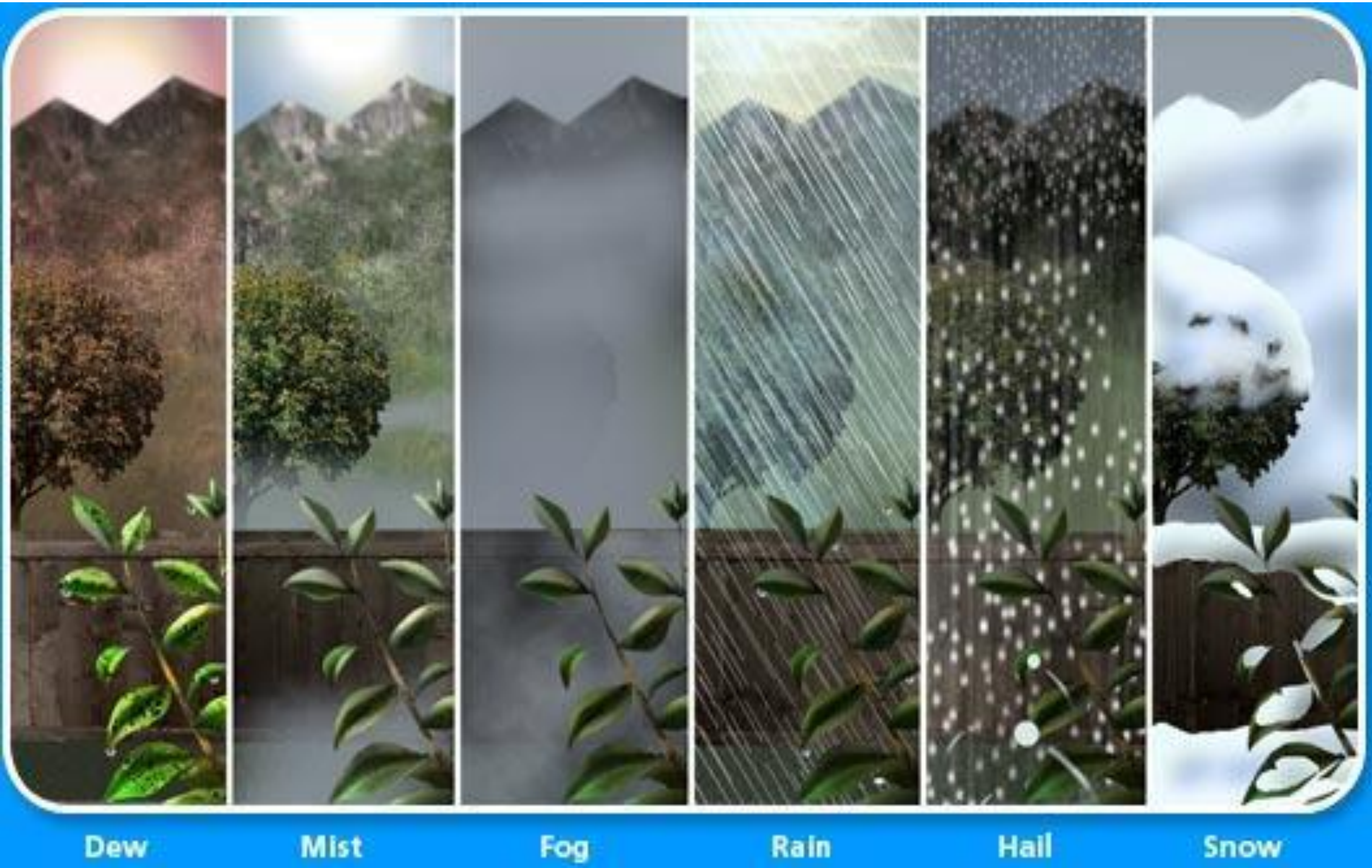
- Rainfall with an intensity of 2.5mm per hour is called light rain
- Rainfall with an intensity between 2.5mm per hour and 7.5mm per hour is called as moderate rain
- Rainfall exceeds 7.5mm per hour is called ad heavy rain
- Precipitation is measured by an instrument called rain gauge which is also known as hyetometer, Ombrometer or pluviometer.

Forms of precipitation:

The forms of precipitation are

- **Drizzle**: It is fine sprinkle of numerous water droplets of size less than 0.5mm and intensity less than 1.5mm/hr.
- **Rain**: It is used to describe precipitation in the form of water drops of sizes in the range of 0.5mm to 6mm.
- **Glaze**: When rain or drizzle comes in contact with cold ground at around 0° C, the water drop freezes to form an ice coating called as Glaze.
- **Sleet**: It is frozen raindrops of transparent grains which forms when rain falls through air at subfreezing temperature.
- **Snow**: The water vapour when directly changed to ice is known as snow.
- **Hail**: It is a showery precipitation in the term of ice of size more than 8mm.
- **Dew-** It forms directly by condensation on the ground mainly during the night when the surface has been cooled by outgoing radiation.

PRECIPITATION



PRECIPITATION

Type	Approximate Size	State of Water	Description
Mist	0.005 to 0.05 mm	Liquid	Droplets large enough to be felt on the face when air is moving 1 meter/second. Associated with stratus clouds.
Drizzle	Less than 0.5 mm	Liquid	Small uniform drops that fall from stratus clouds, generally for several hours.
Rain	0.5 to 5 mm	Liquid	Generally produced by nimbostratus or cumulonimbus clouds. When heavy, size can be highly variable from one place to another.
Sleet	0.5 to 5 mm	Solid	Small, spherical to lumpy ice particles that form when raindrops freeze while falling through a layer of subfreezing air. Because the ice particles are small, any damage is generally minor. Sleet can make travel hazardous.
Glaze	Layers 1 mm to 2 cm thick	Solid	Produced when supercooled raindrops freeze on contact with solid objects. Glaze can form a thick coating of ice having sufficient weight to seriously damage trees and power lines.
Rime	Variable accumulations	Solid	Deposits usually consisting of ice feathers that point into the wind. These delicate frostlike accumulations form as supercooled cloud or fog droplets encounter objects and freeze on contact.
Snow	1 mm to 2 cm	Solid	The crystalline nature of snow allows it to assume many shapes, including six-sided crystals, plates, and needles. Produced in supercooled clouds where water vapor is deposited as ice crystals that remain frozen during their descent.
Hail	5 mm to 10 cm or larger	Solid	Precipitation in the form of hard, rounded pellets or irregular lumps of ice. Produced in large convective, cumulonimbus clouds, where frozen ice particles and supercooled water coexist.
Graupel	2 mm to 5 mm	Solid	Sometimes called "soft hail," graupel forms as rime collects on snow crystals to produce irregular masses of "soft" ice. Because these particles are softer than hailstones, they normally flatten out upon impact.

Types of precipitation:

1. **Frontal precipitation:**

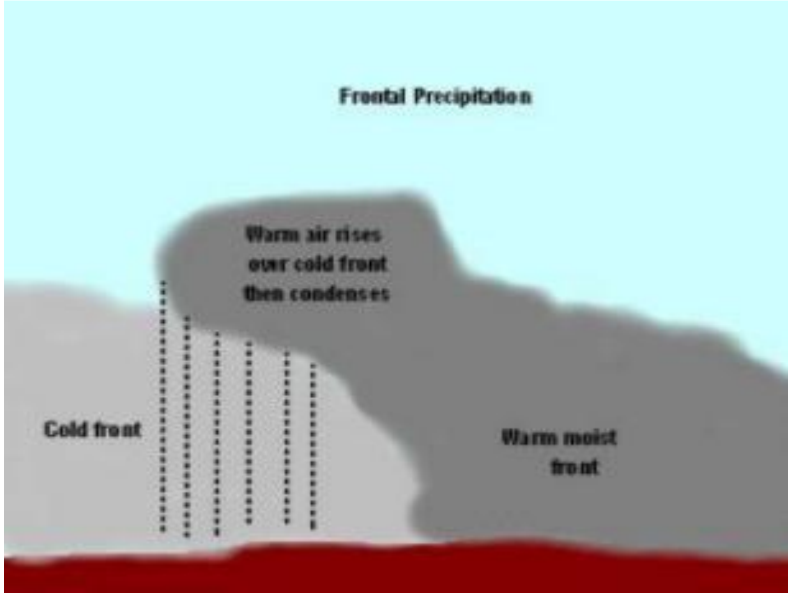
This is the precipitation that is caused by the expansion of air on ascent along or near a frontal surface.

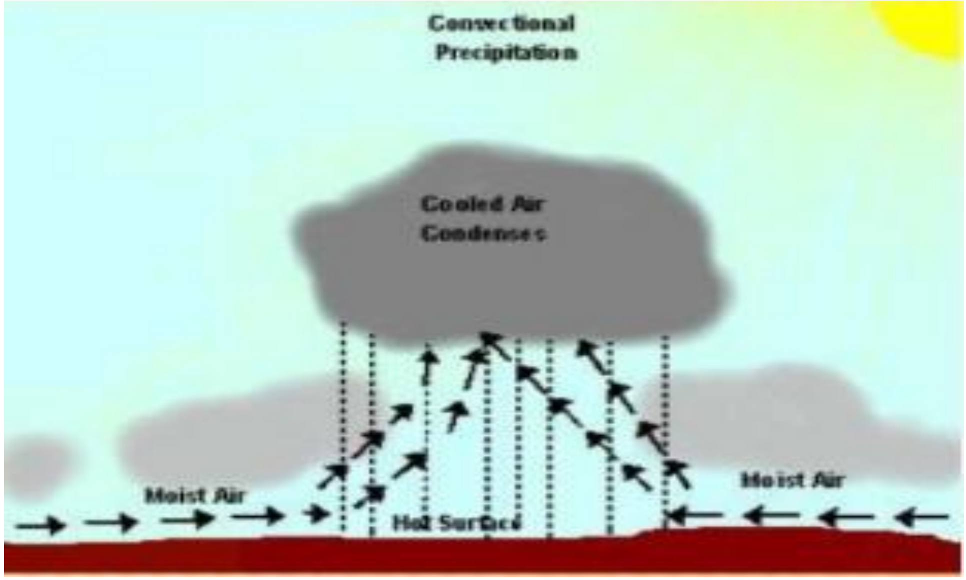
2. **Convective precipitation:**

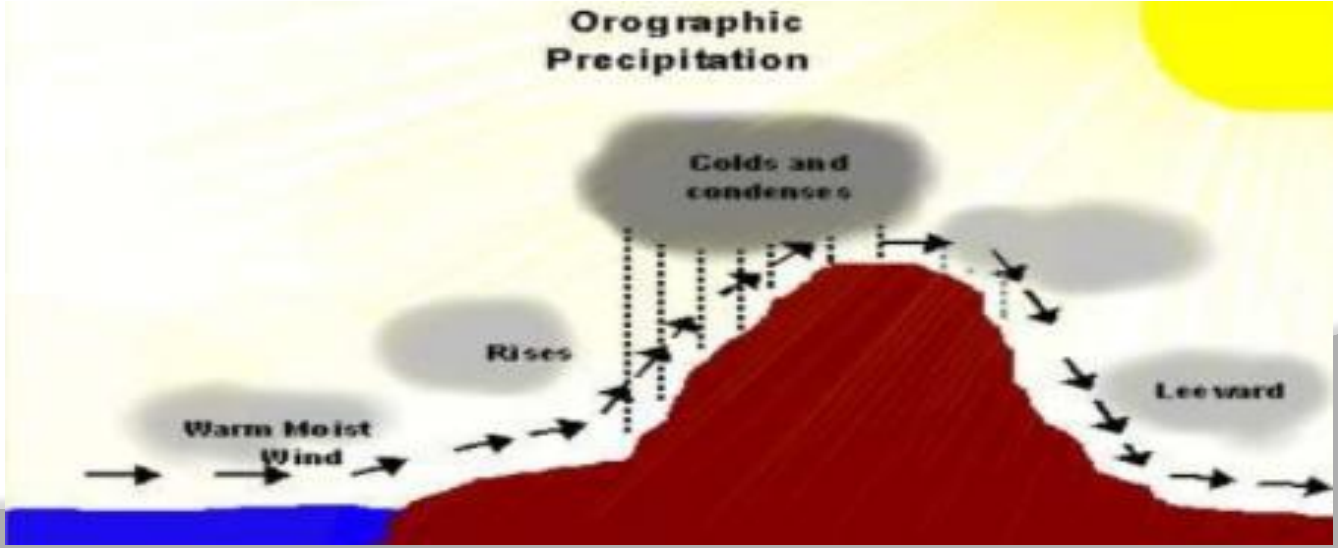
Precipitation caused by the upward movement of air which is warmer than its surroundings. This precipitation is generally showery nature with rapid changes of intensities.

3. **Orographic precipitation:** Precipitation caused by the air masses which strike the mountain barriers and rise up, causing condensation and precipitation. The greatest amount of precipitation will fall on the windward side of the barrier and little amount of precipitation will fall on lee ward side.

PRECIPITATION







MEASUREMENT OF RAINFALL

Measurement of precipitation (Rain and Snow) can be done by various devices. These measuring devices and techniques are :

- Rain Gauges
- Snow Gauges
- Radars
- Satellites
- Scratching of snow packs
- Water equivalent in snow packs

MEASUREMENT OF RAINFALL

- Rainfall is expressed in terms of the depth to which rainwater would stand on an area, if all the rain were collected on it.
- Thus, 1cm of rainfall over a catchment area of $1km^2$ represents a volume of water equal to $10^4 m^3$. A gauge is any measuring instrument which measures a measurable quantity, directly or indirectly.
- A rain gauge measures rainfall. Rainfall is measured in litres per square meter which is equivalent to mm and can be conveniently converted to meter or cm. The precipitation is collected and measured in a **Raingauge.**
- In India, the rain gauges commonly used are Symon's gauge.

TYPES OF RAIN GAUGES

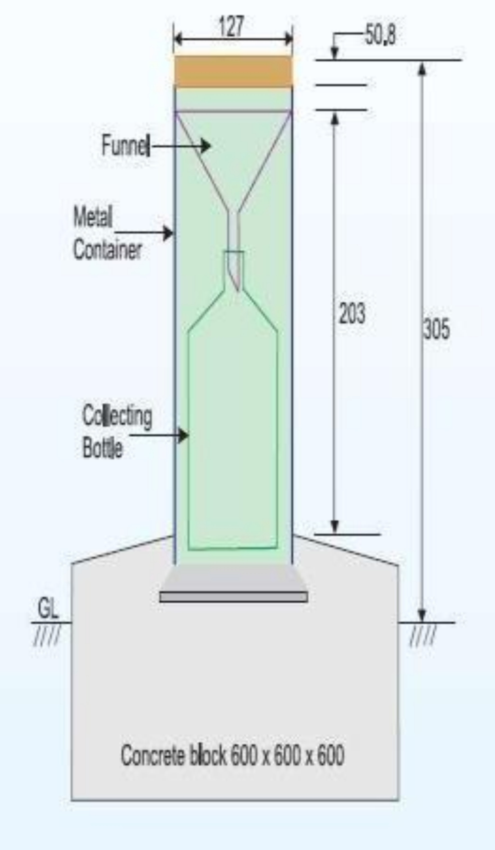
There are two main types of rain gauges which are used to measure the precipitation. These are:

1. Non recording rain gauges –Symons rain gauge
2. Recording rain gauges

1. **Non recording rain gages :**

These are basic storage devices that measure the cumulative amount of rain. A common type of these gauges is called the 8-inch Standard Rain Gauge (SRG) which has been used by the weather offices of US National Weather Service (NWS) for over 100 years. The standard gauge is simply a large cylinder with a funnel and a plastic measuring tube inside the cylinder.

The non-recording rain gauge used in India is the Symons's rain gauge . It consists of a funnel with a circular rim of 12.7 cm diameter and a glass bottle as a receiver. The cylindrical metal casing is fixed vertically to the masonry foundation with the level rim 30.5 cm above the ground surface.



Symon's Gauge

MEASUREMENT OF RAINFALL

- The rain falling into the funnel is collected in the receiver and is measured in a special measuring glass graduated in mm of rainfall; when full it can measure 1.25 cm of rain.
- The rainfall is measured every day at 08.30 hours IST. The collector is of size 100 to 200 cm.
- During heavy rains, it must be measured three or four times in the day, lest the receiver fill and overflow, but the last measurement should be at 08.30 hours IST and the sum total of all the measurements during the previous 24 hours entered as the rainfall of the day in the register.
- Thus the non-recording or the Symons rain gauge gives only the total depth of rainfall for the previous 24 hours (i.e., daily rainfall) and does not give the intensity and duration of rainfall during different time intervals of the day.

2. RECORDING RAIN GAUGE:

- This is also called self-recording, automatic or integrating rain gauge. This type of rain gauge has an automatic mechanical arrangement consisting of a clockwork, a drum with a graph paper fixed around it and a pencil point, which draws the mass curve of rainfall.
- From this mass curve, the depth of rainfall in a given time, the rate or intensity of rainfall at any instant during a storm, time of onset and cessation of rainfall, can be determined. The gauge is installed on a concrete or masonry platform 45 cm square in the observatory enclosure by the side of the ordinary rain gauge at a distance of 2-3 m from it.
- The gauge is so installed that the rim of the funnel is horizontal and at a height of exactly 75 cm above ground surface. The self-recording rain gauge is generally used in conjunction with an ordinary rain gauge exposed close by, for use as standard, by means of which the readings of the recording rain gauge can be checked and if necessary adjusted.

MEASUREMENT OF RAINFALL

There are three main types of recording rain gauges

1. Float type rain gauges
2. Tipping bucket type rain gauges
3. Weighing type rain gauges

1. Float type rain gauges :

In this type, as the rain is collected in a float chamber, the float moves up which makes a pen to move on a chart wrapped round a clock driven drum. When the float chamber fills up, the water siphons out automatically through a siphon tube kept in an interconnected siphon chamber. The clockwork revolves the drum once in 24 hours. The clock mechanism needs rewinding once in a week when the chart wrapped round the drum is also replaced.

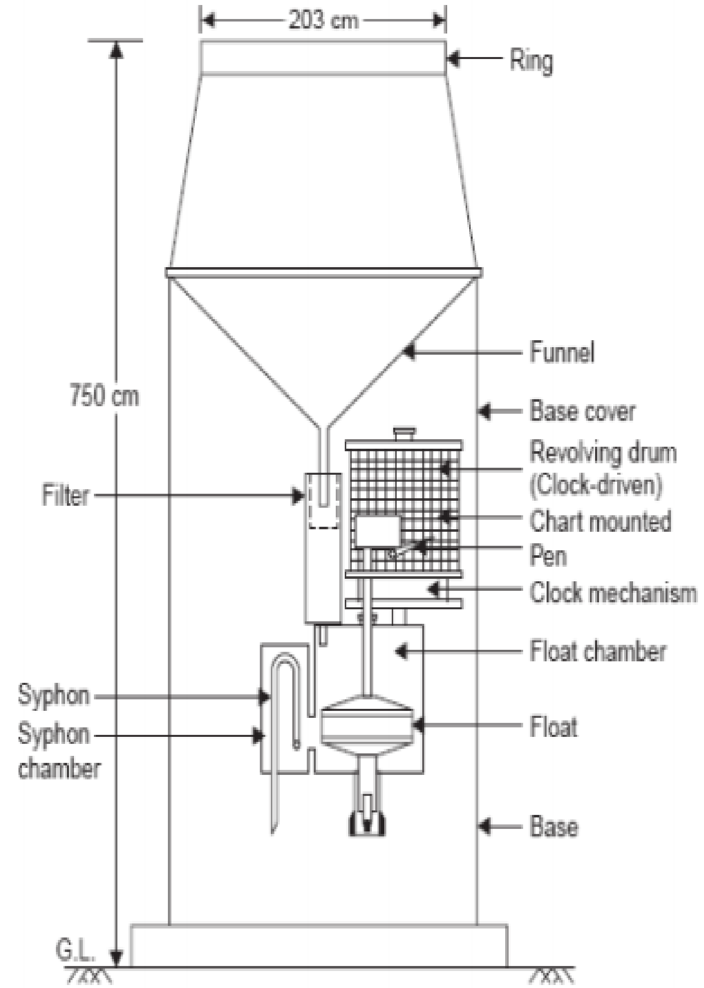
Disadvantages of float gauge :

They are costlier than other non recording rain gauges

Mechanical defects sometimes gives erroneous results

MEASUREMENT OF RAINFALL

- The rise of float with increasing catch of rainfall is recorded. Some gauges must be emptied manually while others are emptied automatically using self starting siphons.
- In most gauges oil or mercury is the float and is placed in the receiver, but in some cases the receiver rests on a both of oil or mercury and the float measures the rise of oil or mercury displaced by the increasing weight of the receiver as the rainfall catch freezes. Float may get damaged by rainfall catch freezer.



Float type rain gauge

2. Weighing precipitation gauge:

- This measures the weight of the falling water, hail or snow and is thus better than the standard gauge as it can also take into account snow and hail. The weight can thus be used to find volume and be later calibrated to find height of rainfall.
- The weighing-type recording gauge may also contain a device to measure the number of chemicals contained in the location's atmosphere. This is extremely helpful for scientists studying the effects of greenhouse gases released into the atmosphere and their effects on the levels of the acid rain.
- Some Automated Surface Observing System (ASOS) units use an automated weighing gauge called the AWPAG (All Weather Precipitation Accumulation Gauge).

MEASUREMENT OF RAINFALL

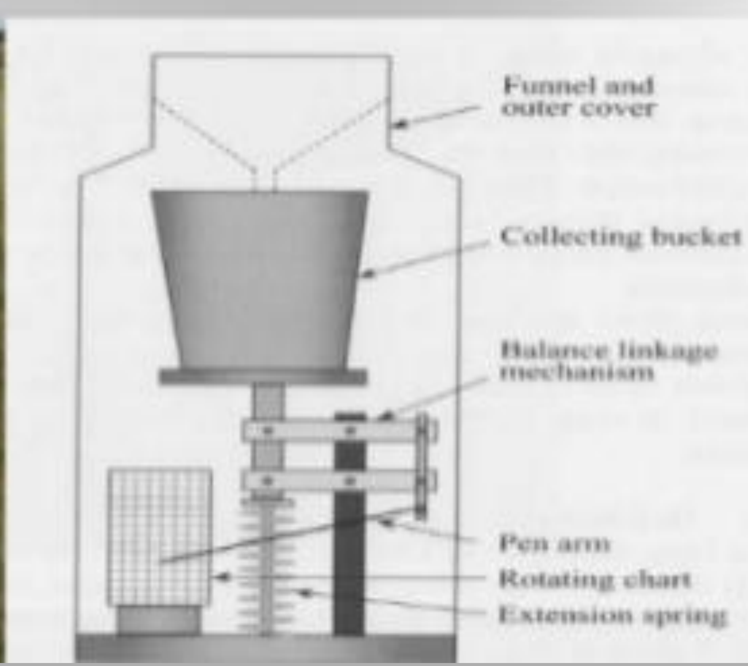
Disadvantages of weighing type rain gauge :

In heavy precipitation there is good chance that bucket will overflow

These instruments are costlier too.

Advantages of weighing type rain gauge :

It can measure all forms of precipitation including snow and rain



3. Tipping bucket rain gauge:

- The tipping bucket rain gauge consists of a funnel that collects and channels the precipitation into a small seesaw-like container. After a pre-set amount of precipitation falls, the lever tips, dumping the collected water and sending an electrical signal.
- An old-style recording device may consist of a pen mounted on an arm attached to a geared wheel that moves once with each signal sent from the collector. In this design, the wheel turns the pen arm moves either up or down leaving a trace on the graph and at the same time making a loud click.

MEASUREMENT OF RAINFALL

Each jump of the arm is sometimes referred to as a 'click' in reference to the noise. The chart is measured in 10 minute periods (vertical lines) and 0.4 mm (0.015 in) (horizontal lines) and rotates once every 24 hours and is powered by a clockwork motor that must be manually wound.

Tipping bucket rain gauge recorder

MEASUREMENT OF RAINFALL

Advantage of tipping bucket :

It is the only recording gauge which can be used in remote places by installing the recorder at a convenient and easily accessible location.

Disadvantages of tipping bucket :

If the bucket is designed to tip at a convenient frequency for a particular intensity of rainfall , they will tip either too soon or too late for other intensities.

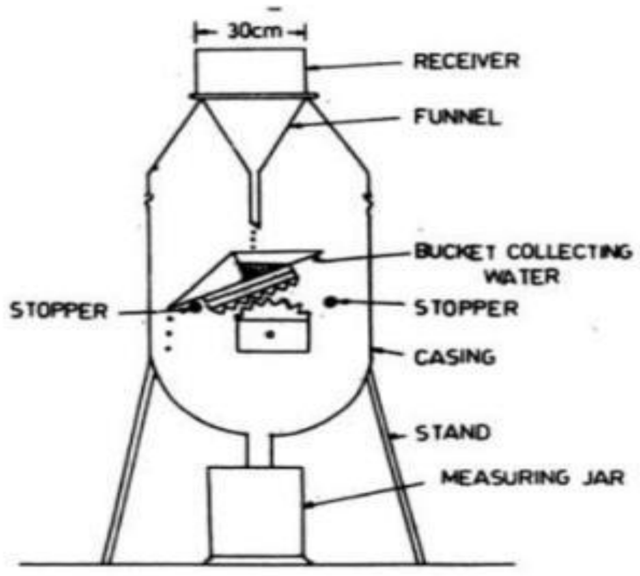
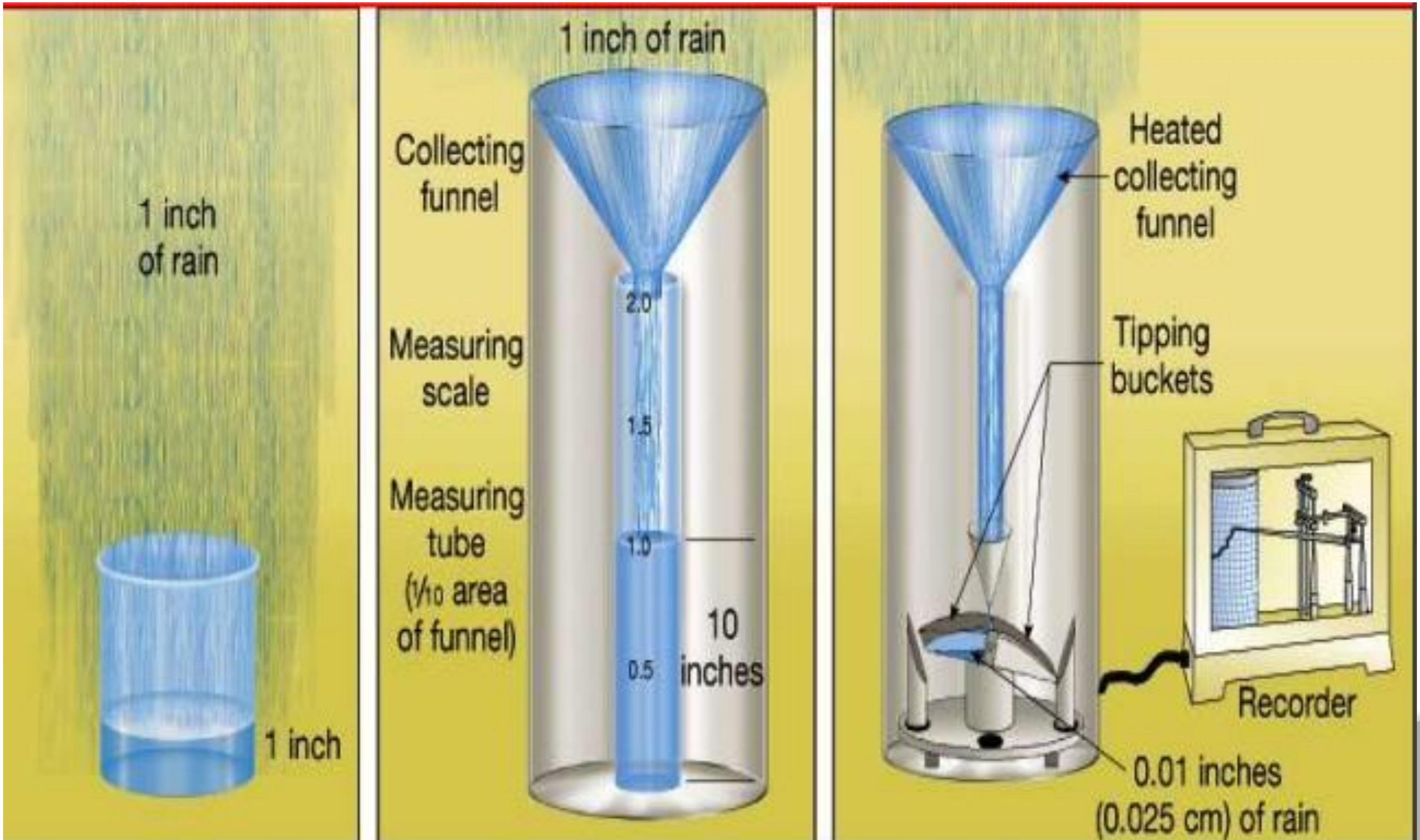


Fig. 5.4. Tipping bucket raingauge.

MEASUREMENT OF RAINFALL



a) Simple rain gauge (b) Standard rain gauge (c) Tipping–bucket gauge

4. Optical rain gauge:

- These have a row of collection funnels. In an enclosed space below each is a laser diode and a photo transistor detector.
- When enough water is collected to make a single drop, it drops from the bottom, falling into the laser beam path.
- The sensor is set at right angles to the laser so that enough light is scattered to be detected as a sudden flash of light. The flashes from these photo detectors are then read and transmitted or recorded.

5. Acoustic rain gauge:

- Also referred to as a hydrophone, it is able to sense the sound signatures for each drop size as rain strikes a water surface within the gauge.
- Since each sound signature is unique, it is possible to invert the underwater sound field to estimate the drop-size distribution within the rain.
- Selected moments of the drop-size distribution yield rainfall rate, rainfall accumulation, and other rainfall properties.

Problems in rainfall measurement:

However common problems that are faced in all kinds of gauges are same.

- They can only be placed manually and they have to be placed at a place where full rainfall is received i.e. away from buildings and trees.
- Also water droplets falling from trees later have to be avoided otherwise rainfall will be over-estimated. Also the some water droplets stick to the apparatus funnel and sides and thus rainfall is under-estimated.

AVERAGE RAINFALL OVER AN AREA

To convert the point rainfall values measured by various raingauge stations into an average value over a catchment, following methods are used.

1. Arithmetic Mean Method
2. Thiessen Polygon Method
3. Isohyetal Method

1. Arithmetic Mean Method:

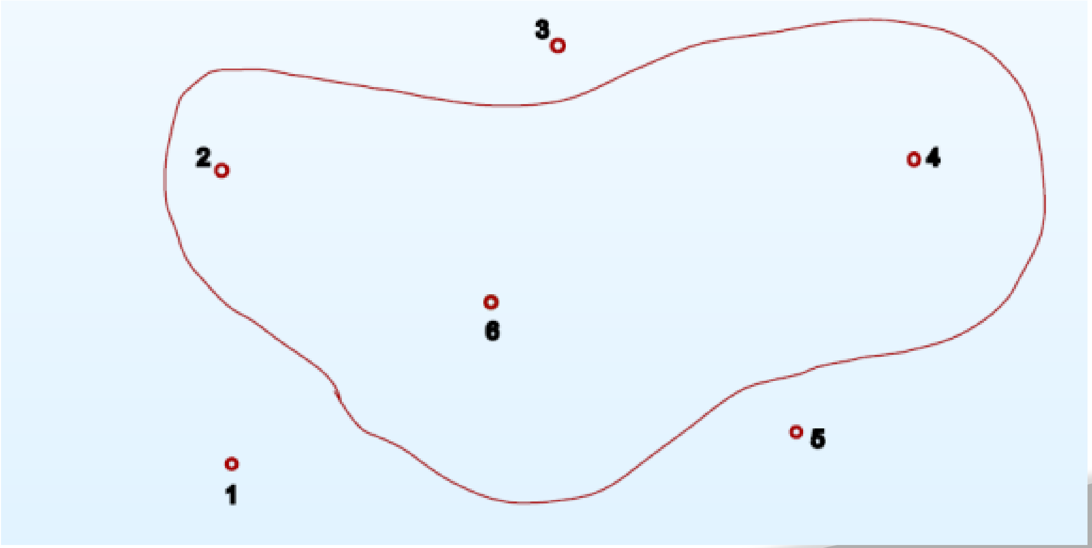
- If there are small variations in the rainfall values measured by the stations, this method can be used.
- If ***P1, P2, . . . , Pn are the rainfall values obtained from n raingauge*** stations within a catchment, then the average precipitation is given by

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

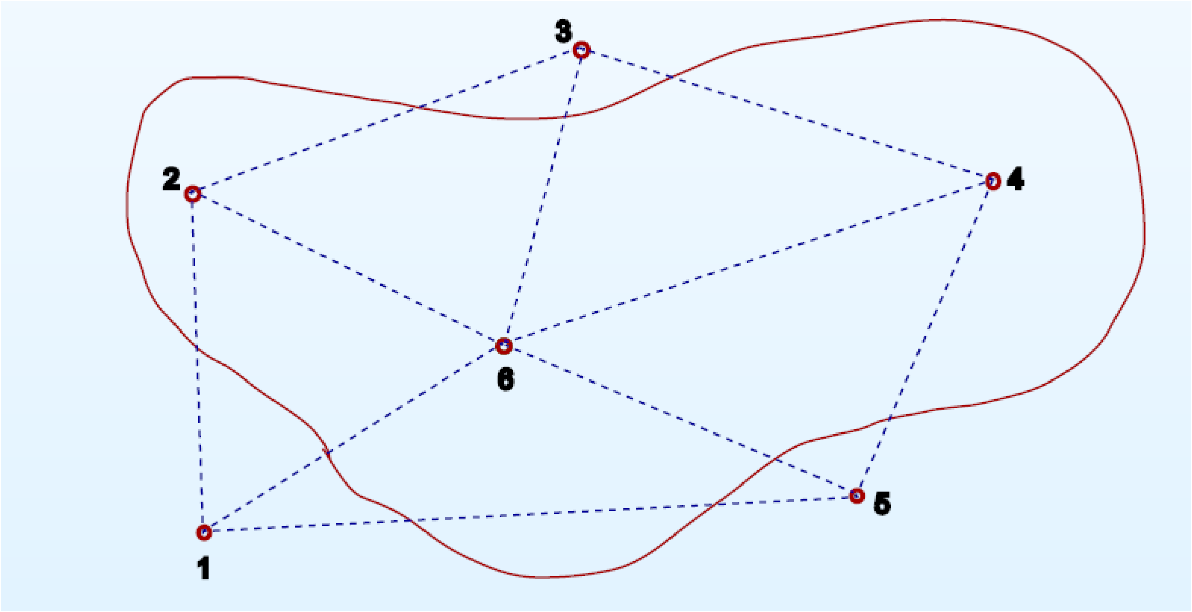
2. Thiessen Polygon Method:

In this method, the rainfall recorded at each station is given a weightage on the basis of an area closest to that station.

1. Draw the catchment area to a scale and mark the raingauge stations on it.

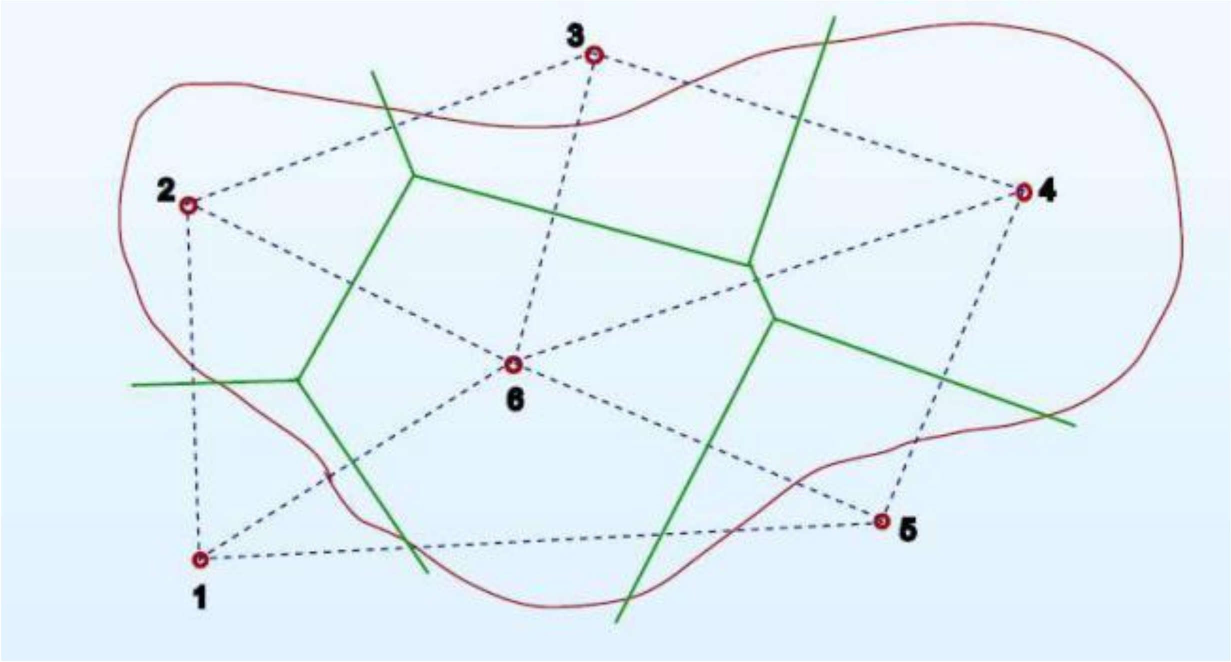


2. Join each station by straight line to create a triangulated network.

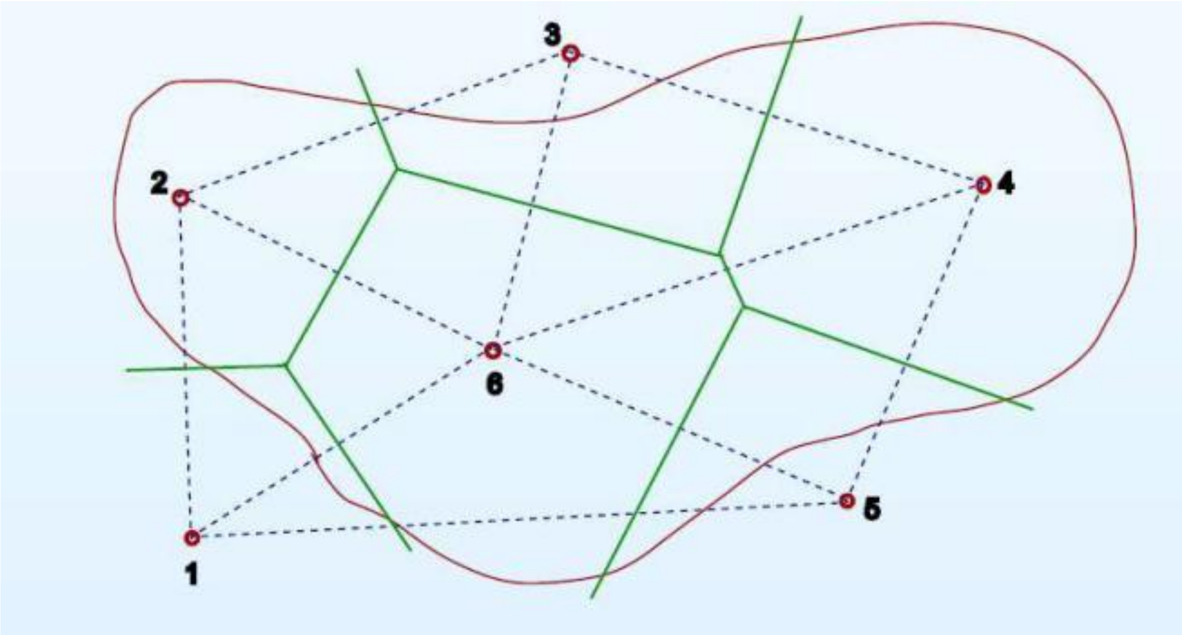


AVERAGE RAINFALL OVER AN AREA

3. Draw perpendicular bisectors on each sides of each triangles. Extend the bisectors to meet the other bisectors and the catchment boundary.



4. The polygons formed by the perpendicular bisectors (and part of catchment boundary) are the influence areas of each stations.



- If there are n number of raingauge stations in and around the catchment and if A1,A2, . . . ,An are the respective influence areas of Thiessen Polygon, then the average rainfall is given by

$$\bar{P} = \frac{P_1A_1 + P_2A_2 + \ldots + P_nA_n}{A_1 + A_2 + \ldots + A_n} = \frac{\sum_{i=1}^{n} P_iA_i}{\sum_{i=1}^{n} A_i} = \sum_{i=1}^{n} P_i \frac{A_i}{A}$$

AVERAGE RAINFALL OVER AN AREA

3. Isohytel Method:

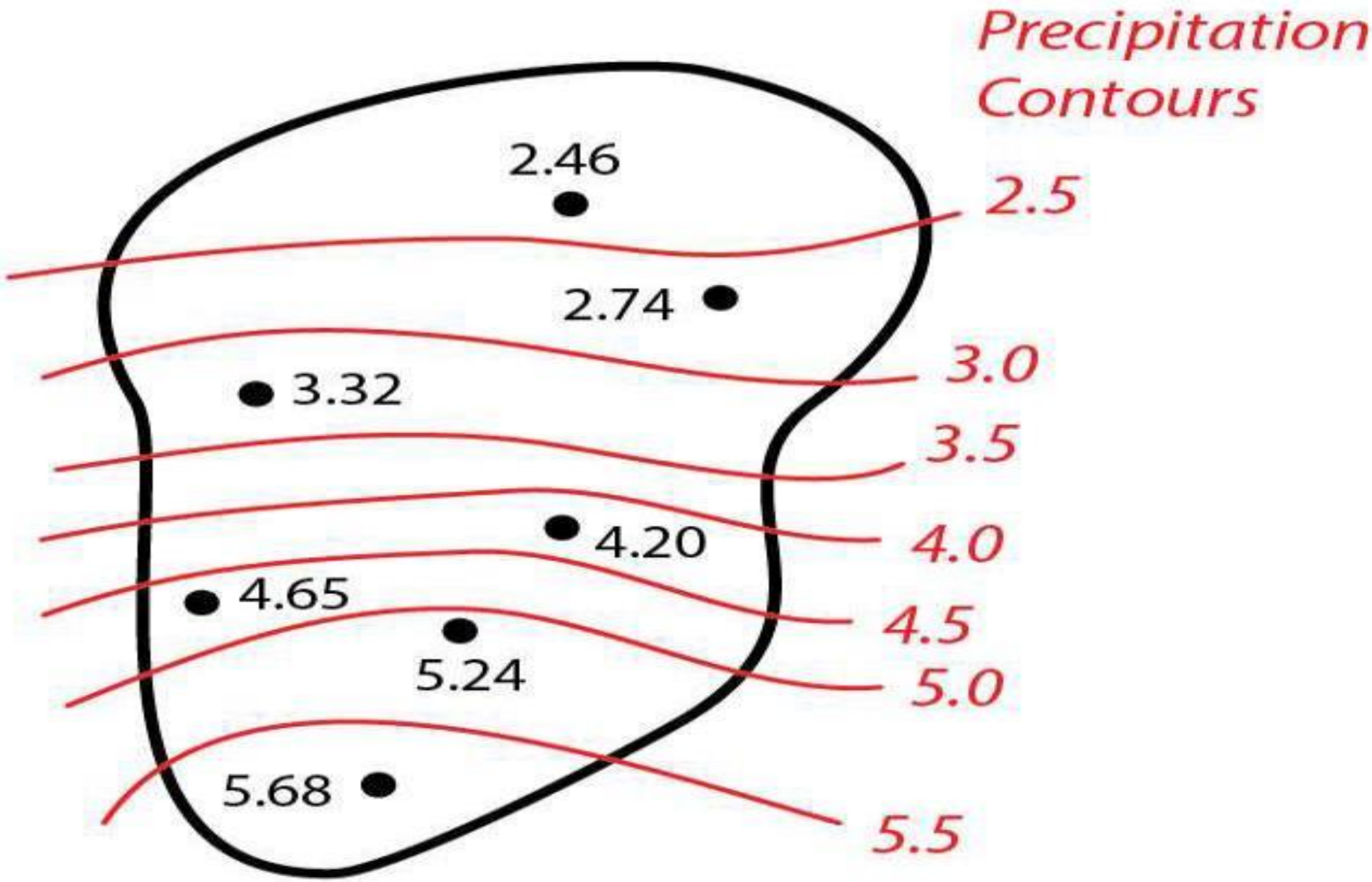
Isohyet: An isohyet is a line joining points of equal rainfall magnitude.

- If *P1, P2, . . . , Pn are the values of isohyets and if A1,A2, . . . ,An−1 are* the inter-isohyet area respectively, then the mean precipitation over the catchment is given by

$$\bar{P} = \frac{A_1\left(\frac{P_1+P_2}{2}\right) + A_2\left(\frac{P_2+P_3}{2}\right) + \ldots + A_{n-1}\left(\frac{P_{n-1}+P_n}{2}\right)}{A}$$

$$\bar{P} = \frac{1}{A}\sum_{i=1}^{n-1} A_i \frac{(P_i + P_{i+1})}{2}$$

AVERAGE RAINFALL OVER AN AREA



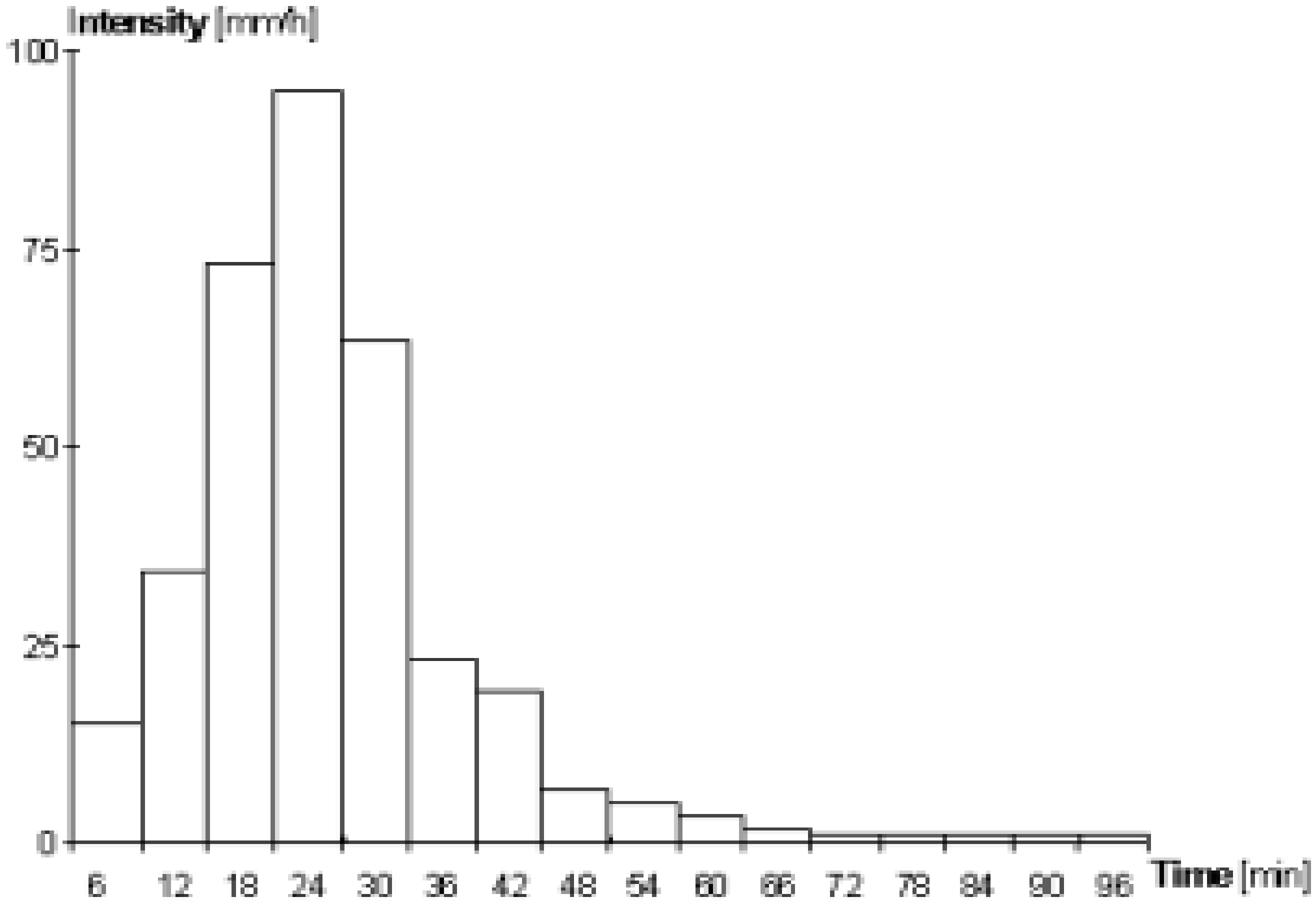
ANALYSIS AND INTERPRETATION OF RAINFALL DATA

- The precipitation process is essentially random in nature. We can't predict with certainty what will be the rainfall for any given period in future.
- The rainfall magnitudes can be estimated only with some probability attached to them. Therefore the analysis of rainfall data obtained over a long period in the past would help the hydrologist to make reasonable probabilistic estimates of rainfall to be used in various designs.
- The rainfall obtained from single rain gauge station is known as the point rainfall or station rainfall.
- If the data at the station covers a period of more than 30 years, the normal annual rainfall, or the normal monthly rainfall for any month can be computed.

ANALYSIS AND INTERPRETATION OF RAINFALL DATA

- If the observed rainfall in any year is less than normal annual rainfall it is called as deficient or dry year.
- If the observed rainfall in any year is more than normal annual rainfall it is called as surplus or wet year.
- The normal monthly rainfall of a station is computed as the arithmetic average of the monthly rainfall or yearly rainfall in last 30 years. Hyetograph – it is a chart or graphic representation of average distribution of rain over the earth.
- It is a plot of intensity of rain fall against time interval the hyetograph is derived from mass curve and is usually represented as bar chart Rainfall intensity progressively increases until it reaches a maximum and then gradually decreases. Where this maximum occurs and how fast the maximum is reached is what differentiates one distribution from another.

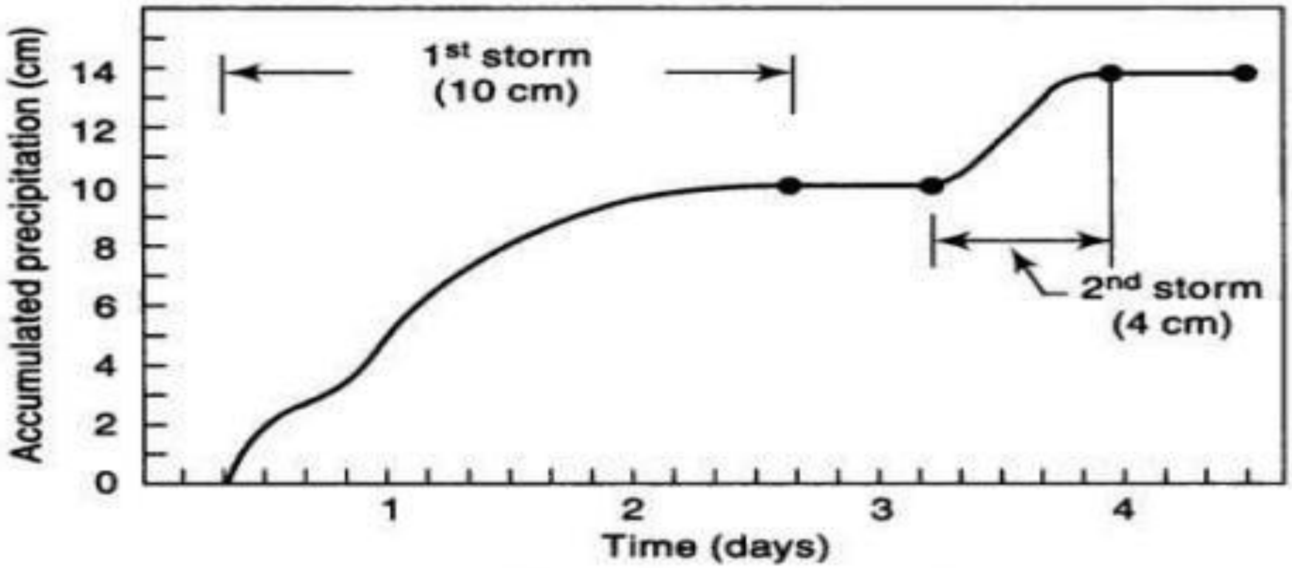
ANALYSIS AND INTERPRETATION OF RAINFALL DATA



MASS CURVE

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 Fig. Mass curves of rainfall are very useful in extracting the information on the duration and magnitude of a storm. Also, intensities at various time intervals in a storm can be obtained by the slope of the curve. For nonrecording raingauges, mass curves are prepared from a knowledge of the approximate beginning and end of a storm and by using the mass curves of adjacent recording gauge stations as a guide.

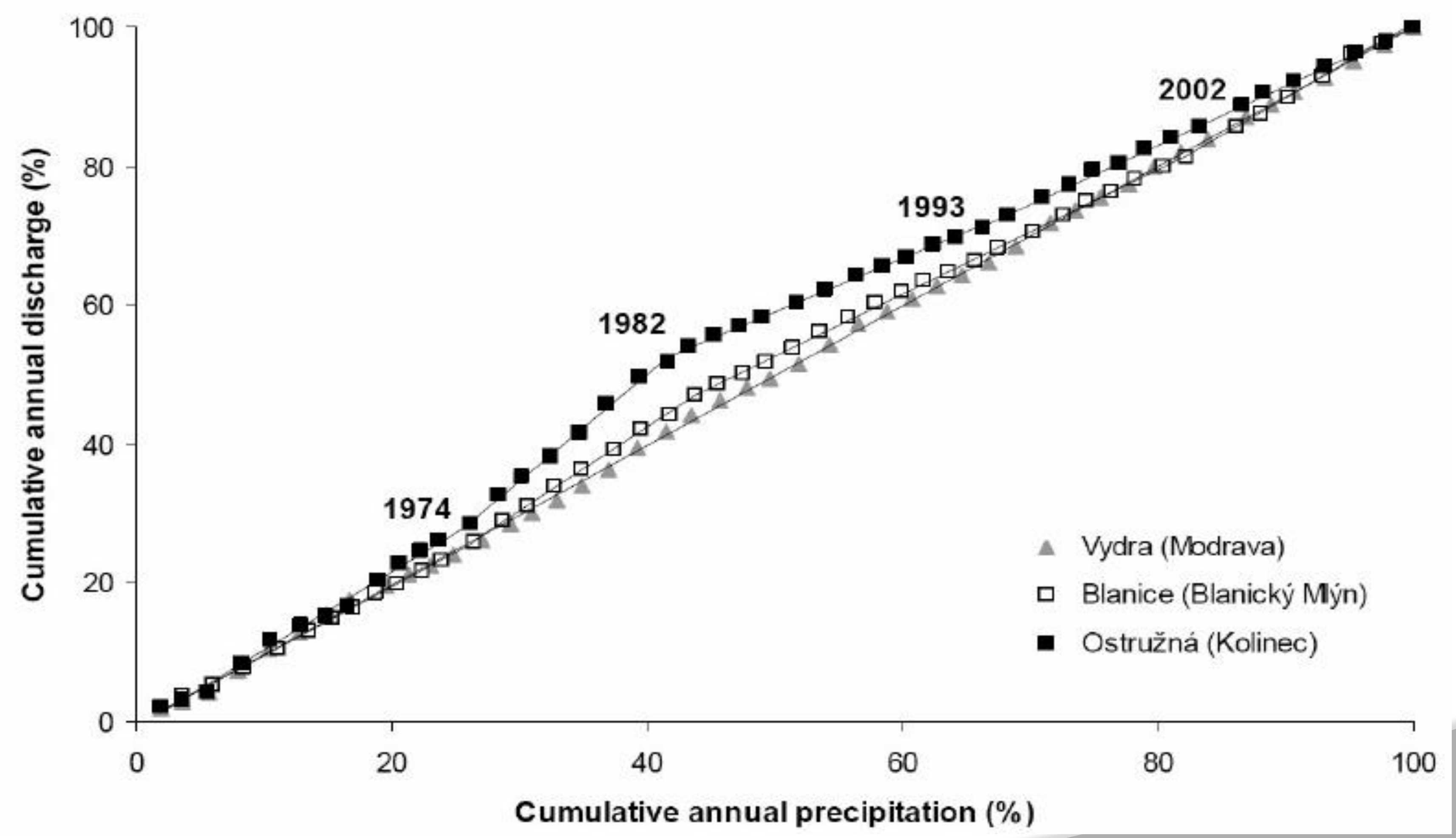


Mass Curve of Rainfall

DOUBLE MASS CURVE

- Double mas curve is technique used to test the consistency of rainfall record at any rain gauge station which is suspected to contain certain errors.
- Inconsistency of rainfall is due to:
- Long and continuous rainfall record but not homogenous.
- Exposure conditions of gauge.
- Change in instrument.
- Faculty for a part of period of record and accuracy of measurement.
- This technique analysis tests the record for its consistency and accuracy and it provides a correction factor to assure that the data is homogenous.
- It enables the data to be estimated for the missing periods are to be extra beyond the existing length of period.

DOUBLE MASS CURVE



RUNOFF

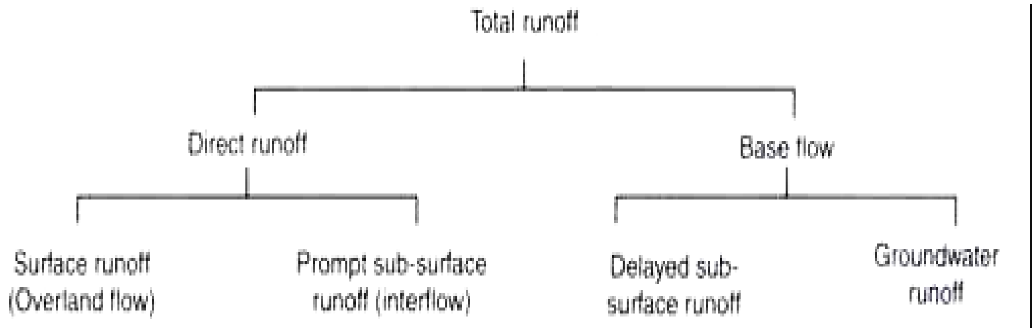
- **Runoff** can be described as the part of the water cycle that flows over land as surface water instead of being absorbed into groundwater or evaporating. According to the U.S. Geological Survey (USGS), runoff is that part of the precipitation, snow melt, or irrigation water that appears in uncontrolled surface streams, rivers, drains, or sewers.

  Components of Runoff:

- The river flow that appears in the river is not made up of overland flow (surface runoff) only. It is actually total runoff contributed to the river in different ways by the drainage basin.

RUNOFF

Depending upon the source from where the portion of total flow gets contributed the components of total runoff can be recognised as shown below schematically:



It is clear from above that total runoff consists of two parts

(i) Direct runoff caused as an immediate result of precipitation; and

(ii) Base flow which is responsible for maintaining a sustained flow throughout the year and is mainly derived from groundwater storage. Direct runoff is made up of overland flow or surface runoff and that part of infiltration which flows laterally through the unsaturated zone of soil mass and joins the stream flow promptly.

RUNOFF

- This portion of total rainfall which produces surface runoff is called rainfall excess.

  Total rainfall = Rainfall excess + losses
- The term losses includes interception, infiltration, evaporation, depression storage etc. Similarly that portion of rainfall which produces direct runoff is called effective rainfall.

  Effective rainfall = Rainfall excess + x

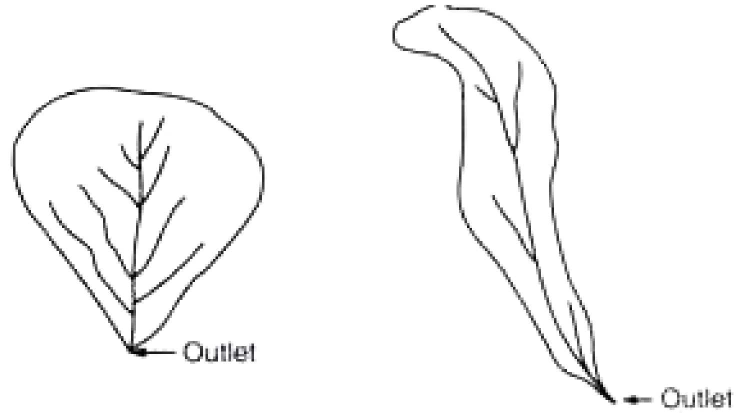
  where x is that portion of rainfall which appears in the stream as promt subsurface runoff.
- Obviously when promt sub-surface runoff is considered together with delayed subsurface runoff.
- Direct runoff = Surface runoff and
- Effective rainfall = Rainfall excess

Runoff is affected mainly by climatic and physiographic factors.

The important factors are mentioned below:

1. Rainfall pattern:

- If the rainfall is very heavy the consequent runoff will also be more. If the rainfall is just showery type with low intensity there may not be runoff at all as the rainwater is completely lost in infiltration, evaporation, etc. If the duration of rainfall is more the runoff will also be prolonged.



(a) Fan shaped catchment (b) Fern shaped catchment

2. Character of catchment surface:

If a surface is rocky then the surface absorption will be practically nil and the runoff will be more. If the surface is compact clayey type runoff will be more, but if the surface is sandy then the absorption losses will be more and runoff will be less.

3. Topography:

If the surface slope is steep runoff will be more as water will pass over the surface rapidly before losses take place. If there are local depressions water will be held up in depressions forming lakes, ponds etc., in the catchment.

4. Shape and size of the catchment:

If the catchment area is large runoff will be more. If the catchment area is fan shaped runoff at outlet will be more as all the water contributes to the stream practically at the same time. If the catchment is fern shaped the runoff will be less.

5. Vegetal cover:

If there is some sort of vegetal cover over the catchment then evaporation loss will be reduced as sun rays cannot reach the ground surface.

6. Geology of the area:

If there are fissures, cracks, fault zones present in the catchment then rainwater finds its way out through these openings. The water lost may find its way to some other catchment or to groundwater or in the sea.

7. Weather conditions:

Temperature of the region also affects the runoff to a great extent. If temperature is more it renders surface dry and when rain occurs more water is absorbed by the ground surface. Evaporation rate will also be more if temperature is high.

Measurement of Runoff:

The quantity of water following down the river can be measured by actual measurements. The methods of discharge measurement have been dealt with subsequently. The records of runoff, i.e., river flow, can be kept on daily, monthly, seasonal or annual basis. Total runoff of the river is also called the yield.

Runoff Effects

While runoff is affected by various things like amount of rainfall and vegetation, too much of it can have a bad effect on the environment as well. Some examples include erosion and pollution.

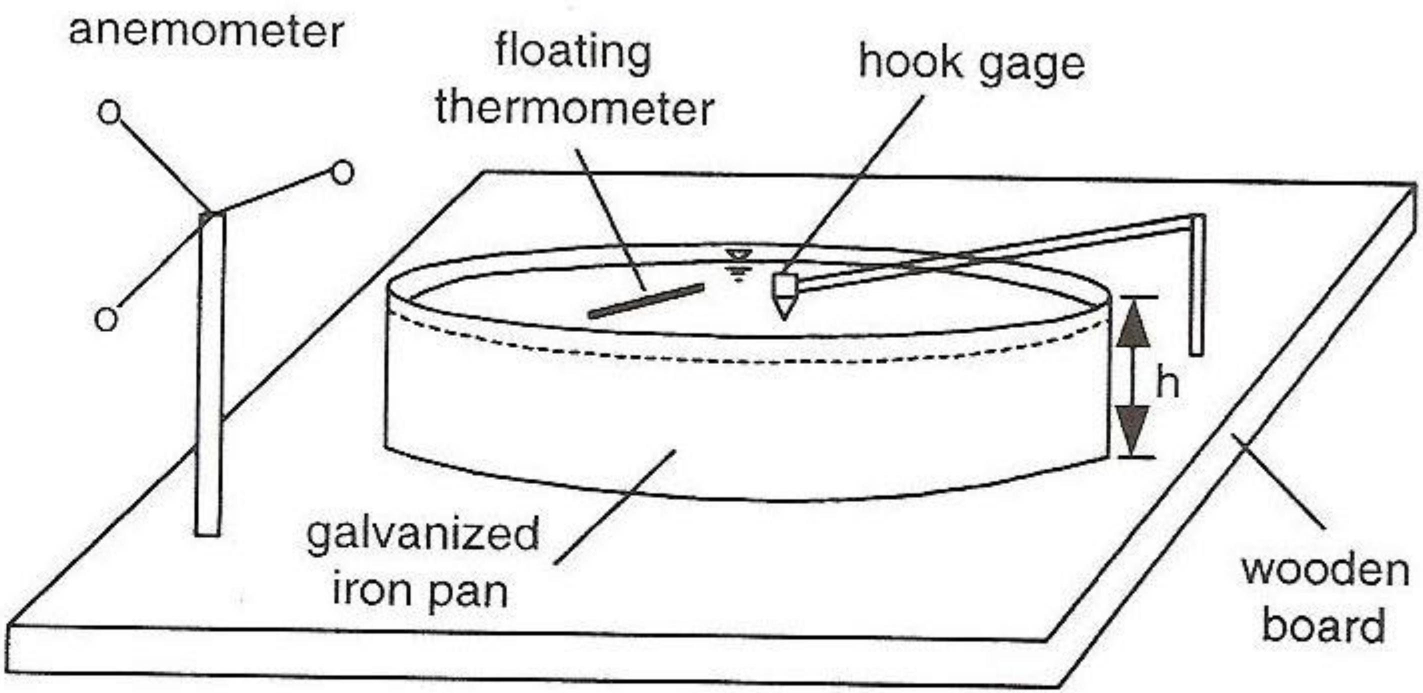
EVAPORATION

- Evaporation is the process by which water changes from a liquid to a gas or vapor.
- Evaporation is the primary pathway that water moves from the liquid state back into the water cycle as atmospheric water vapor.
- Studies have shown that the oceans, seas, lakes, and rivers provide nearly 90 percent of the moisture in the atmosphere via evaporation, with the remaining 10 percent being contributed by plant transpiration

Why evaporation occurs

- Heat (energy) is necessary for evaporation to occur. Energy is used to break the bonds that hold water molecules together, which is why water easily evaporates at the boiling point (212° F, 100° C) but evaporates much more slowly at the freezing point.
- Net evaporation occurs when the rate of evaporation exceeds the rate of condensation. A state of saturation exists when these two process rates are equal, at which point the relative humidity of the air is 100 percent.
- Condensation the opposite of evaporation, occurs when saturated air is cooled below the dew point (the temperature to which air must be cooled at a constant pressure for it to become fully saturated with water), such as on the outside of a glass of ice water. In fact, the process of evaporation removes heat from the environment, which is why water evaporating from your skin cools you.

EVAPORTING PANS:



MEASURING OF EVAPORATION

Atmometer

MEASURING OF EVAPORATION

Floating class-A pan

MEASURING OF EVAPORATION

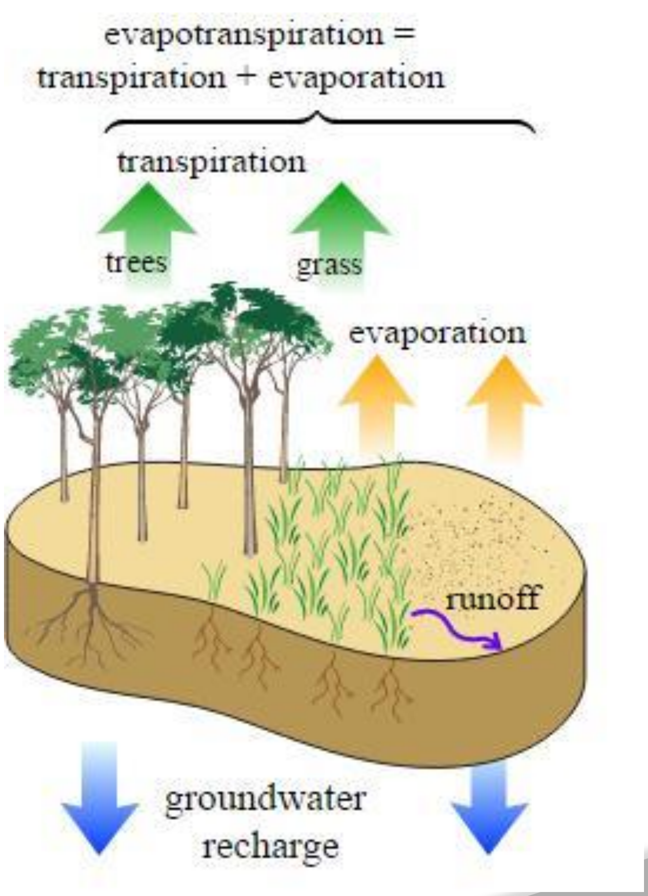
Surface pans

MEASURING OF EVAPORATION

Open Pan Evaporimeter

EVAPOTRANSPIRATION

- **Evapotranspiration** (**ET**) is the sum of evaporation and plant transpiration from the Earth's land and ocean surface to the atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and waterbodies.
- Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves. Evapotranspiration is an important part of the water cycle. An element (such as a tree) that contributes to evapotranspiration can be called an **evapotranspirator**.



EVAPOTRANSPIRATION

- **Potential evapotranspiration** (**PET**)is a representation of the environmental demand for evapotranspiration and represents the evapotranspiration rate of a short green crop (grass), completely shading the ground, of uniform height and with adequate water status in the soil profile.
- It is a reflection of the energy available to evaporate water, and of the wind available to transport the water vapor from the ground up into the lower atmosphere.
- Often a value for the potential evapotranspiration is calculated at a nearby climatic station on a reference surface, conventionally short grass. This value is called the reference evapotranspiration (ET_0).
- **Actual evapotranspiration** is said to equal potential evapotranspiration when there is ample water. Some US states utilize a full cover alfalfa reference crop that is 0.5 m in height, rather than the short green grass reference, due to the higher value of ET.

INFILTRATION

- **Infiltration** is the process by which water on the ground surface enters the soil. It is commonly used in both hydrology and soil sciences. The infiltration capacity is defined as the maximum rate of infiltration. It is most often measured in meters per day but can also be measured in other units of distance over time if necessary. The infiltration capacity decreases as the soil moisture content of soils surface layers increases. If the precipitation rate exceeds the infiltration rate, runoff will usually occur unless there is some physical barrier.
- Infiltrometers, permeameters and rainfall simulators are all devices that can be used to measure infiltration rates.
- Infiltration is caused by multiple factors including; gravity, capillary forces, adsorption and osmosis. Many soil characteristics can also play a role in determining the rate at which infiltration occurs.

INFILTRATION

Factors that affect infiltration:

- **Precipitation:**

  Precipitation can impact infiltration in many ways. The amount, type and duration of precipitation all have an impact. Rainfall leads to faster infiltration rates than any other precipitation events, such as snow or sleet. In terms of amount, the more precipitation that occurs, the more infiltration will occur until the ground reaches saturation, at which point the infiltration capacity is reached.

- **Soil characteristics**

  The porosity of soils is critical in determine the infiltration capacity. Soils that have smaller pore sizes, such as clay, have lower infiltration capacity and slower infiltration rates than soils that have large pore size, such as sands. One exception to this rule is when clay is present in dry conditions. In this case, the soil can develop large cracks which leads to higher infiltration capacity.

- **Soil moisture content:**

  Soil that is already saturated has no more capacity to hold more water, therefore infiltration capacity has been reached and the rate cannot increase past this point. This leads to much more surface runoff. When soil is partially saturated then infiltration can occur at a moderate rate and fully unsaturated soils have the highest infiltration capacity.

- **Organic materials in soils:**

  Organic materials in the soil (including plants and animals) all increase the infiltration capacity. Vegetation contains roots that extent into the soil which create cracks and fissures in the soil, allowing for more rapid infiltration and increased capacity.

- **Slope**

  When the slope of land is higher runoff occurs more readily which leads to lower infiltration rates.

UNIT II
DISTRIBUTION OF RUNOFF

CLOs	Course Learning Outcome
CLO 6	Understand the concept of Hydrograph, effective rainfall, and base flow separation
CLO 7	Analyze the concept of direct runoff hydrograph
CLO 8	Analyze the importance of unit hydrograph, definition, and limitations applications of unit hydrograph.
CLO 9	Understand the derivation of unit hydrograph from direct runoff hydrograph and runoff hydrograph to unit hydrograph
CLO 10	Understand the concept of synthetic unit hydrograph and its applications.

HYDROGRAPH ANALYSIS FLOOD HYDROGRAPH

- A plot of the discharge in a stream plotted against time chronologically is called a hydrograph. OR
- Special graphs that show changes in a river's discharge over a period of time, usually in relation to a rainfall event. OR
- A hydrograph is a graph showing the rate of flow (discharge) versus time past a specific point in a river, or other channel or conduit carrying flow. The rate of flow is typically expressed in cubic meters or cubic feet per second (cms).

Basic Terms

The discharge is measured at a specific point in a river and is typically time variant.

HYDROGRAPH ANALYSIS FLOOD HYDROGRAPH

- Hydrograph is a graphical or tabular presentation of instantaneous runoff/discharge rate against time. Sometimes, it is also known as storm hydrograph, flood hydrograph or simply hydrograph.
- A hydrograph presents the total runoff (direct + base flow) occurring at a given time. It also shows the distribution of total runoff with respect to time at a certain point of measurement. All hydrographs have three characteristics regions viz.,- rising limb, crest segment or peak point and falling limb.
- These characteristics regions are shown in the schematic diagram of the hydrograph (Fig. 2.6). The hydrographs are mainly in two types, i.e., – single peaked and multi-peaked. The multi-peaked hydrograph is also known as complex hydrograph.

HYDROGRAPH ANALYSIS FLOOD HYDROGRAPH

- The occurrence of single or multi-peaked hydrograph depends on rainfall characteristics, complexity of watersheds and their peculiar interactions.
- For example an isolated rainfall yields the single peaked hydrograph, while complex storm (varying rainfall intensity) yields the complex hydrograph.

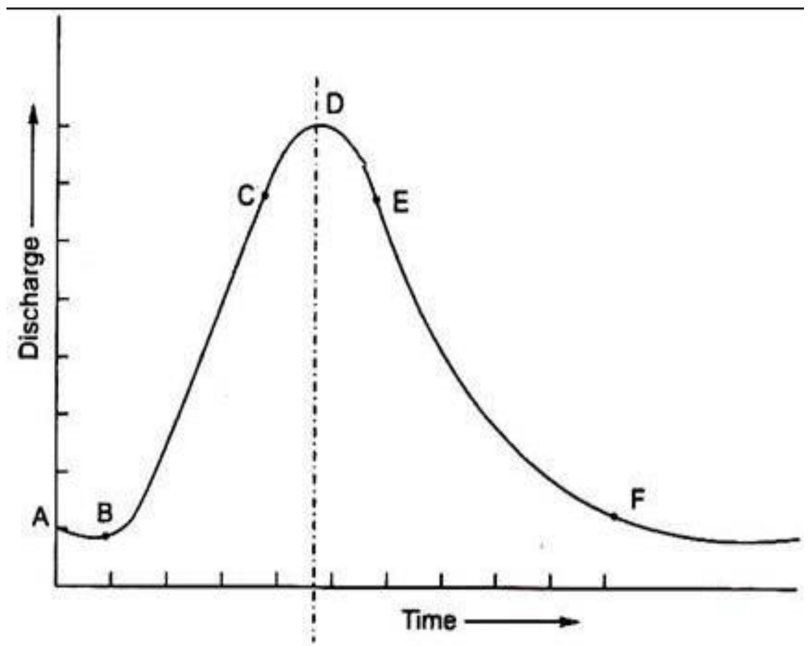


Fig. 2.6. Schematic diagram of hydrograph

Components of Hydrograph:

1. Rising Limb:

- It is also known as concentration curve, is the ascending portion of hydrograph. Its slope steepness depends on the rise of discharge due to gradual building of storage in drainage channels as well as over the watershed surface. The shape of rising limb is dependent on the storm and watershed characteristics, both.
- In general, the shape of rising limb is being concave upwards and rises slowly in the early stage of the flow, but as the storm continues and more and more flow from distant apart reaches to the outlet of watershed, the rising limb rises very rapidly up to the peak point of the hydrograph. The time base of hydrograph is fixed by the duration of outflow. In a simple hydrograph, the extent of rising limb is comparatively shorter than the falling limb, as a result the area below this limb is less to that of the falling limb.

2. Crest Segment:

- This segment is one of the very important parts of the hydrograph, as it contains the peak flow. It is extended from the point of inflection on the rising limb to a similar inflection point on the falling limb.
- The peak flow occurs, when various parts of the watershed yield the runoff simultaneously to the outlet. Generally, in large watersheds the peak flow occurs, when rainfall gets stop.
- The time interval from centre of mass of rainfall to the peak is controlled by the storm and watershed characteristics. Hydrographs of some watersheds resulted from a single and relatively short duration rainfall, have two or more peaks.
- Multi-peak, i.e. complex hydrographs can also occur, when two or more storms occur in a close succession.

3. Falling Limb:

- It is the descending portion of hydrograph, is also known as recession limb. The falling limb is extended from the point of inflection at the end of crest segment to the commencement of natural ground water flow. It represents the withdrawal of water from the storage build up in the watershed during initial phase of hydrograph.
- The point of inflection on the falling limb of the hydrograph indicates the stage, when rainfall has been stopped and channel flow is due to storage made over the watershed.
- The shape of falling limb is dependent only on the physical features of the channel; and is independent of the storm characteristics. Generally, falling limb is in convex shape due to continuous decrease in runoff volume. Variation in areal rainfall distribution minutely affects the shape of recession curve. Unusually high rainfall intensity results the rapid recession, while delayed recession is due to concentration of rainfall in upper portion of the basin.

Factors Affecting the Shape of Hydrograph:

The shape of hydrograph is dependent on the runoff volume and time to peak of the watershed.

- Various factors that affect the shape of hydrograph can be broadly grouped into following two groups:
  1. Climatic factors; and
  2. Physiographic factors.

Each of the two groups of factors, affecting the shape of hydrograph, further contain host of the factors; the important ones are listed below:

EFFECTIVE RAINFALL

1. Climatic Factors:

These are mainly the storm characteristics, given as:

i. Types of precipitation

ii. Intensity of rainfall

iii. Duration of rainfall

iv. Direction of rainfall

v. Magnitude of rainfall

vi. Other factors, like initial losses and evapotranspiration.

2. Physiographic Factors:

Include the basin as well as channel characteristics, are given as under:

Basin characteristics:

i. Shape

ii. Size

iii. Slope

iv. Nature of the valley

v. Elevation

vi. Land use pattern; and

vii. Soil characteristics of the basin.

Channel Characteristics:

i. Cross-section of the channel

ii. Roughness of the channel

iii. Storage capacity, and

iv. Drainage density etc.

BASE FLOW SEPARATION

- A runoff hydrograph represents the cumulative runoff resulted from surface and sub-surface (base flow) runoff. The surface runoff or direct runoff hydrograph is obtained from the total storm hydrograph by separating the base flow. The separation of base flow is an arbitrary manner, unless a large flow from the antecedent storm is available. Due to this reason the errors made in the base flow separation are taken as negligible.
- A simple hydrograph, which is not affected by the rainfall, prior to or subsequent to the period of observation, any one among following three methods, can be used:

1. Straight Line Method:

- This method consists of drawing a straight line from the beginning of the surface runoff to an arbitrary point on the recession limb, representing the end of the direct runoff. In Fig. 2.7, it is shown by the line a. b, in which point ‘a’ represents the beginning of direct runoff, is identified by the view of sharp change in the runoff rate.

- The arbitrary point ‘b’ is roughly located at the time $N = 0.84\ A^{0.2}$ days after the peak of the hydrograph, in which ‘A’ is the watershed area (km^2) and N is in days. The accuracy of N depends on careful study of a number of isolated storm hydrographs. This method of base flow separation is the simplest among all three methods.

2. Method-II:

- In this method the base flow curve existing prior to the commencement of surface runoff, is extended till it intersects the straight line drawn from the peak of the hydrograph. This point is joined to the arbitrary point (b), simply by a straight line. In Fig. 2.7, it is shown by straight line ac and cb. The area below this line of hydrograph represents the base flow, while the area above the line is noted as direct runoff. This method is most suitable and widely used for base flow separation.

3. Method-III:

This method is based on the use of composite base flow recession curve. In this method, the base flow recession curve, after depletion of the flood water is extended back-ward till it intersects the straight line, drawn from the point of inflection.

In Fig. 2.7, it is shown by joining the point a to point f and point f to b by smooth curve. This method is appro-priate, particularly when ground water contribution is expected to be significant and reaches the stream, quickly.

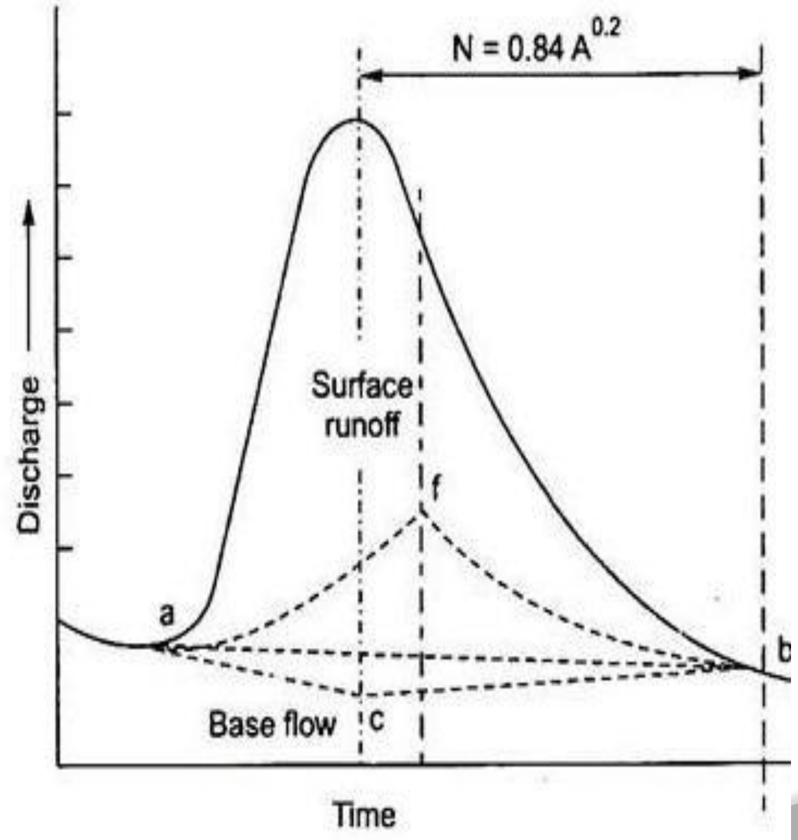
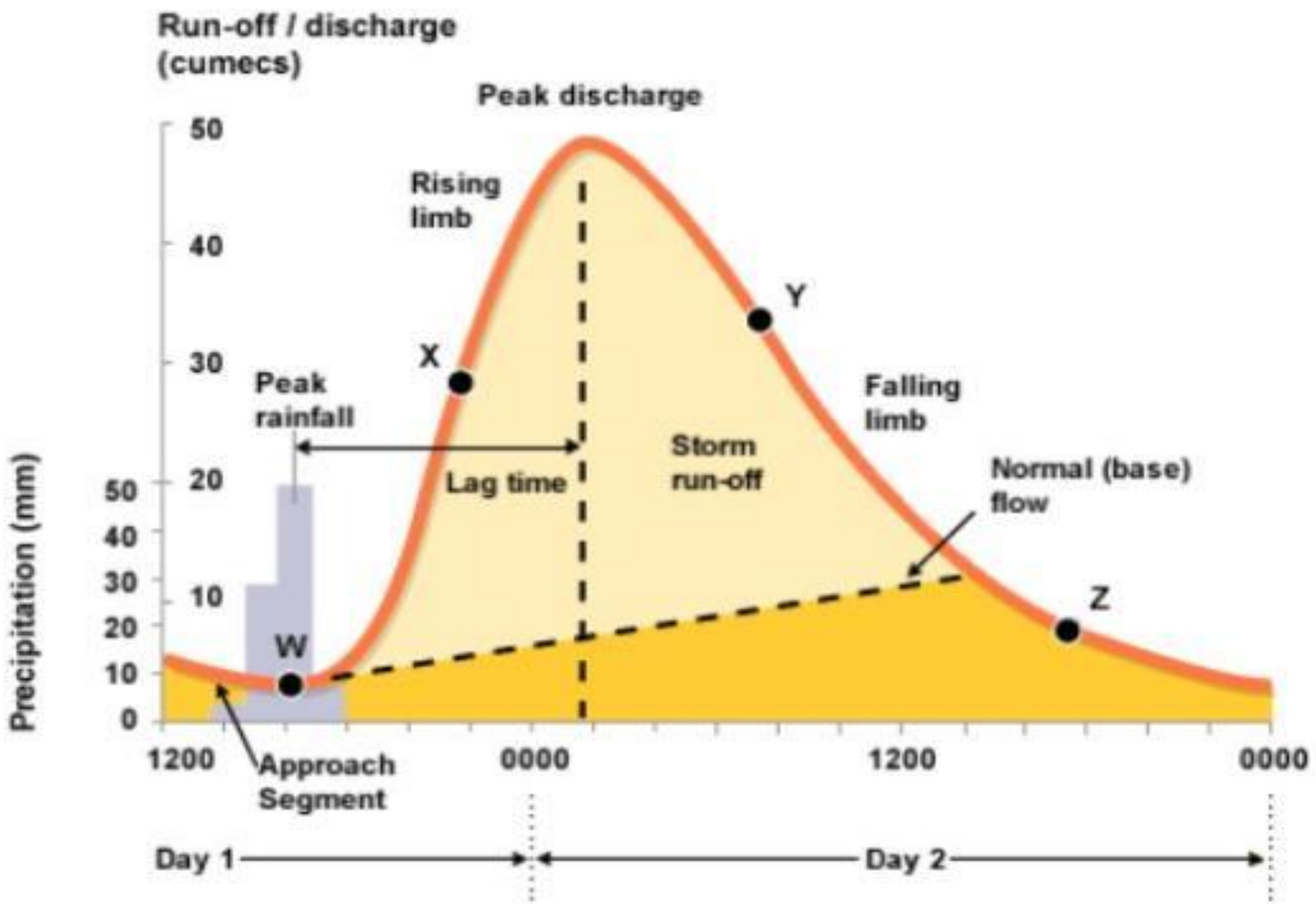
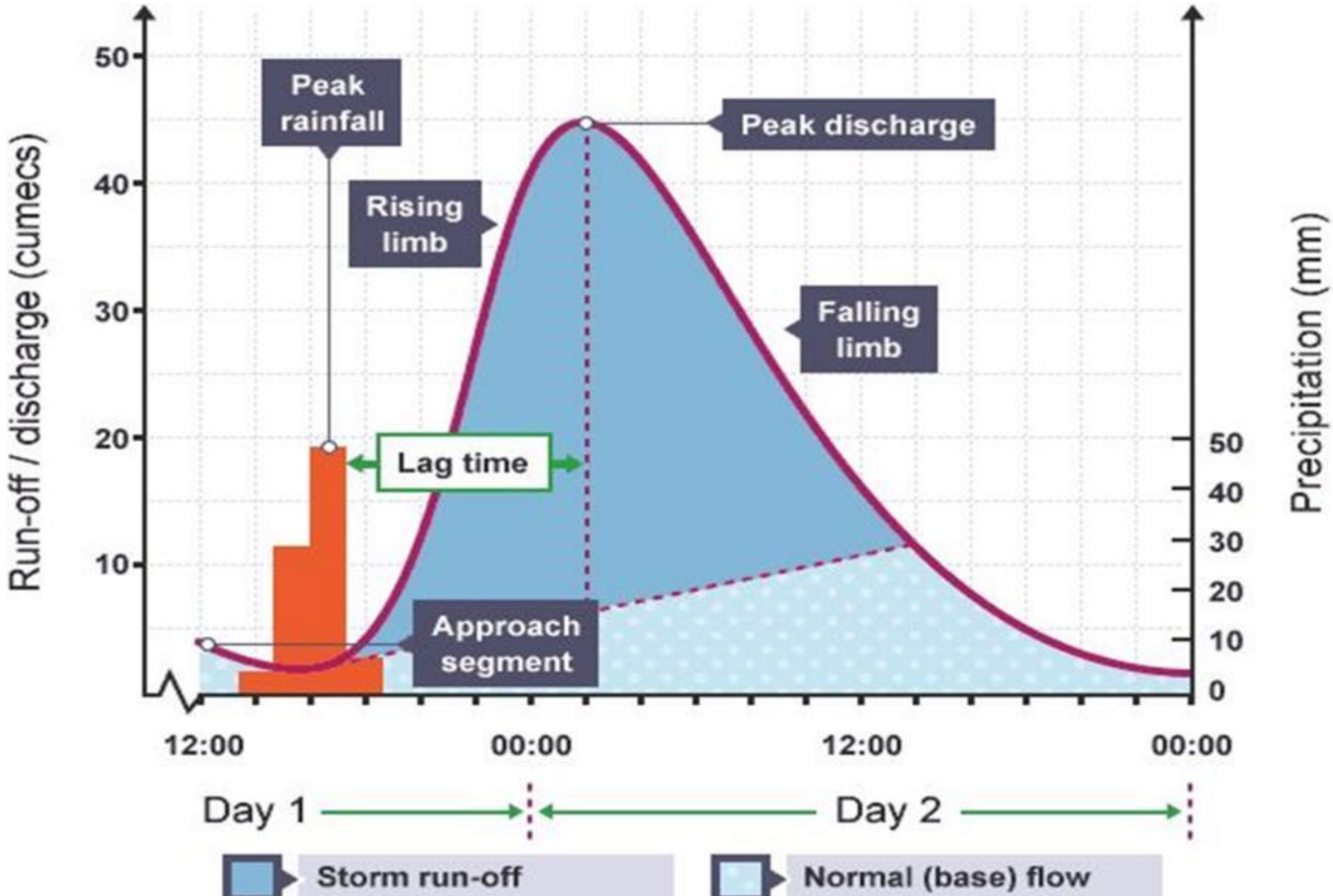


Fig. 2.7. Base flow separation

BASE FLOW SEPARATION

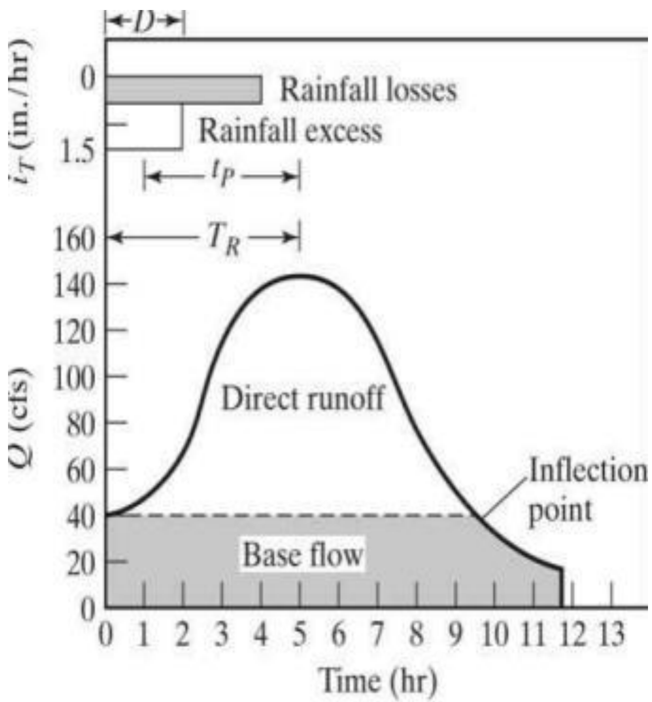


BASE FLOW SEPARATION



UNIT HYDROGRAPH

- An unit hydrograph (UH) is the hypothetical unit response of a watershed (in terms of runoff volume and timing) to a unit input of rainfall. It can be defined as the **direct runoff hydrograph** (DRH) resulting from one unit (e.g., one cm or one inch) of effective rainfall occurring uniformly over that watershed at a uniform rate over a unit period of time.
- As a UH is applicable only to the direct runoff component of a hydrograph (i.e., surface runoff), a separate determination of the baseflow component is required.



(a)

- The amount of run-off resulting from 1 unit (1cm, 1mm, 1ft, etc.) of rainfall excess. It is essentially tool for determining the direct runoff response to rainfall.

Basic Assumptions of UH:

1. The effective rainfall is uniformly distributed within its duration
2. The effective rainfall is uniformly distributed over the whole drainage basin .The base duration of direct runoff hydrograph due to an effective rainfall of unit duration is constant.
3. The ordinates of DRH are directly proportional to the total amount of DR of each hydrograph. For a given basin, the runoff hydrograph due to a given period of rainfall reflects all the combined physical characteristics of basin (time-invariant)

UNIT HYDROGRAPH

- **FEATURES OF UNIT HYDROGRAPH ARE:**

  Has a rising limb. It is also known as the increasing limb. This limb indicates an increase in discharge over time due to initial infiltration that had occurred during rainfall. The initial losses also leads to higher rates of discharge.

  The recession limb is also known as the declined limb indicating maximum water storage due decreased discharge of direct runoff.

  The crest segment which is a segment that indicates maximum discharge due to high drainage runoff. It is also referred to as the peak of the discharge of a given storm.

ASSUMPTIONS OF A UNIT HYDROGRAPH:

- There is time invariance as time is not exactly uniformly distributed to the hydrograph.
- There is no valid linear response thus no linearity considered on the hydrograph.
- The base periods of the hydrograph over effective rainfall uniformly distributed over a given period of time are not the same.
- The effective rainfall is uniformly distributed over a given period of time.
- The effective rainfall is also uniformly distributed through out the year.

LIMITATIONS OF A UNIT HYDROGRAPH:

Unit hydrograph method is not applicable to areas with a major portion of storm precipitation being on form of snow.

- Principle of time in-variance sometimes does not hold as the basin characteristics will chabge with man made adjustments as well as seasons.
- The linearity principle is strictly valid since unit hydrographs derived from small rainfall events generally has lower peaks than those derived from more larger storms.
- The storms that are selected should always be of short duration due to uniform rainfall intensity over long duration.
- Unit hydrographs can only be applied to drainage basins with small areas only and not of the larger areas.

Derivation of Unit hydrograph:

1. A number of isolated storm hydrographs caused by short spells of rainfall excess, each of approximately the same duration (0.9 to 1.1D h) are selected from a study of continuously gauged runoff of the stream
2. For each of these surface runoff hydrographs, the base flow is separated
3. The area under DRH is evaluated and the volume of direct runoff obtained is divided by the catchment area to obtain the depth of ER
4. The ordinates of the various DRHs are divided by the respective ER values to obtain the ordinates of the unit hydrograph

UNIT HYDROGRAPH

Flood hydrographs used in the analysis should be selected so as to meet the following desirable features with respect to the storms responsible for them:

1. The storms should be isolated storms occurring individually
2. The rainfall should be fairly uniform during the duration and should cover the entire catchment area
3. The duration of rainfall should be 1/5 to 1/3 of the basin lag
4. The rainfall excess of the selected storm should be high (A range of ER values of 1.0 to 4.0 cm is preferred).

- Because of spatial and temporal variations in rainfall and due to deviations of the storms from the assumptions in the unit hydrograph theory, the various unit hydrographs developed will not be exactly identical
- In general, the mean of these curves is adopted as the unit hydrograph of the given duration for the catchment
- The average of the peak flows and the time to peaks are computed first.

UNIT HYDROGRAPH

- Then a mean curve of best fit (by eye judgment) is drawn through the averaged peak to close on an averaged base length
- The volume of the DRH is determined and any departure from unity is corrected by adjusting the peak value
- It is assumed that the rainfall excess occurs uniformly over the catchment during the duration D hours of a unit hydrograph
- An ideal duration for a unit hydrograph is one in which small fluctuations in rainfall intensity does not have any significant effect on the runoff
- The duration of the unit hydrograph should not exceed 1/5 to 1/3 of the basin lag
- In general, for catchments larger than 250sq.km., 6 hour duration is satisfactory.

Unit Hydrograph from a Complex Storm:

- When suitable simple isolated storms are not available, data from complex storms of long duration will have to be used to derive the unit hydrograph
- The problem is to decompose a measured composite flood hydrograph into its component DRHs and base flow
- A common unit hydrograph of appropriate duration is assumed to exist
- This is the inverse problem of derivation of the flood hydrograph
- Consider a rainfall excess made up of three consecutive durations of D hours and ER values of .
- After base flow separation of the resulting composite flood hydrograph, a composite DRH is obtained. Let the ordinates of the composite DRH be drawn at a time interval of D hours.

SYNTHETIC UNIT HYDROGRAPH

Synthetic hydrographs are derived by:

- Relating hydrograph characteristics such as peak flow, base time etc. with watershed characteristics such as area and time of concentration.
- Using dimensionless unit hydrograph
- Based on watershed storage

Need for synthetic UH:

UH is applicable only for gauged watershed and for the point on the stream where data are measured For other locations on the stream in the same watershed or for nearby (ungauged) watersheds, synthetic procedures are used.

SYNTHETIC UNIT HYDROGRAPH

Snyder's method allows the computations of

1. lag time (t_L);
2. UH duration (t_r);
3. UH peak discharge (q_p);
4. Hydrograph time width at 50% and 75% (W_{50}, W_{75}) of peak flow.

1. Lag time (t_L): time from the center of rainfall – excess to the UH peak

where t_L = Time [hrs];

C_1 = 0.75 for SI unit; 1.0 for English unit;

C_t = Coefficient which is a function of watershed slope and shape, 1.8~2.2 (for steeper slope, C_t is smaller);

L = length of the main channel [mi, km]; L_c = length along the main channel to the point nearest to the watershed centroid .

2. UH Duration (t r):

$$t_r = t_L / 5.5$$

where tr and tL are in [hrs]. If the duration of UH is other than tr , then the lag time needs to be adjusted as

$$t_{pL} = t_L + 0.25\,(t_R - t_r)$$

where tLR = adjusted lag time; tR = desired UH duration.

3. UH Peak Discharge (qp):

$$q_p = \frac{C_2 C_p}{t_{pR}}$$

or where C2 = 2.75 for SI unit; 640 for English unit; Cp = coefficient accounting for flood wave and storage condition, 0.4 ~ 0.8; qp = specific discharge, [m3/s/km2] or [ft3/s/mi2] To compute actual discharge, Qp = Axqp

SYNTHETIC UNIT HYDROGRAPH

4. Time Base (tb):

Assuming triangular UH,

$$t_b = C3/q_p$$

where t_b – [hrs]; C_3 = 5.56 for SI unit, 1290 for English unit.

5. UH Widths:

$$W_{75} = \frac{C_{w,75}}{q_p^{1.08}} \quad \text{or} \quad W_{50} = \frac{C_{w,50}}{q_p^{1.08}}$$

where $C_{W,75}$ = 1.22 for SI unit; 440 for English unit; $C_{W,50}$ = 2.14 for SI unit; 770 for English unit;. W_{50}, W_{75} are in hours; Usually, 1/3 of the width is distributed before UH peak and 2/3 after the peak Remember to check that the volume of UH is close to 1 cm or 1 inch.

UNIT III
GROUND WATER OCCURRENCE

CLOs	Course Learning Outcome
CLO 11	Understand the Ground water Occurrence and types of aquifers
CLO 12	Define and understand the different terminology of water resource engineering like aquifer parameters, porosity, specific yield, permeability, and Transmissivity.
CLO 13	Determine the radial flow to wells in confined and unconfined aquifers
CLO 14	Understand the concept of Darcy’s law in aquifiers
CLO 15	Understand the Types of wells, well construction, and well development.

GROUND WATER :

Water located beneath the earth's surface in soil pore spaces and in the fractures of rock formations. The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water is called the water table.

SUB SURFACE WATER :

Water in a soil mantle is called as sub surface water.

Water beneath the surface can essentially be divided into two zones.

- The unsaturated zone (also known as the "zone of aeration") which includes soil water zone,
- The zone of saturation which includes ground water.

GROUND WATER

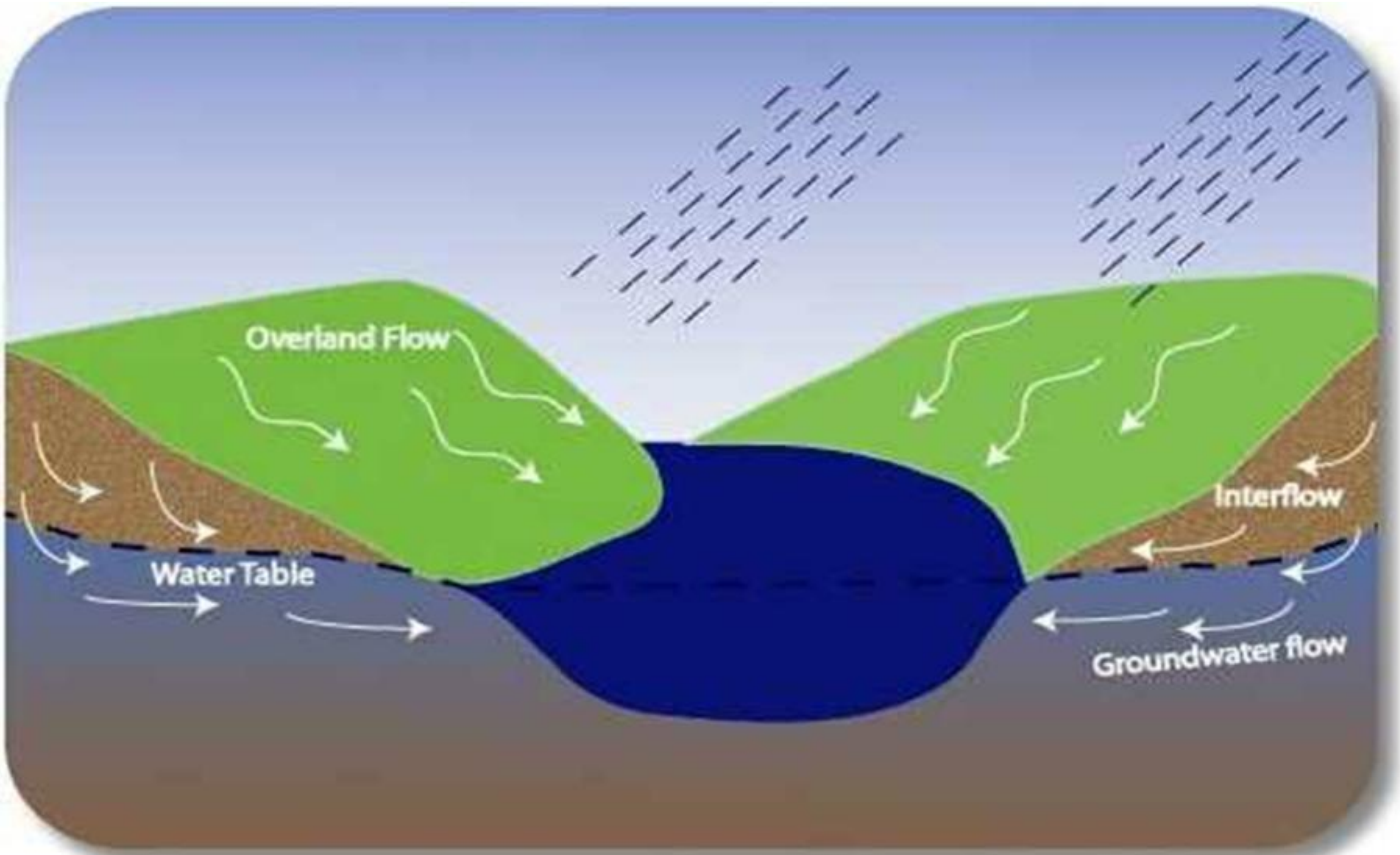
- The water table divides the zone of aeration from the zone of saturation.
- In the saturation zone, all the pores of soil are filled with water.
- In the aeration zone, soil pores are partially saturated with water.
- The aeration zone has 3 sub-zones.

i) Soil water zone

ii) Intermediate zone

iii) Capillary fringe

GROUND WATER



SOIL WATER ZONE:

• Soil water is held in the pore spaces between particles of soil.

• Soil water is the water that is immediately available to plants.

• This water can be removed by air drying or by plant absorption, but cannot be removed by gravity.

Plants extract this water through their roots until the soil capillary force (force holding water to the particle) is equal to the extractive force of the plant root.

• At this point the plant cannot pull water from the plantrooting zone and it wilts (called the wilting point).

• The amount of water held in the soil after excess water has drained is called the field capacity of the soil.

GROUND WATER

INTERMEDIATE ZONE:

- This is the layer that is available next to the soil water zone.
- It lies in between the soil water zone and the capillary zone.

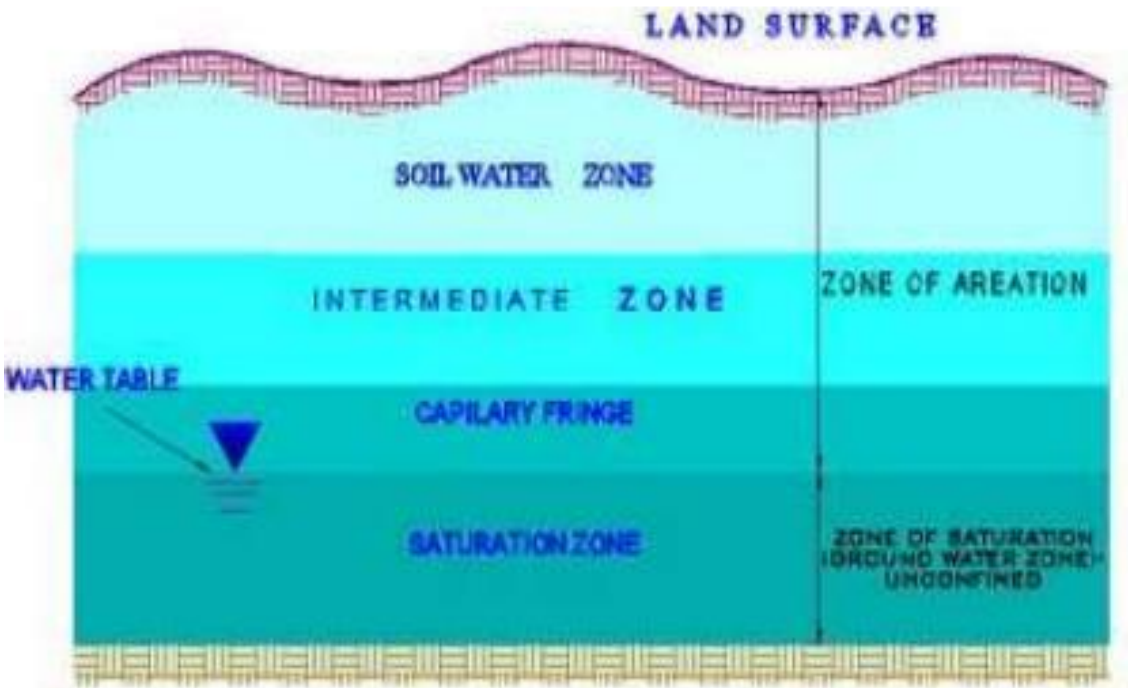
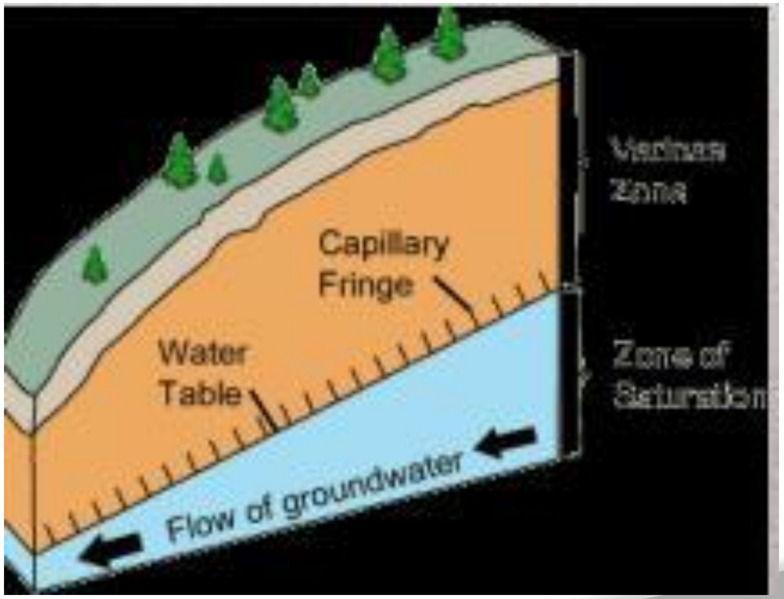


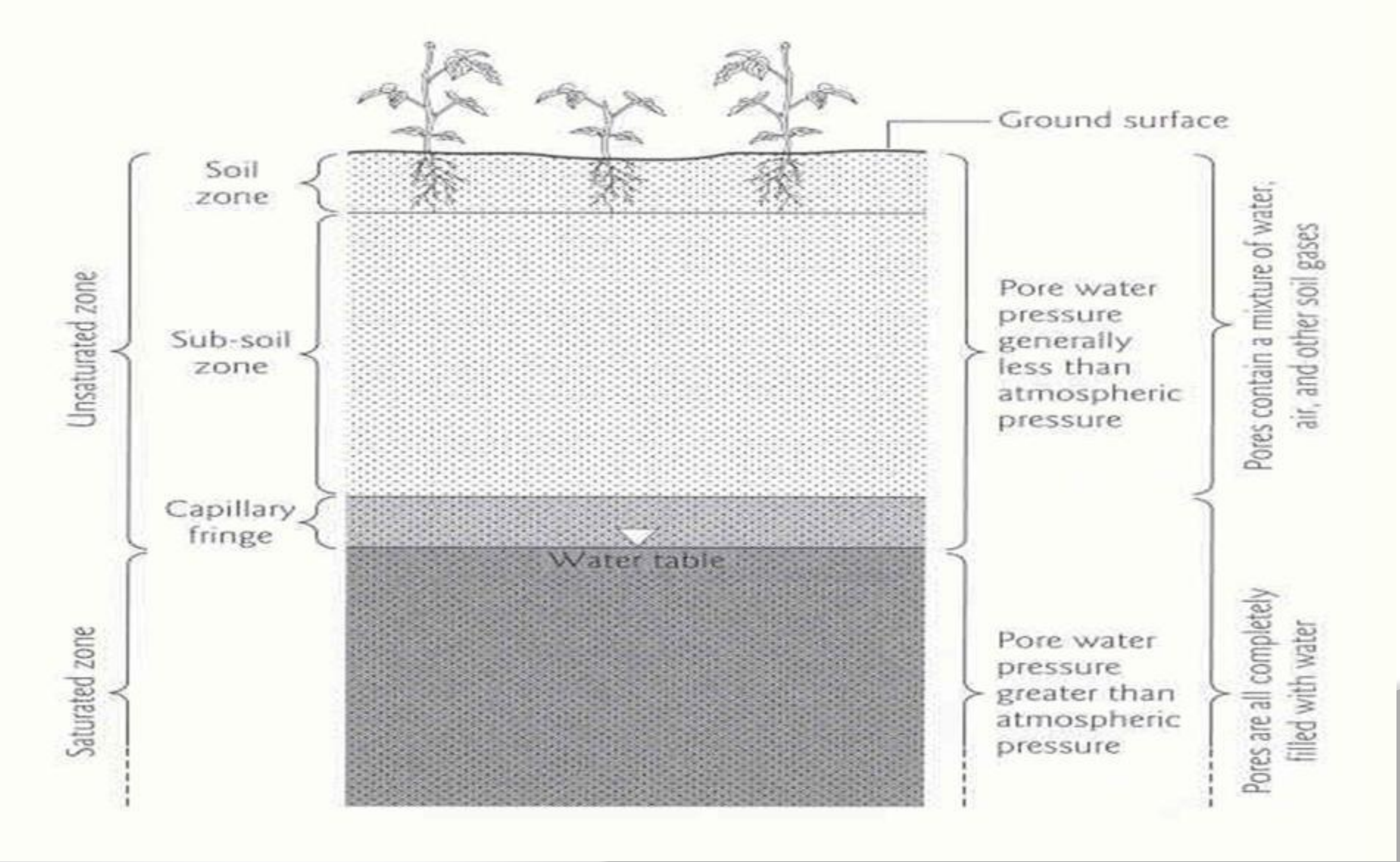
FIG. CLASSIFICATION OF SUBSURFACE WATER

CAPILLARY ZONE:

- The capillary fringe is the subsurface layer in which groundwater seeps up from a water table by capillary action to fill pores.
- Pores at the base of the capillary fringe are filled with water due to tension saturation.



GROUND WATER



GROUND WATER

- This saturated portion of the capillary fringe is less than total capillary rise because of the presence of a mix in pore size.
- If pore size is small and relatively uniform, it is possible that soils can be completely saturated with water for several feet above the water table.

Saturated zone is classified into 4 categories.

i) Aquifer

ii) Aquiclude

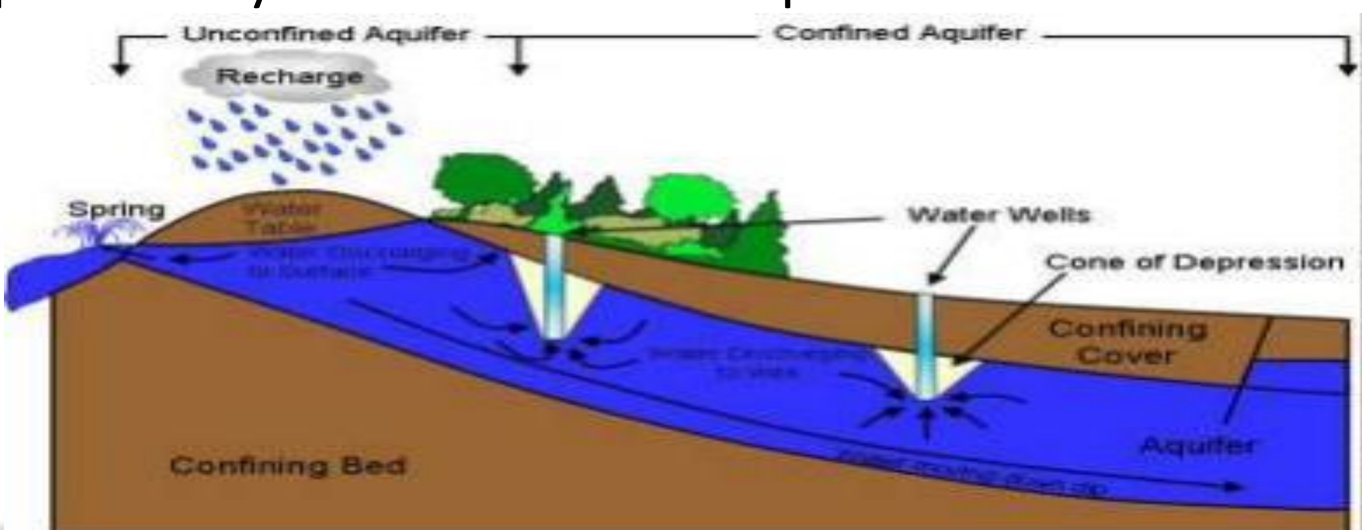
iii) Aquifuge

iv) Aquitard

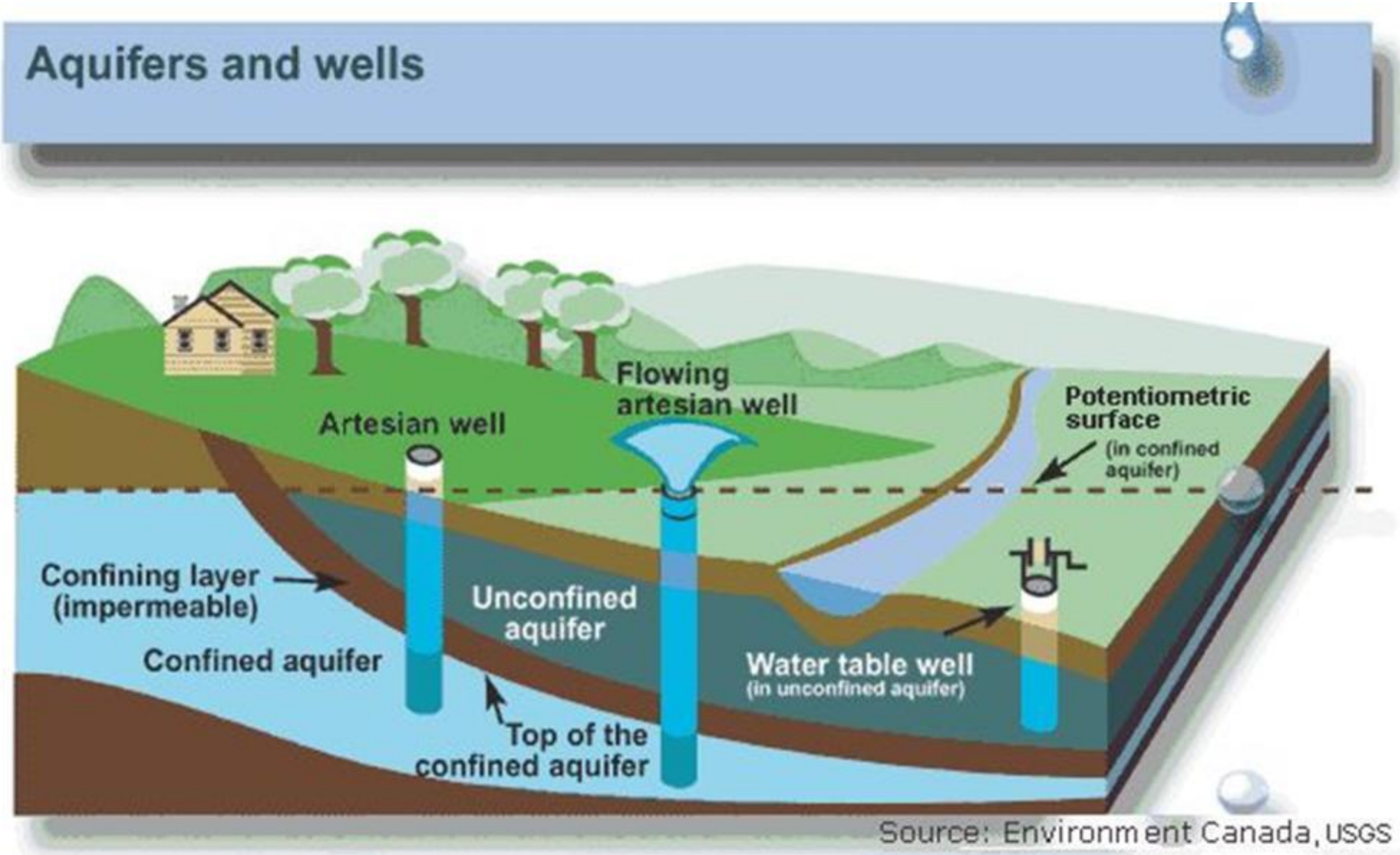
AQUIFER

AQUIFER

- An aquifer is a layer of porous substrate that contains and transmits groundwater.
- An aquifer is an underground layer of water-bearing permeable rock or unconsolidated materials (gravel, sand, or silt) from which groundwater can be extracted using a water well.
- Aquifers may occur at various depths.

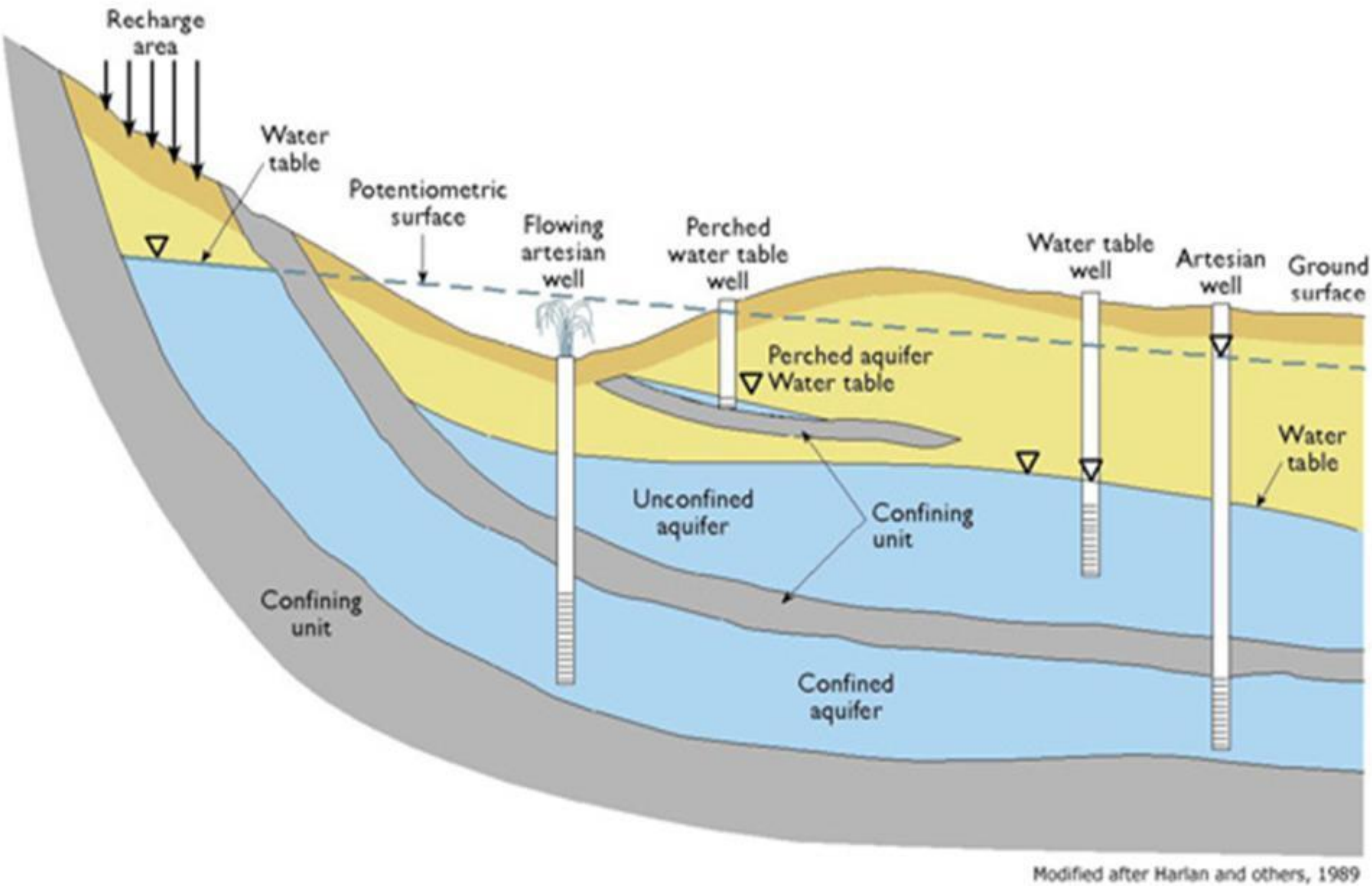


AQUIFER



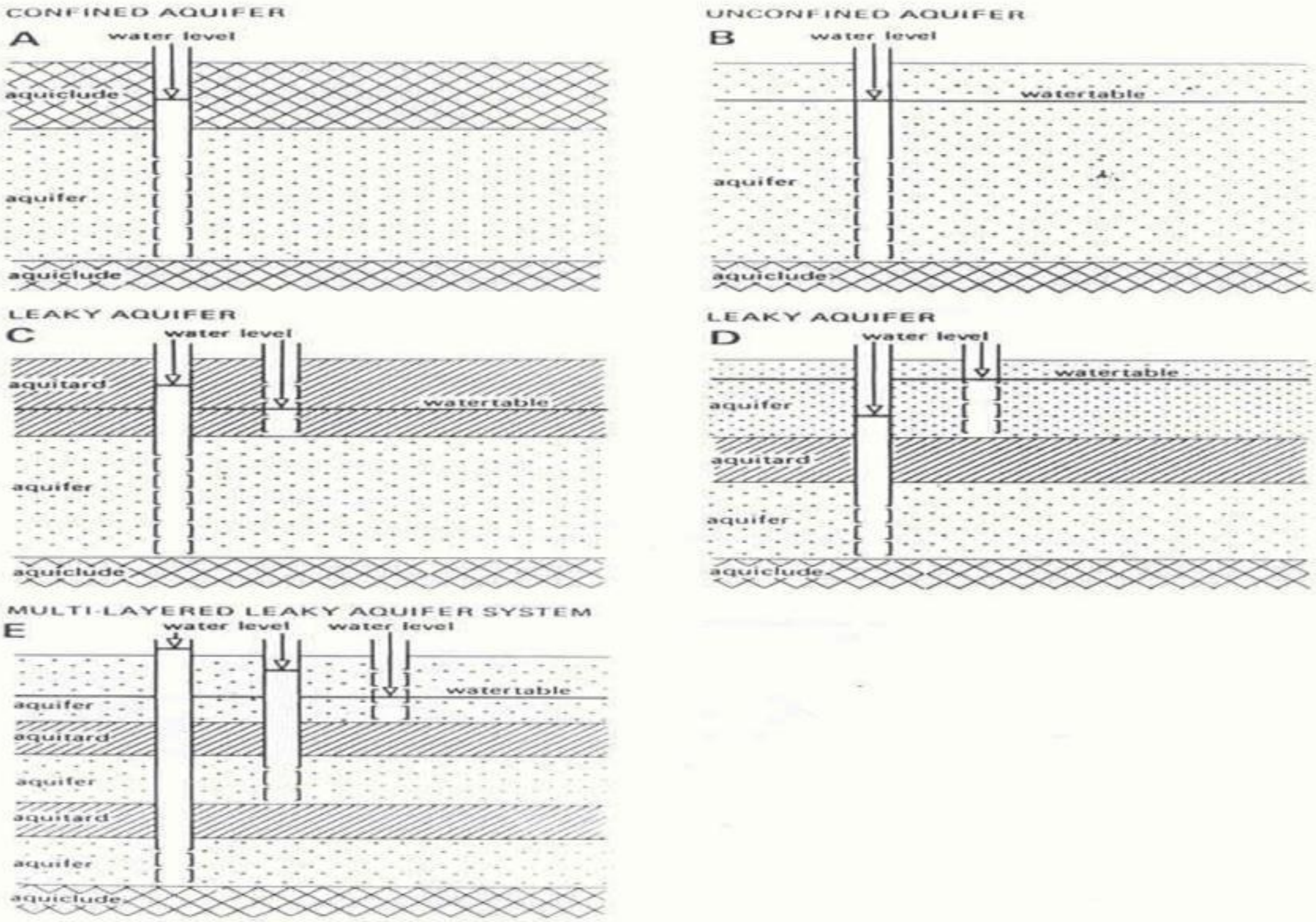
Aquifers and wells
Flowing artesian well
Artesian well
Potentiometric surface
(in confined aquifer)
Confining layer (impermeable)
Unconfined aquifer
Confined aquifer
Water table well
(in unconfined aquifer)
Top of the confined aquifer
Source: Environment Canada, USGS

AQUIFER



Recharge area
Water table
Potentiometric surface
Flowing artesian well
Perched water table well
Water table well
Artesian well
Ground surface
Perched aquifer
Water table
Water table
Unconfined aquifer
Confining unit
Confining unit
Confined aquifer
Modified after Harlan and others, 1989

AQUIFER



CONFINED AQUIFER
A
water level
aquiclude
aquifer
aquiclude
UNCONFINED AQUIFER
B
water level
watertable
aquifer
aquiclude
LEAKY AQUIFER
C
water level
aquitard
watertable
aquifer
aquiclude
LEAKY AQUIFER
D
water level
watertable
aquifer
aquitard
aquifer
aquiclude
MULTI-LAYERED LEAKY AQUIFER SYSTEM
E
water level
water level
watertable
aquifer
aquitard
aquifer
aquitard
aquifer
aquiclude

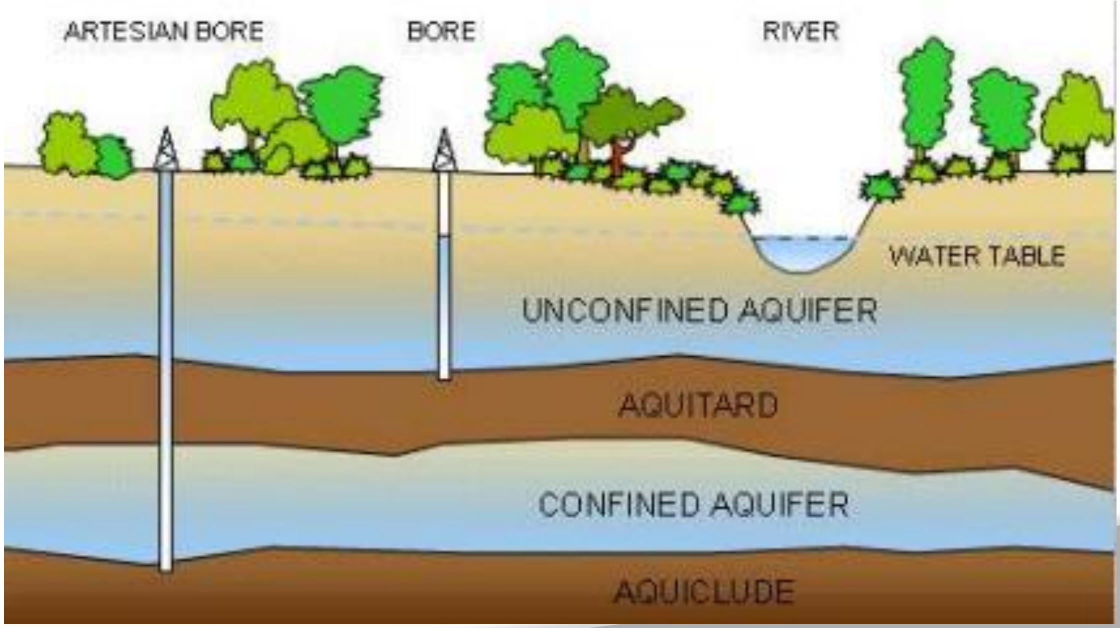
TYPES OF AQUIFER

UNCONFINED AQUIFER:

- Unconfined aquifers are sometimes also called water table or phreatic aquifers, because their upper boundary is the water table
- When water can flow directly between the surface and the saturated zone of an aquifer, the aquifer is unconfined.
- The deeper parts of unconfined aquifers are usually more saturated since gravity causes water to flow downward.

CONFINED AQUIFER:

- A water-bearing subsurface stratum that is bounded above and below by formations of impermeable, or relatively impermeable soil or rock.
- Also know as an artesian aquifer.



PROPERTIES OF THE AQUIFER

- Porosity
- Specific yield
- Specific retention
- Storage by efficiency (field capacity)
- Permeability
- Transmissibility

PROPERTIES OF THE AQUIFER

POROSITY:

- Porosity or void fraction is a measure of the void (i.e., "empty") spaces in a material, and is a fraction of the volume of voids over the total volume, between 0–1, or as a percentage between 0–100%.
- Porosity of surface soil typically decreases as particle size increases.

SPECIFIC YIELD:

The quantity of water which a unit volume of aquifer, after being saturated, will yield by gravity; it is expressed either as a ratio or as a percentage of the volume of the aquifer; specific yield is a measure of the water available to wells.

FIELD CAPACITY:

• Field capacity is the amount of soil moisture or water content held in soil after excess water has drained away . • The physical definition of field capacity is the bulk water content retained in soil.

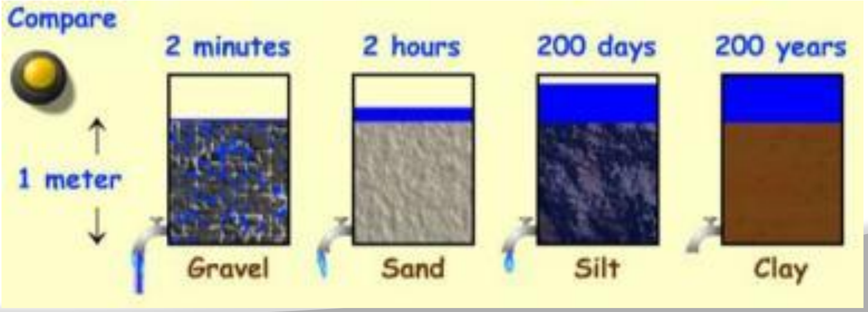
PROPERTIES OF THE AQUIFER

SPECIFIC RETENTION:

The ratio of the volume of water that a given body of rock or soil will hold against the pull of gravity to the volume of the body itself. It is usually expressed as a percentage.

PERMEABILITY

- Just as the porosity of a soil affects how much water it can hold, it also affects how quickly water can flow through the soil.
- The ability of water to flow through a soil is referred to as the soil's permeability.

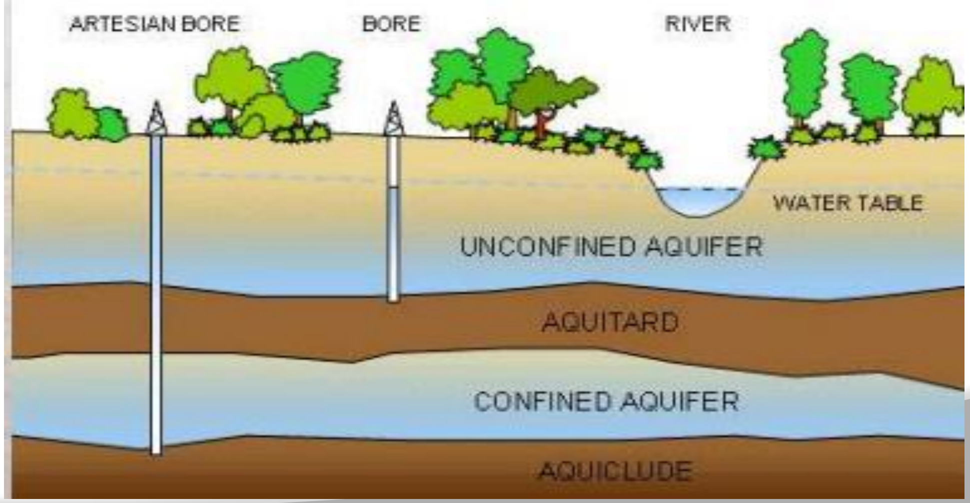


TRANSMISSIBILITY

- A measure of the ratio of the response amplitude of the system in steady-state forced vibration to the excitation amplitude; the ratio may be in forces, displacements, velocities, or accelerations.
- The transmissibility of an unconfined aquifer depends upon the depth of the GWT.

AQUICLUDE

- It is a solid, impermeable area underlying or overlying an aquifer. If the impermeable area overlies the aquifer pressure could cause it to become a confined aquifer.
- A solid, impermeable area underlying or overlying an aquifer.
- It can absorb water but cannot transmit it in significant amount.



AQUIFUGE:

- An impermeable body of rock which contains no interconnected openings or interstices and therefore neither absorbs nor transmits water.

AQUITARD:

- A bed of low permeability adjacent to an aquifer; may serve as a storage unit for groundwater, although it does not yield water readily.

DARCY'S LAW

- Darcy's law is a simple proportional relationship between the instantaneous discharge rate through a porous medium, the viscosity of the fluid and the pressure drop over a given distance.
- Darcy's law is only valid for slow, viscous flow;

$$Q=Tiw$$

i= hydraulic gradient

w= width of the aquifer

T= co.eff of transmissibility of the aquifer

DARCY’S LAW

Typically any flow with a Reynolds number less than one is clearly laminar, and it would be valid to apply Darcy's

$$Re=(\rho Vd)/\mu$$

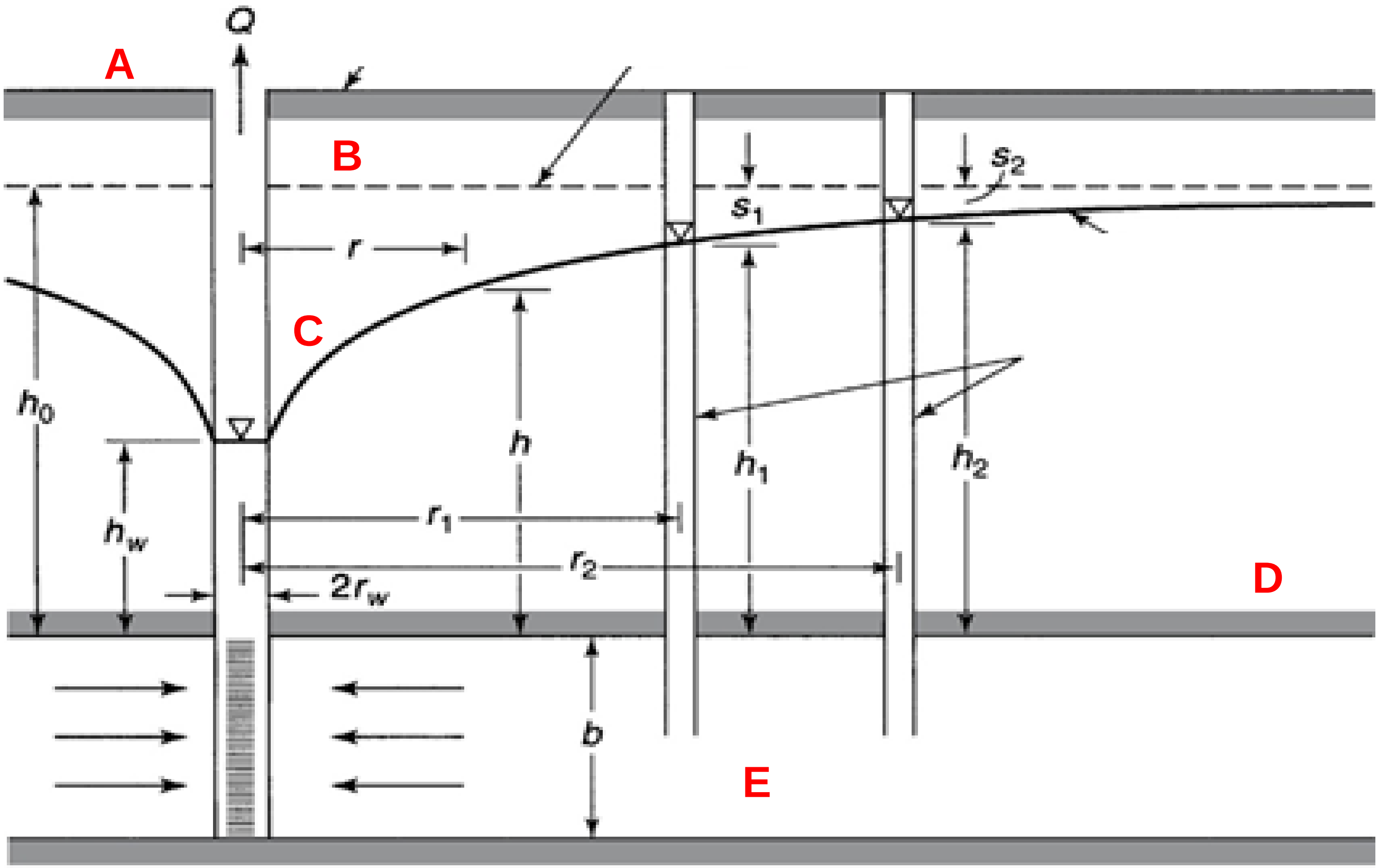
where ρ is the density of water (units of mass per volume)

v is the specific discharge (not the pore velocity — with units of length per time)

d30 is a representative grain diameter for the porous media (often taken as the 30% passing size from a grain size analysis using sieves - with units of length)

μ is the viscosity of the fluid.

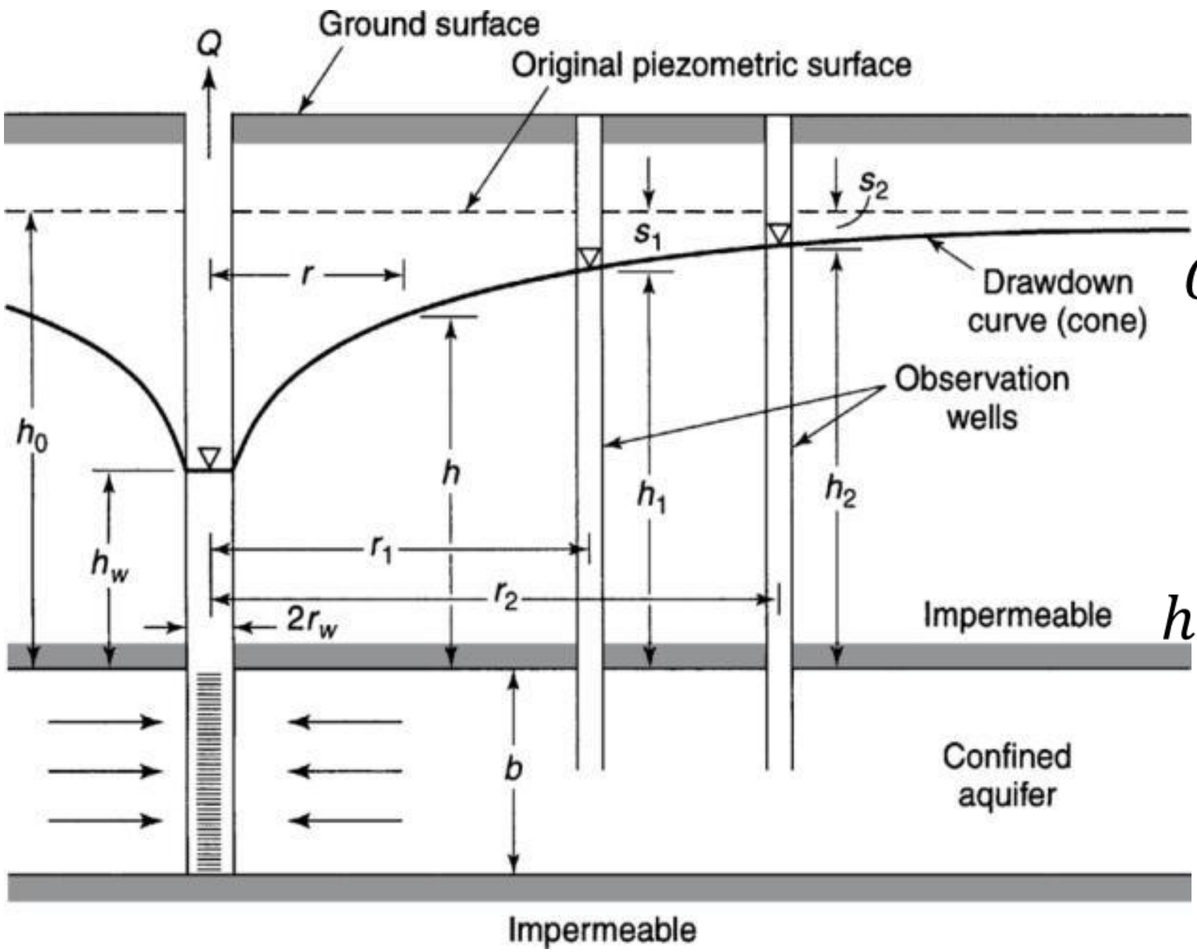
RADIAL FLOW TO WELLS IN CONFINED AQUIFER



The well labeled A is a

A Artesian well; B Flowing well; C Observation well; D Fracking well;
E None of the options

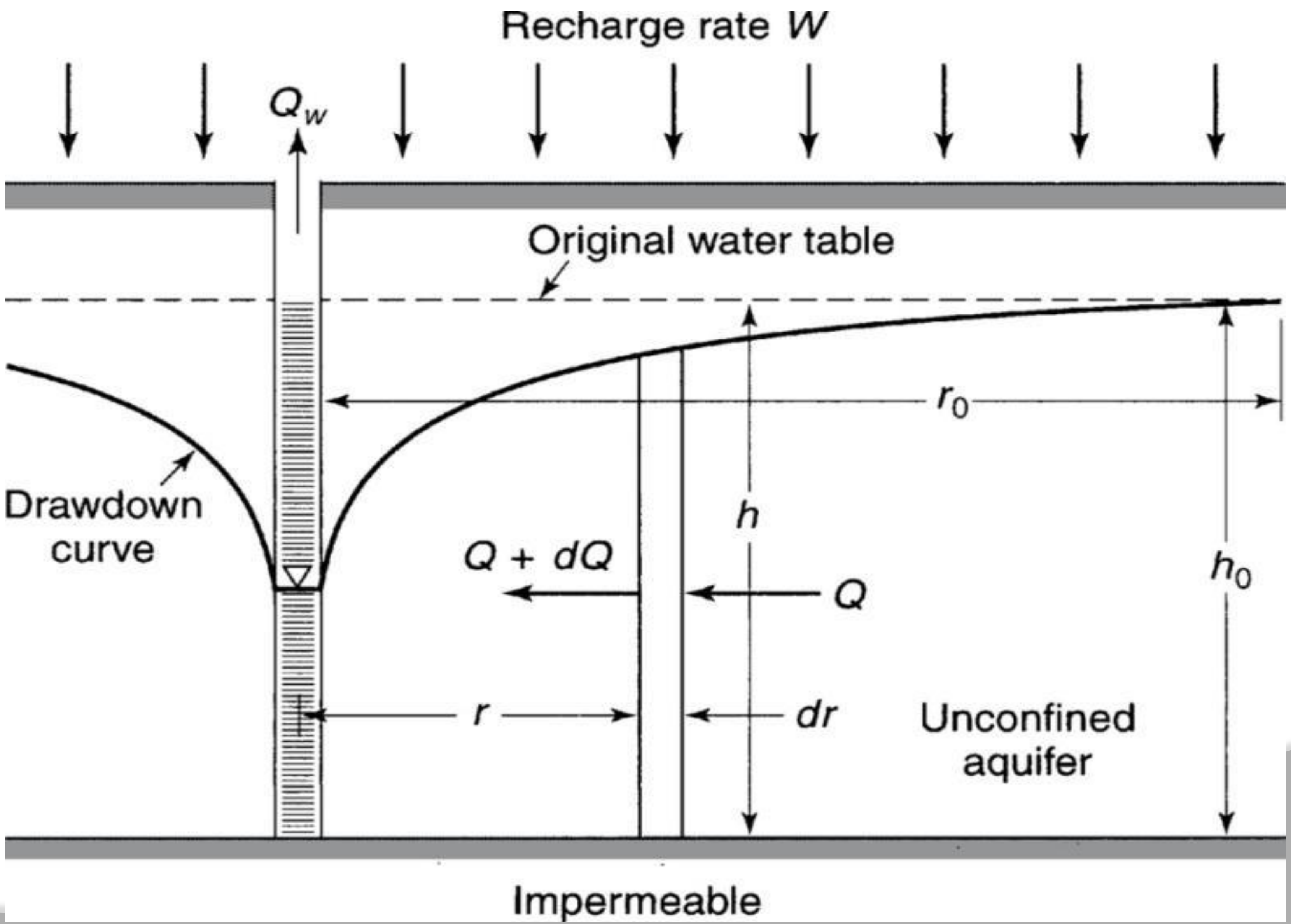
RADIAL FLOW TO WELLS IN CONFINED AQUIFER



$$Q = 2\pi K b \frac{h - h_w}{\ln(r/r_w)}$$

$$h - h_w = \frac{Q \ln(r/r_w)}{2\pi K b}$$

RADIAL FLOW TO WELLS IN UNCONFINED AQUIFER



RADIAL FLOW TO WELLS IN UNCONFINED AQUIFER

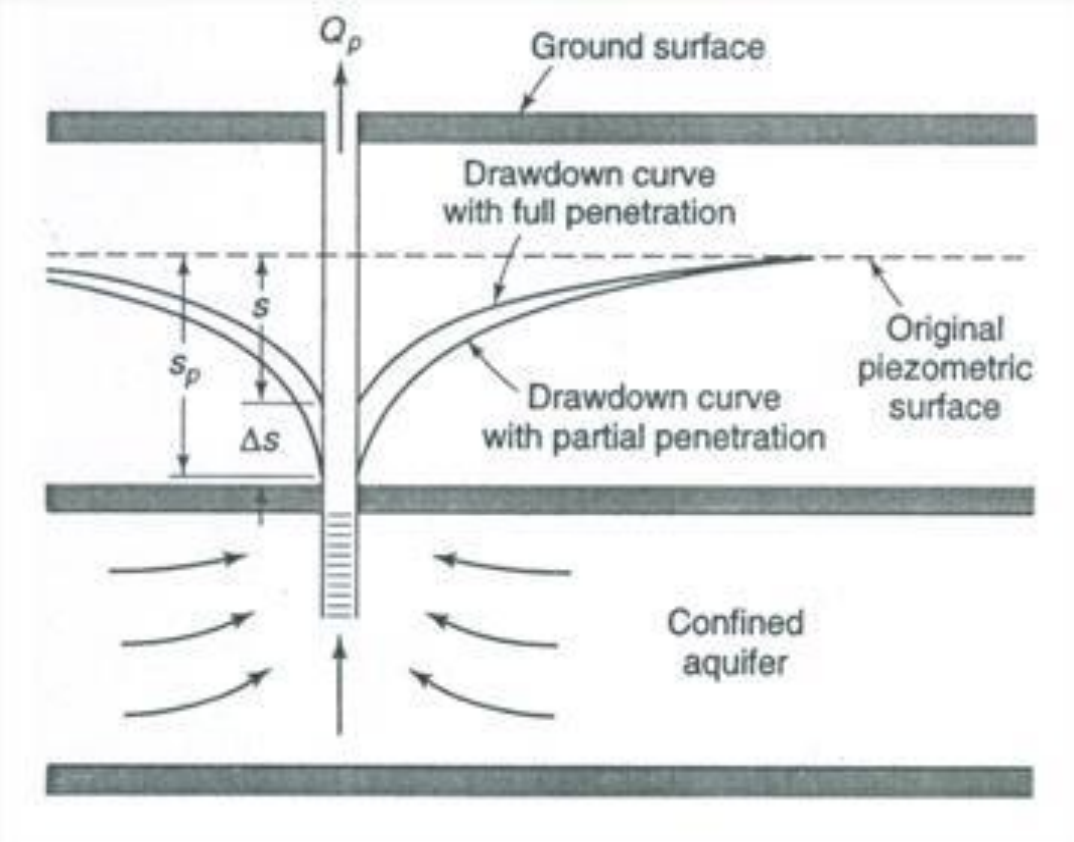


Fig. 10.4. Effect of a partially penetrating well on drawdown.

$$Q = \pi K \times \frac{h_2^2 - h_1^2}{\ln\left(\frac{r_2}{r_1}\right)}$$

UNIT IV
NECESSITY AND IMPORTANCE OF IRRIGATION

CLOs	Course Learning Outcomes
CLO 16	Understand the work necessity and importance of irrigation, advantages and ill effects of irrigation, types of irrigation
CLO 17	Explain the methods of application of irrigation water and understand the India agricultural soils, methods of improving soil fertility, crop rotation, and preparation of land for irrigation
CLO 18	Understand the standards of quality for irrigation water, soil, water, plant relationship, vertical distribution of soil moisture, soil moisture constants.

CLOs	Course Learning Outcomes
CLO 19	Calculate the soil moisture tension, consumptive use, duty and delta and understand the factors affecting duty.
CLO 20	Determination of design discharge for a water course. Depth and frequency of irrigation, irrigation efficiencies, water logging

DEFINITION

- Irrigation is defined as a process of supplying water to crops artificially.
- The science of planning and designing a water supply system to the plants, crops, for their normal growth during the period of no rainfall with the help of dam, weir, barrage, reservoir and canal system with head works, cross drainage works.

Necessity of Irrigation:

- Insufficient Rainfall.
- Uneven or Non-Uniform Rainfall Distribution
- Improvement of Perennial Crops.
- Development of Desert Area.

BENEFITS OF IRRIGATION

- Yields of crops
- Optimum benefits
- Elimination of mixed cropping
- Prosperity of farmers
- Sources of Revenue
- Hydro-Electric Power Generation
- Water Supply
- Self-Sufficiency in Food
- Navigation
- Development of fishery
- Tree Plantation
- Protection from Famine
- Increase of Ground water Level
- Aid to Civilization.
- Nutrition of Population
- Recreation
- Social and Cultural Improvement

Ill- Effects of Irrigation

There are some ill-effects of irrigation .However, benefits are more than ill-effects.

- **Effects on Raising Water Table or Water logging:**

  In unlined irrigation canal, excessive seepage of water through bed and sides takes place which raises the water table of the surrounding areas. Soil in the root zone of the crop is saturated and become alkaline which is harmful to the crops and plants. Thus the nearby area may be waterlogged.

- **Damp Climate :**

  Temperature of the command area of an irrigation projects may be lowered and damp climate prevails, which adversely affect the health of the community living in this area.

III- Effects of Irrigation

- **Breeding Places of Mosquitoes :**

  Due to excess application of water, seepage and leakage from canal, marshy land may be formed leading to breeding place of mosquitos.

- **Loss of Valuable Land :**

  Valuable land may be submerged due to construction of reservoir by dam, weir and

  barrages.

- **Return of Revenue :**

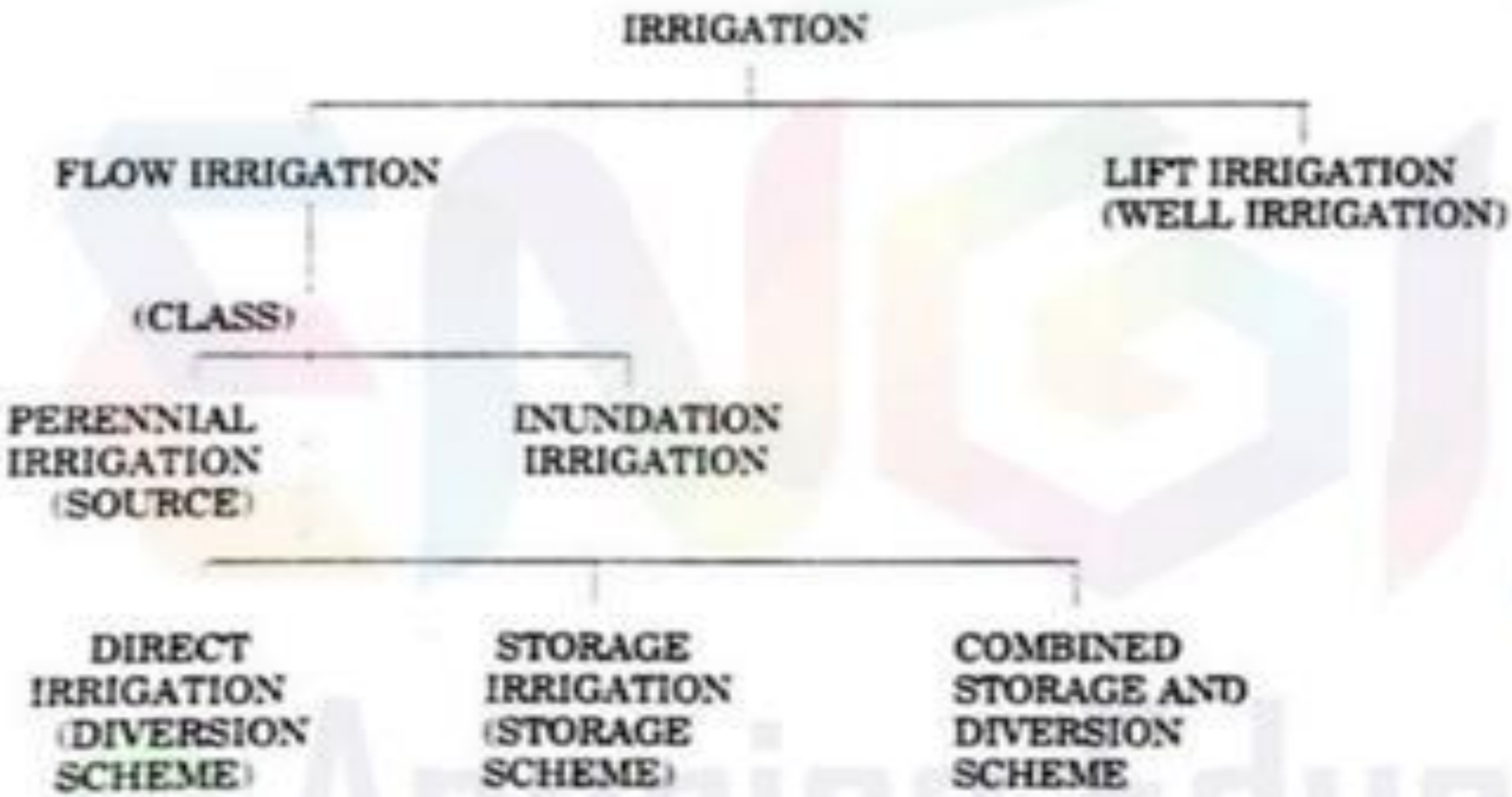
  Irrigation projects are complex and expensive. If project fails due to absence of regular maintenance, return of revenue to the government becomes low compared to its cost of construction. Maintenance cost is quite high for normal functioning of the project.

III- Effects of Irrigation

TYPES OF IRRIGATION

1.7. TYPES OF IRRIGATION

Irrigation has the following main types or classes : (*a*) Flow Irrigation, and (*b*) Lift Irrigation.



TYPES OF IRRIGATION

Two main types of irrigation are:

Flow Irrigation:

Flow irrigation is that type of in which flow of water to crop field from the source takes place due to component of gravity force.

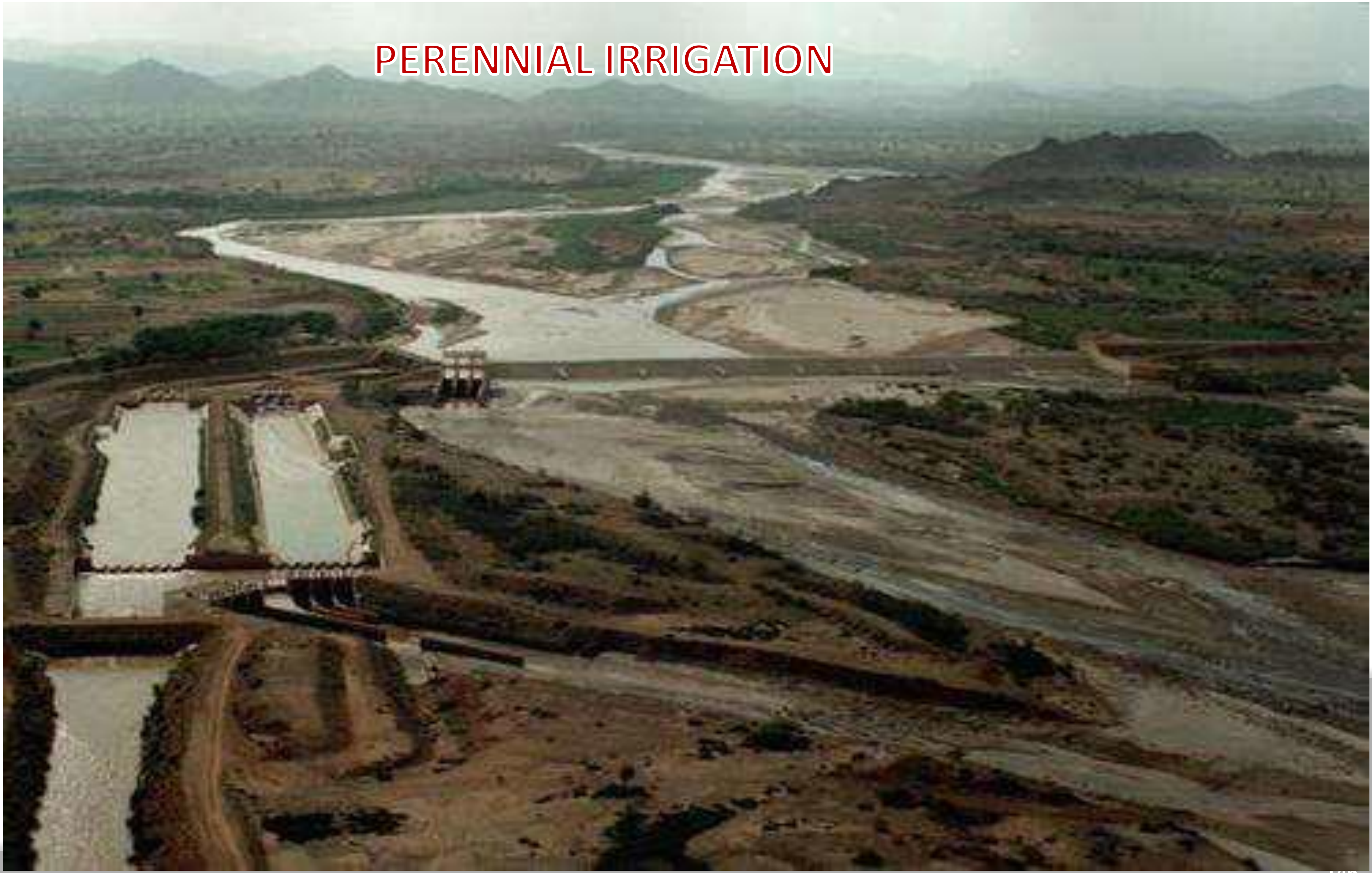
a. Perennial Irrigation:

In this type of source of water is from a river which is perennial.

A weir or barrage is constructed across this river. Sometimes dam may be constructed to form a reservoir upstream. Main canal with a regulator is constructed where one or both banks supply water to the crop field.

TYPES OF IRRIGATION

TYPES OF IRRIGATION



b. Inundation or flood irrigation

It is that type of irrigation in which no control structures like weir, barrage, regulator, etc are constructed. During rainy season, water level in the river rises and canal bed level is kept below High Flood Level (HFL) of the river. The portion of water above the canal bed is diverted to inundate the crop field.

This inundation water is drained off or allowed to absorb in the crop field prior to planting the crop. The whole system depends on the water level in the river. Although no such expenditure is involved in this system, over-irrigation may damage the crops. Therefore, this system is not popular.

TYPES OF IRRIGATION

TYPES OF IRRIGATION

Depending upon the source from which the water is drawn, flow irrigation can further sub divided into 3 types:

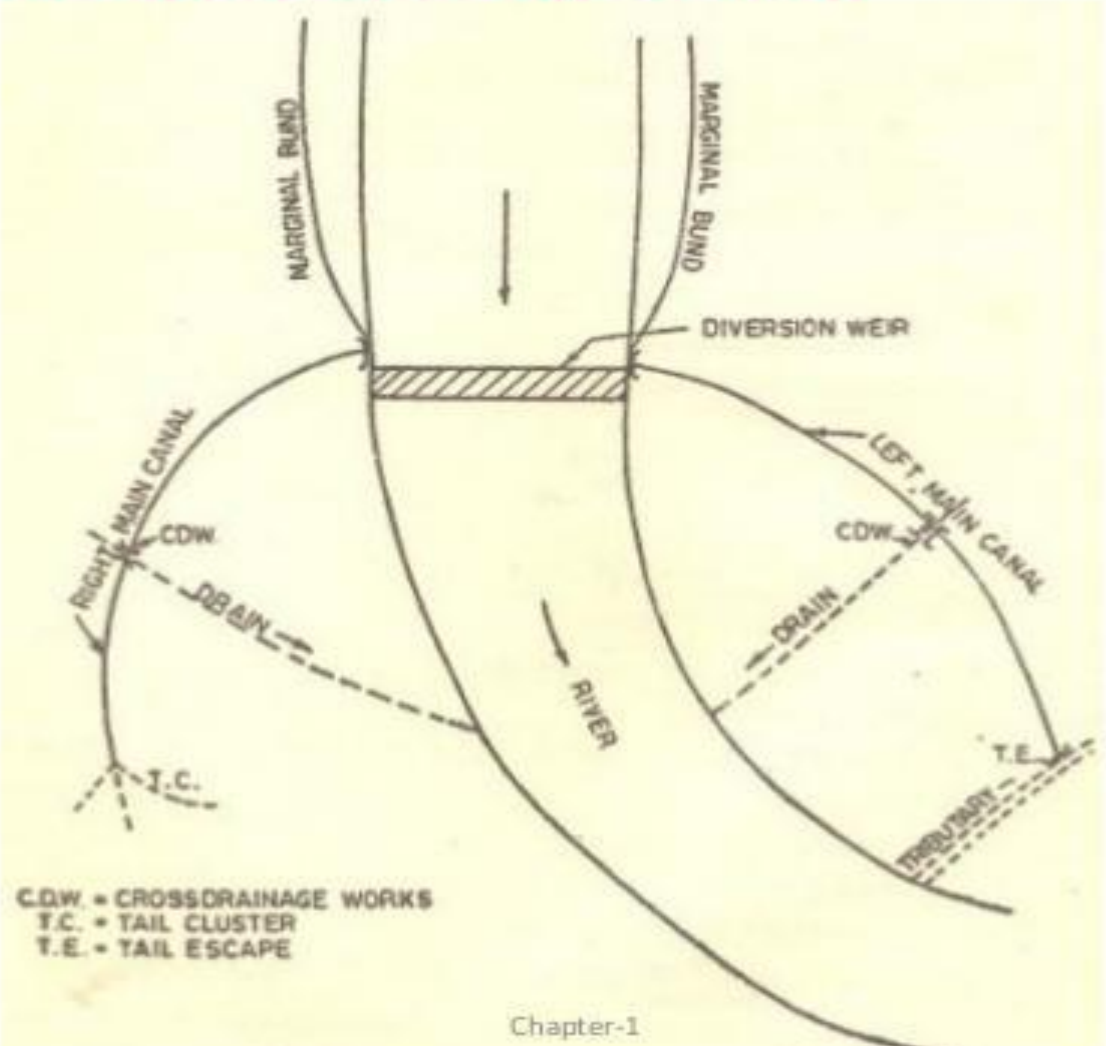
a. Direct Irrigation(River canal Irrigation): Diversion Scheme

In Direct Irrigation no storage of water upstream of diversion weir is provided. Water is directly diverted to canals, without any storage. Water through the canals with regulators is diverted directly to the canals.

b. Storage Irrigation(Reservoir or tank irrigation): Storage Scheme

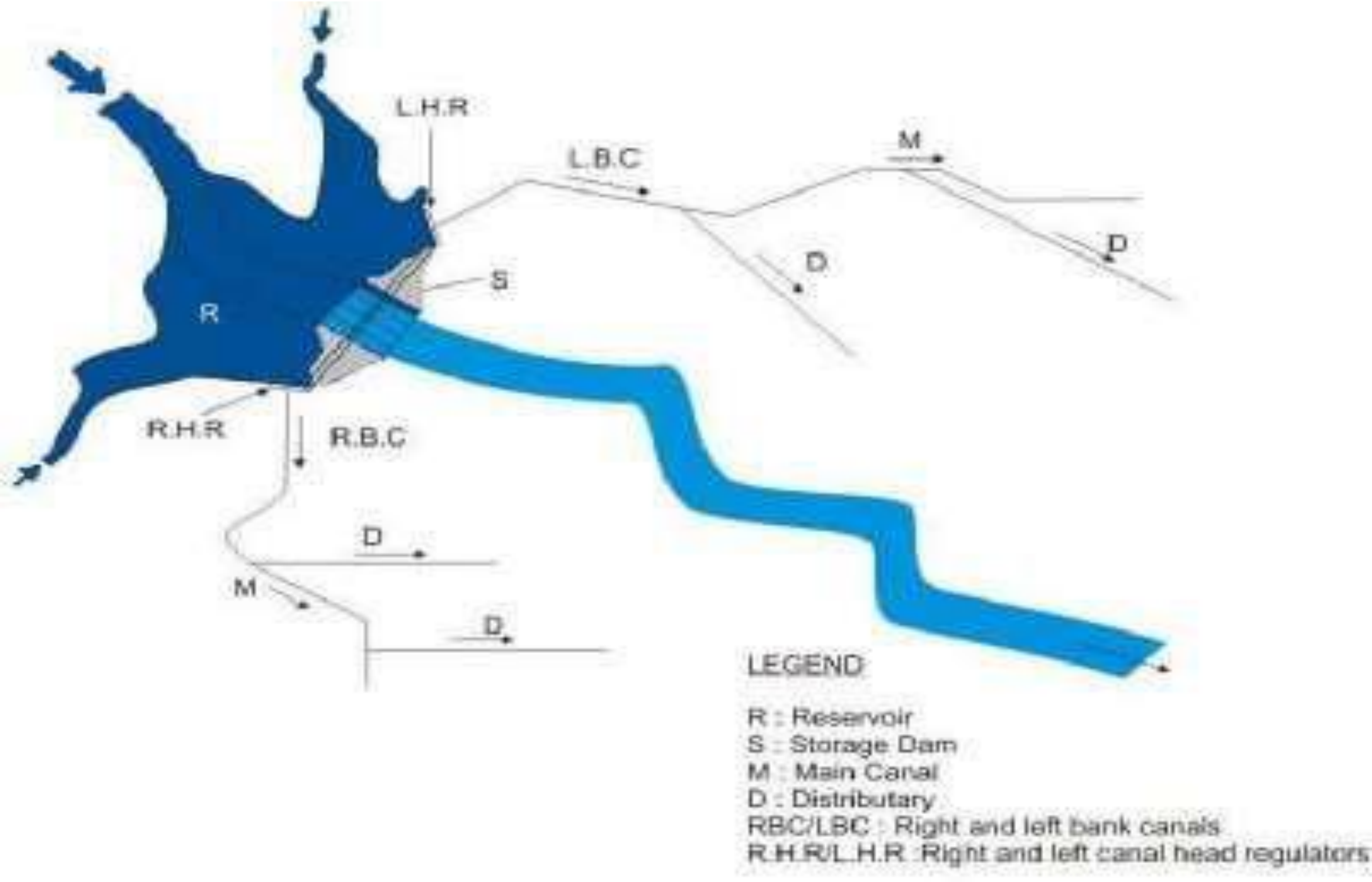
A dam is constructed across the reservoir to store water upstream in a reservoir. It is of a bigger magnitude, water stored is used for hydroelectric production, water supply, etc. besides irrigation depending upon the volume of water stored. A network of canal system is used. In this scheme bigger area could be irrigated to raise more crops. The scheme is costlier than other schemes.

TYPES OF IRRGATION PROJECTS/SCHEMES



Direct irrigation project

TYPES OF IRRIGATION



c. Combined Storage and Diversion Scheme :

In this system, a dam is constructed across a river to form a reservoir. This stored water is used to produce electricity.

A powerhouse is constructed just downstream of the dam. The discharge from the lower house is fed back into river downstream of the dam, a pickup weir at a suitable side is constructed to divert this available water to the crop field by the canals.

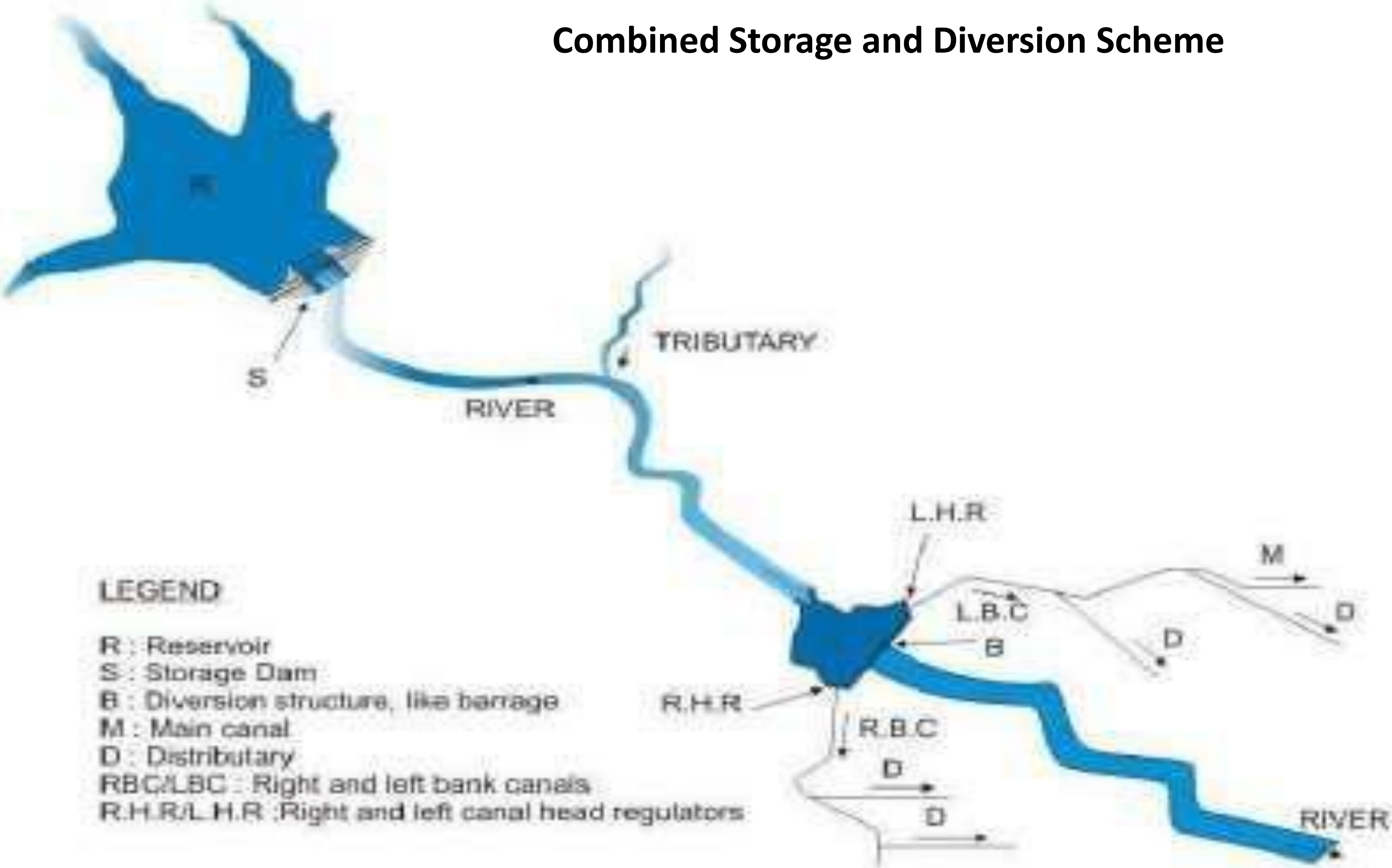
TYPES OF IRRIGATION

This type of scheme and the combined storage and diversion scheme, along with main aim of irrigation, following aims and purposes may be served :

- Hydroelectric power generation
- Water supply
- Flood Control in the river valley
- Fishery
- Recreation

TYPES OF IRRIGATION

Combined Storage and Diversion Scheme



2. Lift Irrigation:

Lift Irrigation is the process of lifting water normally from underground sources and sometimes from surface source by pump, i.e. mechanical power or man or animal power and then direct this lifted water is supplied to the agricultural field.

DIFFERENT TYPES OF SOIL

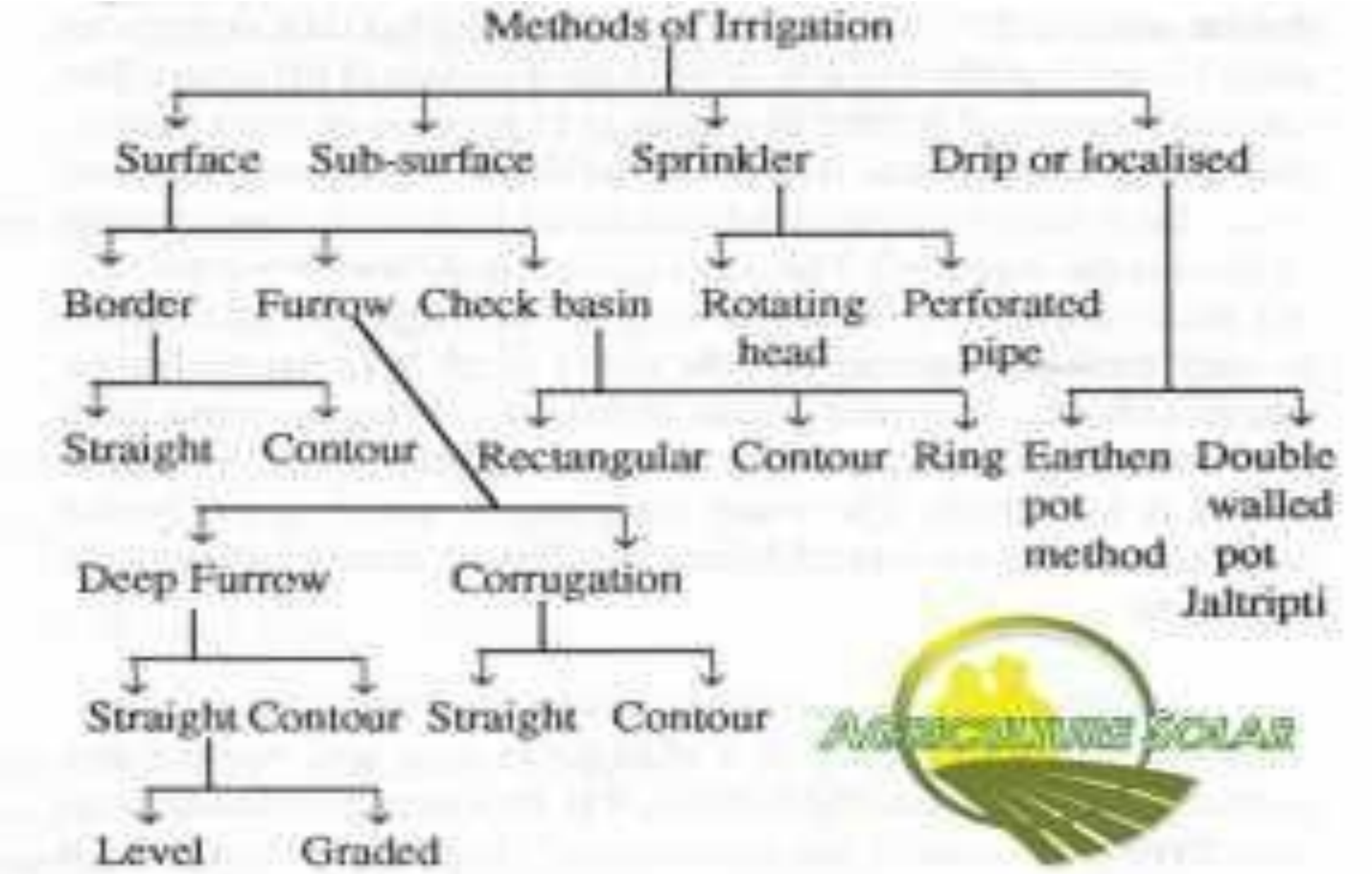
- **Residual Soil :**

  It is formed due to disintegration of natural rocks by the action of air, moisture, frost and vegetation.

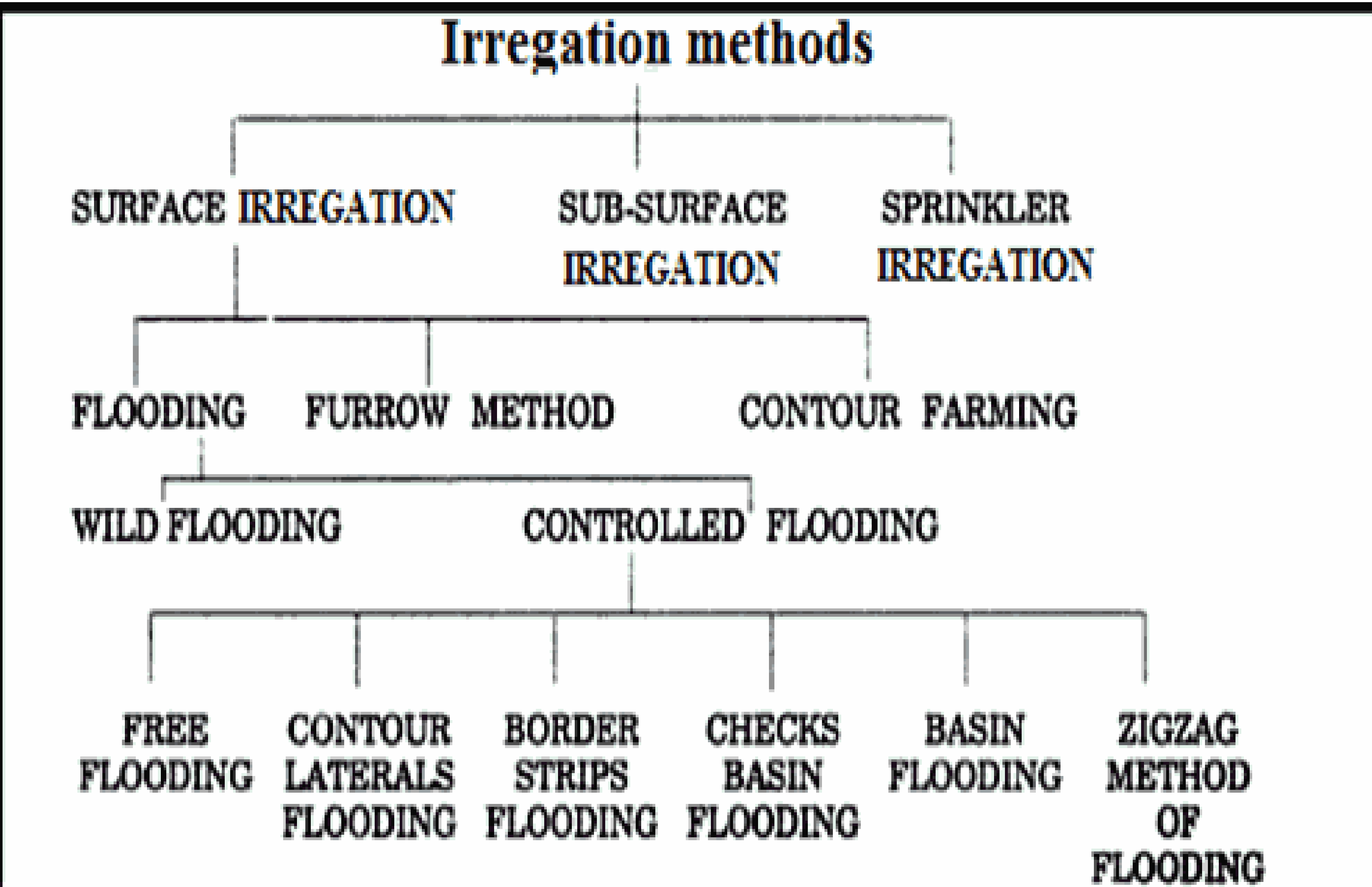
- **Alluvial Soil:**

  This soil is formed by the deposition of silt, sediment by the river during flood time. This soil is available in Indo-Gangetic plains, the Brahmaputra basin and basin of other big rivers of India. Alluvial soil has very good moisture retention capacity and is strong in chemicals, manure essential for crop and plant growth.

METHODS OF IRRIGATION



METHODS OF IRRIGATION



METHODS OF IRRIGATION

a) Surface Irrigation: Just flooding water. About 90% of the irrigated areas in the world are by this method.

b) Sprinkler Irrigation: Applying water under pressure. About 5 % of the irrigated areas are by this method.

c) Drip or Trickle Irrigation: Applying water slowly to the soil ideally at the same rate with crop consumption.

d) Sub-Surface Irrigation: Flooding water underground and allowing it to come up by capillarity to crop roots

SURFACE IRRIGATION:

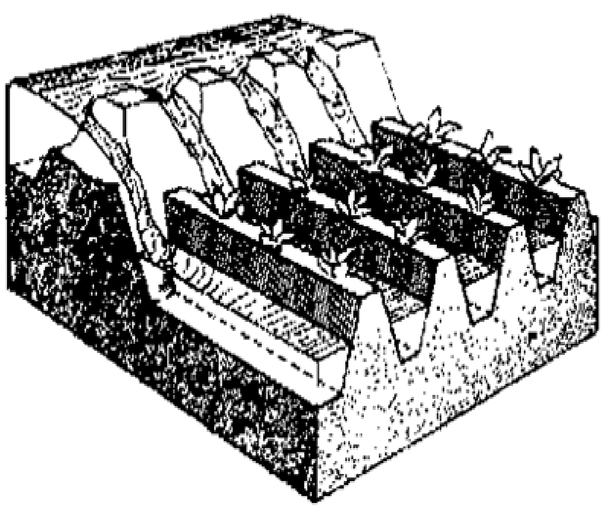
Water is applied to the field in either the controlled or uncontrolled manner.

- **Controlled:** Water is applied from the head ditch and guided by corrugations, furrows, borders, or ridges.
- **Wild flooding** (Uncontrolled): Surface irrigation is entirely practiced where water is abundant. The low initial cost of development is later offset by high labor cost of applying water. There are deep percolation, runoff and drainage problems .

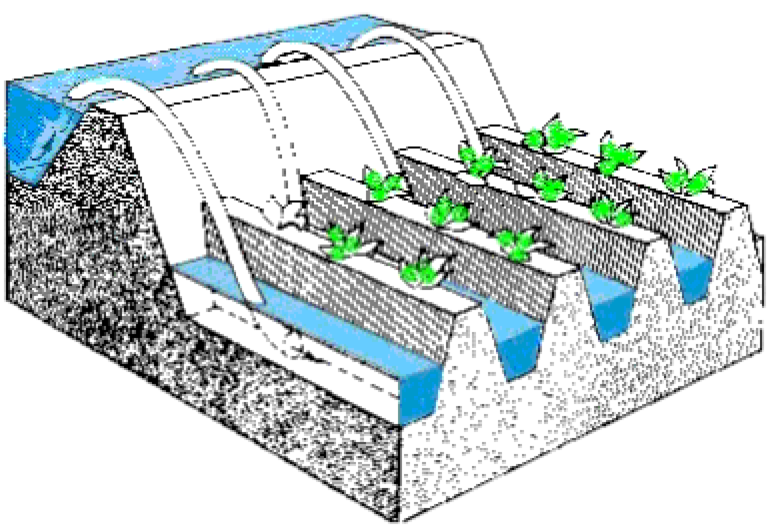
SURFACE IRRIGATION

FURROW IRRIGATION

- In furrow irrigation, only a part of the land surface (the furrow) is wetted thus minimizing evaporation loss.
- Furrow irrigation is adapted for row crops like corn, banana, tobacco, and cabbage. It is also good for grains.
- Irrigation can be by corrugation using small irrigation streams.
- Furrow irrigation is adapted for irrigating on various slopes except on steep ones because of erosion and bank overflow.



Furrow Irrigation with cutting edges



Furrow Irrigation with Siphons

FURROW IRRIGATION

BORDER IRRIGATION

- In a border irrigation, controlled surface flooding is practiced whereby the field is divided up into strips by parallel ridge sand, each strip is irrigated separately by introducing water upstream and it progressively covers the entire strip.
- Border irrigation is suited for crops that can withstand flooding for a short time e.g. wheat.
- It can be used for all crops provided that the system is designated to provide the needed water control for irrigation of crops.
- It is suited to soils between extremely high and very low infiltration rates.

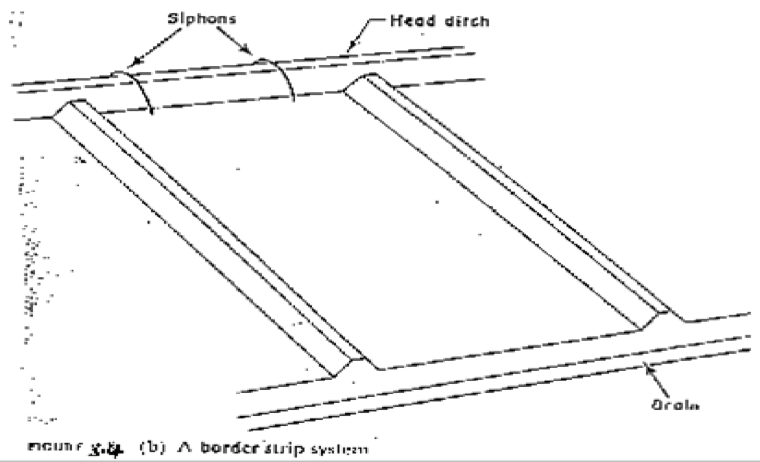
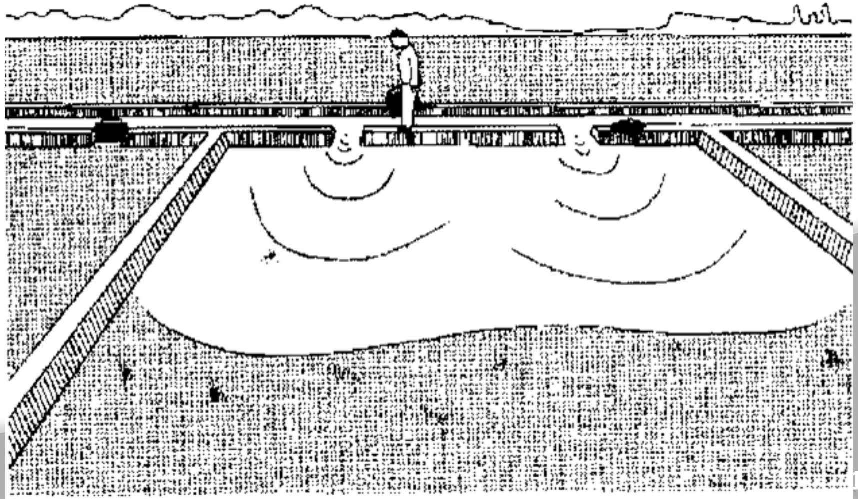
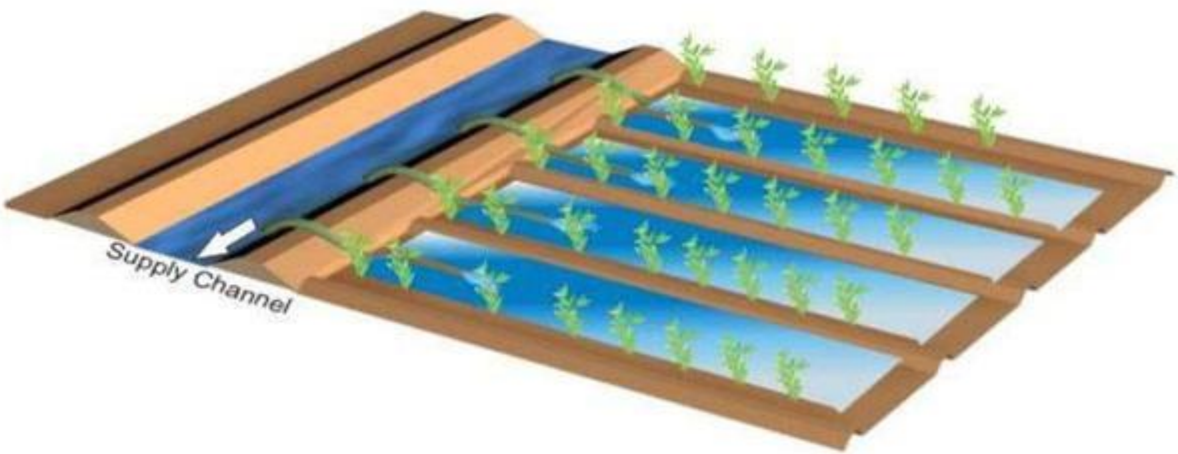


FIGURE (b) A border strip system



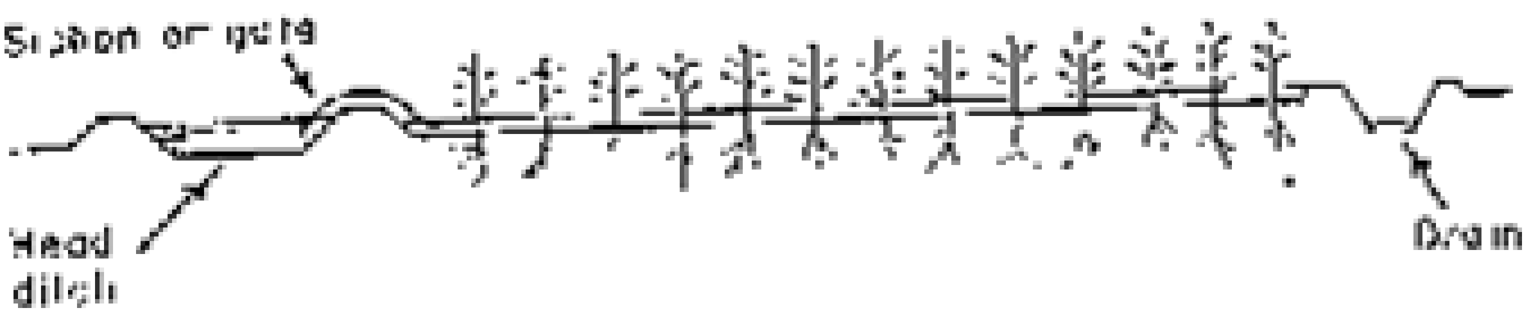
- **Border irrigation:**

  Borders are usually long uniformly graded strips of land separated by earth bunds (low ridges) as shown in Figure.



BASIN IRRIGATION

- In basin irrigation, water is flooded in wider areas. It is ideal for irrigating rice.
- The area is normally flat. In basin irrigation, a very high stream size is introduced into the basin so that rapid movement of water is obtained.
- At the end, a bond is put and water can pond the field. Water does not infiltrate a lot initially.
- The opportunity time difference between the upward and the downward ends are reduced.



(a) A basin

BASIN IRRIGATION

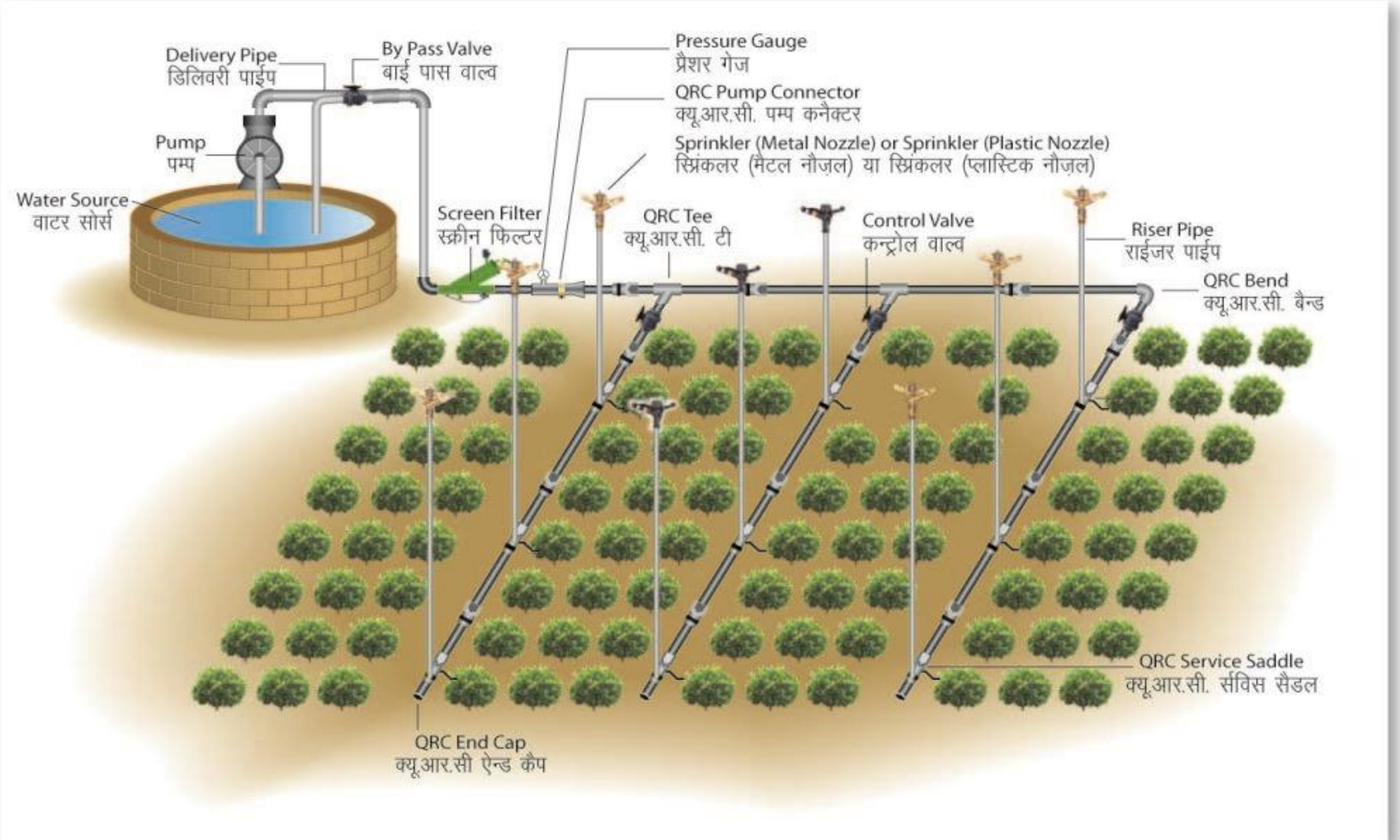
BASIN IRRIGATION

SPRINKLER/OVERHEAD IRRIGATION

- The sprinkler system is ideal in areas where water is scarce.
- A Sprinkler system conveys water through pipes and applies it with a minimum amount of losses.
- Water is applied in form of sprays sometimes simulating natural rainfall.
- The difference is that this rainfall can be controlled in duration and intensity.
- If well planned, designed and operated, it can be used in sloping land to reduce erosion where other systems are not possible.

SPRINKLER/OVERHEAD IRRIGATION

SPRINKLER/OVERHEAD IRRIGATION



Layout of Sprinkler Irrigation System (छिड़काव सिंचाई प्रणाली का रेखाचित्र)

SPRINKLER/OVERHEAD IRRIGATION

SPRINKLER TYPES

Rain gun:

- A mobile machine with a big sprinkler.
- The speed of the machine determines the application rate. The sprinkler has a powerful jet system.

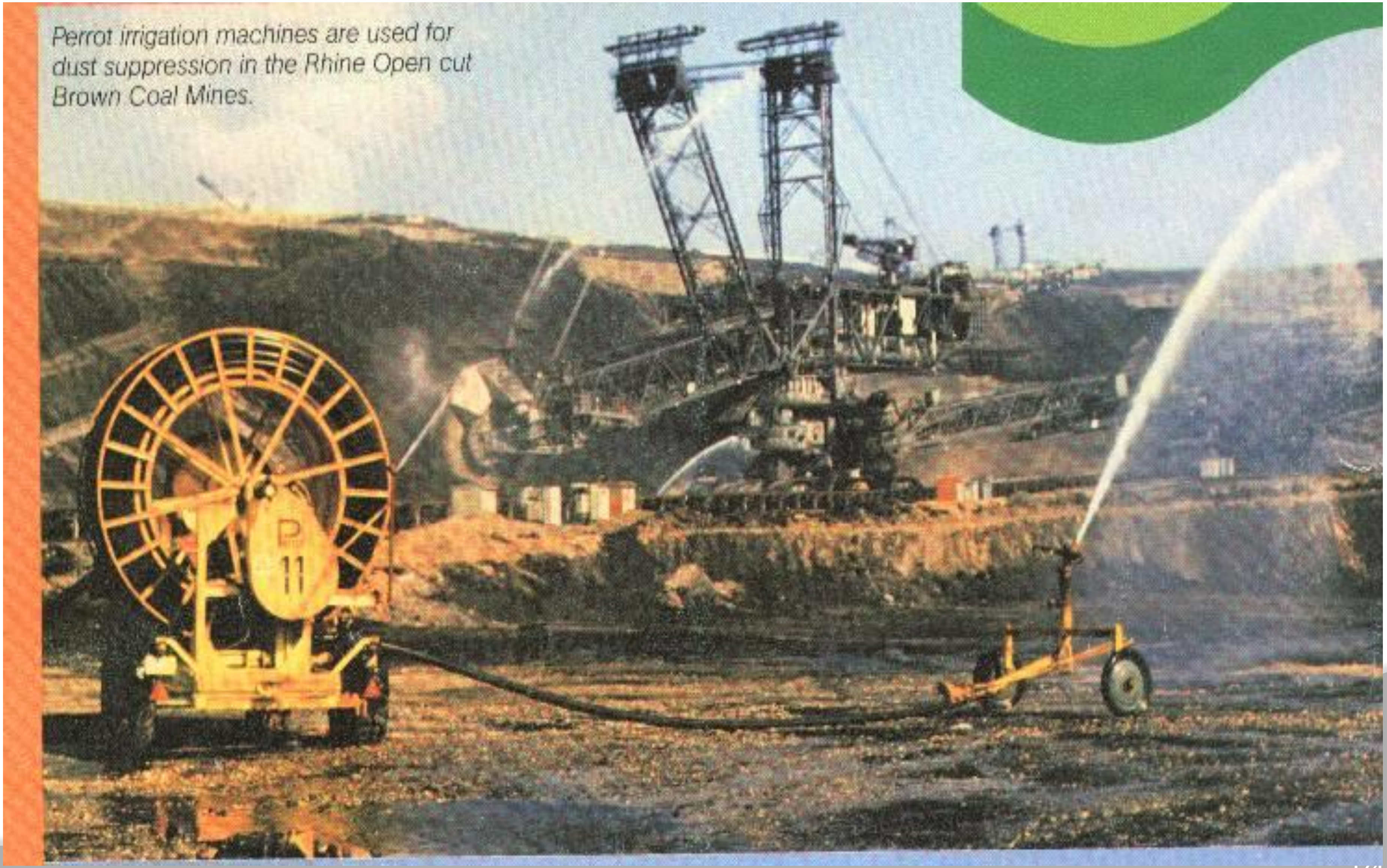
Lateral Move:

- A mobile long boom with many sprinklers attached to them.
- As the machine moves, it collects water from a canal into the sprinklers connected to the long boom.

Centre Pivot:

- The source of water is stationary e.g. a bore hole.
- The boom with many sprinklers rotates about the water source.

RAIN GUN


Perrot irrigation machines are used for dust suppression in the Rhine Open cut Brown Coal Mines.
P 11

RAIN GUN

LINEAR MOVE

ns http://www.clemson.edu/irri

Figure 5. A Linear Move system. Notice the concrete water supply channel (and the fact that the system spans both sides of the channel).

LINEAR MOVE

LATERAL MOVE OR LINEAR MOVE

CENTRE PIVOT

CENTRE PIVOT

SPRINKLER TYPES

Center Pivot Type

Four Wheels Towing Type

Four Wheels Lateral Move Type

Sweep and Contact Directly!

Two Wheels Lateral Move Type

DRIP/TRICKLE IRRIGATION

In this irrigation system:

i) Water is applied directly to the crop i.e., entire field is not wetted.

ii) Water is conserved

iii) Weeds are controlled because only the places getting water can grow weeds.

iv) There is a low pressure system.

v) There is a slow rate of water application somewhat matching the consumptive use. Application rate can be as low as 1 - 12 l/hr.

vi) There is reduced evaporation, only potential transpiration is considered.

vii) There is no need for a drainage system.

The Major Components of a Drip Irrigation System include:

a) Head unit which contains filters to remove debris that may block emitters; fertilizer tank; water meter; and pressure regulator.

b) Mainline, Laterals, and Emitters which can be easily blocked.

DRIP/TRICKLE IRRIGATION

DRIP/TRICKLE IRRIGATION

SUB-SURFACE IRRIGATION

- This irrigation is applied in places where natural soil and topographic condition favour the water application to the soil under the surface, a practice called sub-surface irrigation. These conditions include:

  a) Impervious layer at 15 cm depth or more

  b) Pervious soil underlying the restricting layer.

  c) Uniform topographic condition

  d) Moderate slopes

- The operation of the system involves a huge reservoir of water and level is controlled by inflow and outflow.
- The inflow is water application and rainfall while the outflow is evapotranspiration and deep percolation.
- It does not disturb normal farm operations. Excess water can be removed by pumping.

SUB-SURFACE IRRIGATION

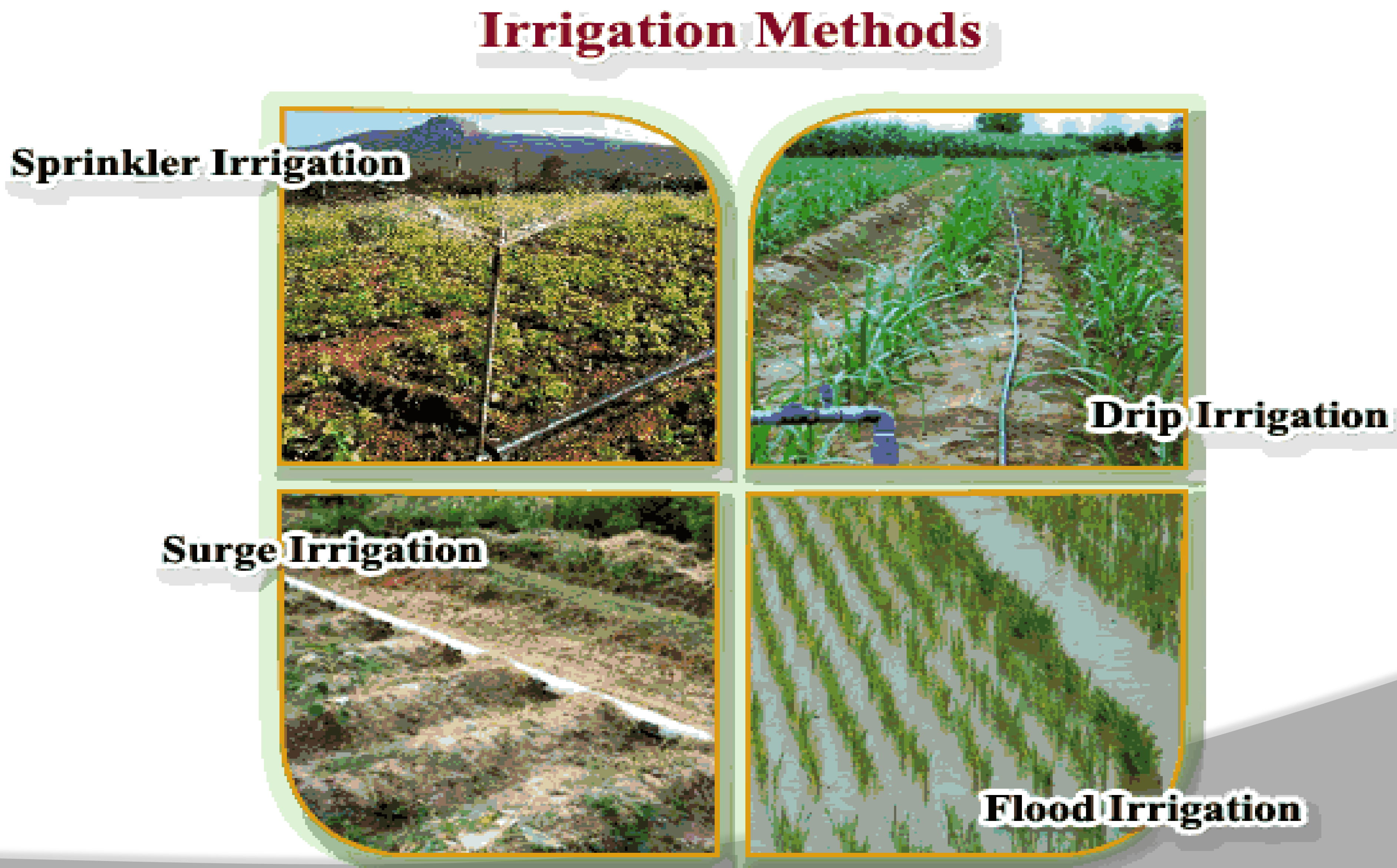
Subsurface Irrigation

- **Subsurface irrigation** (or simply sub irrigation) is the practice of applying water to soils directly under the surface. Moisture reaches the plant roots through capillary action.

SUB-SURFACE IRRIGATION

OVERALL TYPES OF IRRIGATION

OVERALL METHODS OF IRRIGATION



IRRIGATION METHODS SUITABLE FOR DIFFERENT CROPS

Irrigation Methods Suitable for Different Crops

Sl.No.	*Irrigation Method*		*Crops*
1.	Flooding	:	Rice and Jute
2.	Check basin	:	Groundnut, Pulses, Finger millet
3.	Border strip	:	Close growing crops
4.	Furrow	:	Cotton, Maize, Tobacco, Potato, Sorghum, Sugarcane, Vegetables
5.	Surge	:	Maize, Sorghum
6.	Corrugation (shallow and small furrow)	:	Wheat, Groundnut, *Setaria sp.*
7.	Drip	:	Sugarcane
8.	Sprinkler	:	Vegetable and fruit crops

SITE SELECTION OF IRRIGATION

The following criteria should be considered for the Irrigation site:

a) Water supply available
b) Topography of area to be irrigated
c) Climate of the area
d) Soils of the area
e) Crops to be grown
f) Economics
g) Local traditions and skills

Delta of a crop and Duty of water and their relation

Delta:

- Some quantity of water is required for any crop to come to its maturity. The total quantity of water required for any crop during its base period(B) for its full fledged nourishment when expressed in depth of water(i.e. in 'cm' or in 'inches') is called its Delta.
- The total quantity of water(i.e. volume of water) is divided by the total irrigated area to obtain Delta of crop of the irrigated area.
- We have talked about base period(B), it is the time period between the first watering of the crop during its sowing to last watering before its harvesting. It is generally expressed in 'days'.
- The another related term is Crop period.
- For practical purpose Base period and Crop period are taken as same but they have a little difference.
- Crop period is the time period between sowing of a crop to its harvesting. In this manner, Crop period is slightly greater than the Base period.

Duty:

- Duty of a water simply expresses the number of hectare of land that can be irrigated for the full growth of the given crop by supplying 1 cumec water continuously during the entire base period of that crop. It is generally represented by 'D'. Its unit is hectare/cumec. For example, if water flowing at the rate of 1 cumec, runs continuously for B days of the crop matures 100 hectares then Duty of that crop is 100 hectare/cumec to the base of B days.
- Duty varies from point to point. It increases as one moves to downstream from the head of main canal to the head of branches. It is due to the transmission losses in the channels.

Relation between Delta and Duty:

Let a crop of Base period B for which 1 cumec water is supplied continuously for its full growth.

Then the total volume of water supplied during B days for that Crop

$$= (1*B*24*60*60) \text{ cubic meter.}$$

By the definition of duty, it is clear that it matures D hectares of land.

Then the total depth of water supplied during base period

$$B = (1*B*24*60*60)/(D*10000)$$

$$= 8.64B/D \text{ meters}$$

We know total depth of water supplied during base period of a crop is Delta.

Then,

$$\text{Delta} = 8.64B/D \text{ meters.}$$

IRRIGATION WATER LOSSES

Irrigation water losses in canals; these are due to:

1. Evaporation from the water surface
2. Deep percolation to soil layers underneath the canals
3. Seepage through the bunds of the canals
4. Overtopping the bunds
5. Bund breaks
6. Runoff in the drain
7. Rat holes in the canal bunds

IRRIGATION EFFICIENCIES

- The **scheme irrigation efficiency** (e in %) is that part of the water pumped or diverted through the scheme inlet which is used effectively by the plants. The scheme irrigation efficiency can be sub-divided into:
- The **conveyance efficiency (ec)** which represents the efficiency of water transport in canals, and - the **field application efficiency (ea)** which represents the efficiency of water application in the field.
- The conveyance efficiency (ec) mainly depends on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals.
- In large irrigation schemes more water is lost than in small schemes, due to a longer canal system. From canals in sandy soils more water is lost than from canals in heavy clay soils. When canals are lined with bricks, plastic or concrete, only very little water is lost. If canals are badly maintained, bund breaks are not repaired properly and rats dig holes, a lot of water is lost.

IRRIGATION EFFICIENCIES

Once the conveyance and field application efficiency have been determined, the **scheme irrigation efficiency (e)** can be calculated, using the following formula:

$$e = \frac{ec \times ea}{100}$$

with

e = scheme irrigation efficiency (%)
ec = conveyance efficiency (%)
ea = field application efficiency (%)

A scheme irrigation efficiency of 50-60% is good; 40% is reasonable, while a scheme Irrigation efficiency of 20-30% is poor.

UNIT V
CLASSIFICATION OF CANALS

CLOs	Course Learning Outcomes
CLO 21	Understand the mechanical classification of canals
CLO 22	Design of irrigation canals by Kennedy’s and Lacey’s theories, balancing depth of cutting
CLO 23	Calculate by using IS standards for a canal design canal lining. Design discharge over a catchment, computation of design discharge, rational formula.
CLO 24	Understand the SCS curve number method and flood frequency analysis of stream flow

CLASSIFICATION OF CANALS

The irrigation canals can be classified in different ways based on the following considerations.

1. **Classification based on the nature of source of supply:**

In this method canals may be classified as

- Permanent canals
- Inundation canals

- **A permanent canal** is one which draws water from a permanent source of supply. The canal in such cases is made as a regular graded canal (fixed slope). It is provided with permanent regulation and distribution works. A permanent canal may also be perennial canal or non-perennial canal depending on whether the source supplying water is a perennial one or a non-perennial.

CLASSIFICATION OF CANALS

- An **inundation canal** is one which draws water from a river when the water level in the river is high or the river is in floods. These canals are not provided with any regulatory works, but an open cut is made in the banks of the canal to divert water.

Classification based on the function of the canal:

Here the canals may be classified as

- Feeder canals
- Carrier canals
- Navigation canals
- Power canals
- A **feeder canal** is constructed for the purpose of supplying water to two or more canals only but not directly irrigating the fields.

CLASSIFICATION OF CANALS

- A carrier canal carries water for irrigating the fields and also feeds other canals for their needs.
- A canal serving the purpose of in-land navigation is called a navigation canal.
- A power canal supplies water to a hydro electric power generation plant for generation of electrical power.

Classification based on the discharge and its relative importance in a given network of canals:

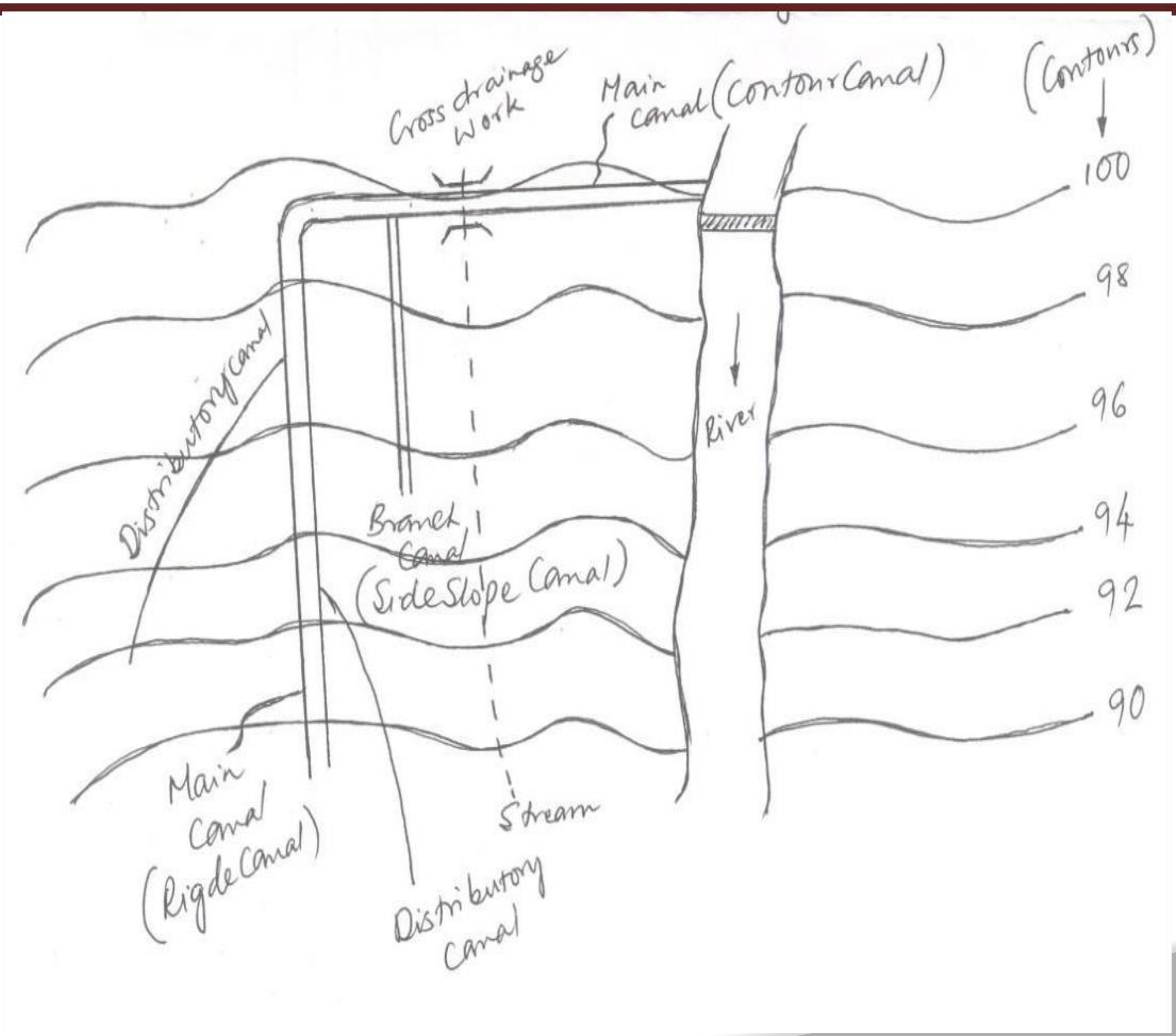
On this basis an irrigation canal system consists of

- Main canal
- Branch canal
- Major distributary
- Minor distributary
- Water course or Field channel

CLASSIFICATION OF CANALS

- **A main canal** is the principal canal in a network of irrigation canals. It directly takes off from a river, reservoir or a feeder canal. It has large capacity and supplies water to branch canals and even to major distributaries.
- **Branch canals** take off from a main canal on either side at regular intervals. They carry a discharge of about 5 cumec and are not usually used to directly irrigate the fields.
- **A major distributary** takes off a branch canal or a main canal. It has a discharge capacity of 0.25 to 5 cumec. They are used for direct irrigation and also to feed minor distributaries.
- **Minor distributaries** are canals taking off from the branch canals and major distributaries. They carry a discharge less than 0.25 cumec. These canals supply water to field channels.
- **A water course or field channel** takes off from either a major or minor distributary or a branch canal also. These are constructed and maintained by the cultivators/farmers.

CLASSIFICATION OF CANALS



CLASSIFICATION OF CANALS

Classification based on Canal alignment:

On the basis of canal alignment, the canals are classified as

- Ridge canal or watershed canal
- Contour canal
- Side slope canal

A Ridge canal or watershed canal is one which runs along the ridge or watershed line. It can irrigate the fields on both sides. In case of ridge canals the necessity of cross drainage works does not arise as the canal is not intercepted by natural streams or drains.

A contour canal is one which is aligned nearly parallel to the contours of the country/area. These canals can irrigate the lands on only one side. The ground level on one side is higher and hence bank on the higher side may not be necessary. A contour canal may be intercepted by natural streams/drains and hence cross drainage works may be essential.

- A Side slope canal is one which is aligned at right angles to the contour of the country/area. It is a canal running between a ridge and a valley. This canal is not intercepted by streams and hence no cross drainage works may be essential. This canal has steep bed slope since the ground has steep slope in a direction perpendicular to the contours of the country/area.

Classification based on the financial output:

On the basis of the financial output /revenue from the canals, the canals are called as

- Productive canals
- Protective canals

CLASSIFICATION OF CANALS

- **Productive canal** is one which is fully developed and earns enough revenue for its running and maintenance and also recovers the cost of its initial investment. It is essential the cost of its initial investment is recovered within 16 years of construction.
- **Protective canals** are those constructed at times of famine to provide relief and employment to the people of the area. The revenue from such a canal may not be sufficient for its maintenance. The investment may also not be recovered within the stipulated time.

Classification based on the soil through which they are constructed:

On the above basis the canals are classified as

1. Alluvial canals
2. Non-alluvial canals.

- Canals constructed in alluvial soils are known as **alluvial canals**. Alluvial soils are found in the Indo-Gangetic plains of North India. The alluvial soils can be easily scoured and deposited by water.
- Canals constructed through hard soils or disintegrated rocks are called **non-alluvial canals**. Such soils are usually found in Central and South India.

CLASSIFICATION OF CANALS

Classification based on Lining being provided or not:

On the above basis the canals are classified as

1. Unlined canals
2. Lined canals

An **unlined canal** is one which the bed and banks of the canal are made up of natural soil through which it is constructed. A protective lining of impervious material is not provided. The velocity of flow is kept low such that bed and banks are not scoured.

A **lined canal** is one which is provide with a lining of impervious material on its banks and beds, to prevent the seepage of water and also scouring of banks and bed. Higher velocity for water can be permitted in lined canals and hence cross sectional area can be reduced.

COMPARISON BETWEEN KENNEDY'S AND LACEY'S THEORIES

Kennedy assumes that the eddies are produced on the bed of canal only but Lacey proposed that eddies are produced along complete wetted perimeter.

Lacey states that as the shape of an irrigation canal is fixed to particular geometrical figure, it cannot achieve final regime conditions and hence may be said to achieve initial regime only. Kennedy assumes that when there is neither silting nor scouring the channel is in its regime condition.

Kennedy selects Kutter's formula for designing irrigation canal. But in Kutter's formula value of N is fixed.

Kennedy use term C.V.R (m) but he did not give any basis for calculating m. He simply states that it depends on the silt change & silt grade flowing in canal. But lacey has introduced silt factor f. The formula is f = 1.76 √ mr

Kennedy gives no idea for calculating longitudinal regime slope . but lacey gives a regime slope formula.

. Lacey gave important wetted regime perimeter equation

Pw = 4.825 Q1/2

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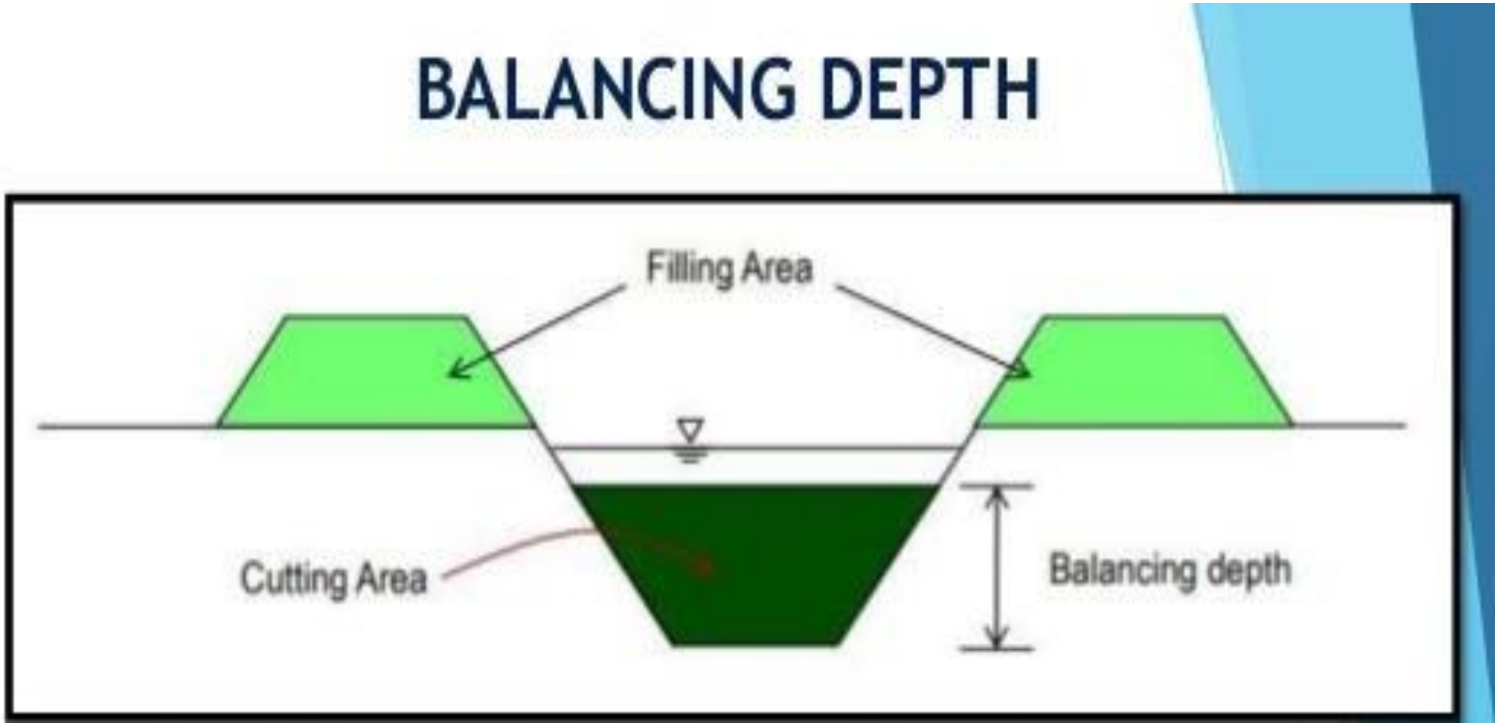
BALANCING DEPTH



If for a channel section the depth of cutting is such that the quantity of excavation or cutting is equal to the earth filling required for making the banks, then depth of cutting is known as balancing depth or most economical depth of cutting.

BALANCING DEPTH

The important methods involved in estimation of peak flow or Design discharge:

(1) Empirical Formulae, (2) Envelope Curves, (3) Rational Method, (4) Unit Hydrograph Method, and (5) Frequency Analysis.

1. Empirical Formulae:
In this method area of a basin or a catchment is considered mainly. All other factors which influence peak flow are merged in a constant.

A general equation may be written in the form:

$$Q = Ca^n$$

Where Q is peak flow or rate of maximum discharge
C is a constant for the catchment
A is area of the catchment and n is an index

BALANCING DEPTH

The constant for a catchment is arrived at, after taking following factors into account:

(a) Basin characteristics:

(i) Area,
(ii) Shape, and
(iii) Slope.

(b) Storm characteristics:
(i) Intensity,
(ii) Duration,
(iii) Distribution.

Limitations:
1. This method does not take frequency of flood into consideration.
2. This method cannot be applied universally.
3. Fixing of constant is very difficult and exact theory cannot be put forth for its selection.

BALANCING DEPTH

(i) Dicken's formula:

It was formerly adopted only in Northern India but now it can be used in most of the States in India after proper modification of the constant.

$$Q = C.M^{3/4}$$

Where

Q is discharge in m^3/sec.

M is area of catchment in km^2.

C is a constant.

KENNEDY THEORY

- Kennedy's theory of designing unlined Canals: Kennedy selected a number of canal sections in the upper Bari-Doab region which did not required any silt clearance for more than 35 years and were supposed to be flowing with non-silting and non-scouring velocity. Kennedy put forward the following facts out of his study.
- The bed of the canal offers frictional resistance to the flow of water, as a result critical eddies (Turbulences) arise from the bottom of the bed. These eddies keep the sediments carried by water in suspension. Some eddies also arise from the sides of the canal, but do not support the sediments. Hence, the sediment supporting capacity is proportional to the bed width of the canal.

KENNEDY THEORY

- The critical velocity or non-silting and non scouring velocity (Vo) is a function of the depth of the flowing water (D). It is given by the relationship is

$$V_0 = c\,m\,D^n$$

Where, \`c‘ is and \`n‘ are coefficients suggested by Kennedy for canals of Bari-Doad region. The values of \`c‘ differs for different materials are

  - Light Sandy silt c = 0.53
  - light sandy silt c = 0.59
  - Sandy loan c = 0.65
  - Coarse silt c = 0.70

- Values of c and n can be taken as c = 0.55 and n = 0.64
- Thus, the equation for critical velocity becomes Vo = 0.55 m D 0.64.Where, V represents mean velocity of flow.

KENNEDY THEORY

Unless, otherwise specified m = 1.0

The mean velocity of flow is given by $V = C\sqrt{RS}$

Where C represents Chezzy's constant and is given by

$$C = \frac{23+(1\div N)+(0.0015\div S)}{1+(23+(0.0015\div S)\times(N\div\sqrt{R})}$$

Where, N represents Kutter's Rugosity coefficient,

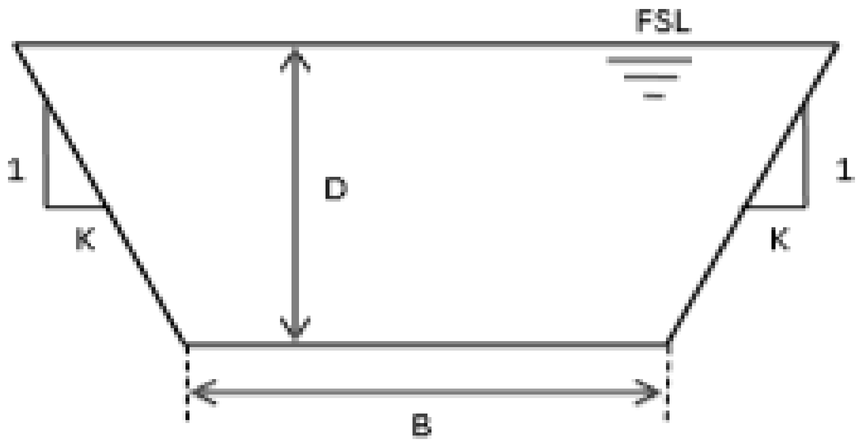
S represents Bed slope of the canal

R represents Hydraulic mean radius and is given by R= A/P

Where A is cross sectional area of canal and P is wetted perimeter.

- When a canal is designed by Kennedy's method it is required that Vo is equal to V. i.e., Critical velocity ratio m = 1

Note: The cross section for an irrigation canal is assumed as a trapezoidal channel as follows.



Cross Sectional Area of flow $A = BD + KD^2$

Wetted Perimeter $P = B + 2D\sqrt{1 + K^2}$

Kennedy's procedure for designing unlined canals:

In designing the required canal section, the following equations are adopted.

$$Q = A \; V_o$$

$$V_o = 0.55 \; m \, D^{0.64}$$

$$V = C\sqrt{RS}$$

$$C = \frac{23 + (1 \div N) + (0.0015 \div S)}{1 + (23 + (0.0015 \div S) \times (N \div \sqrt{R})}$$

Lacey's Regime Theory:

Lacey carried out a detailed study in designing suitable channels in alluvial soils. He developed the regime theory and formulated a number of expressions based on his observations. The salient features of Lacey's theory are stated as follows.

- In a channel constructed in alluvial soil to carry a certain discharge, the bottom width, depth and bed slope of the channel will undergo modifications by silting and scouring till equilibrium is attained. The channel is now said to be a regime channel. (A regime channel is defined as a stable channel whose bed width, depth and side slopes have undergone modifications by silting and scouring and are so adjusted that equilibrium is attained.)

LACEY'S THEORY

A channel is said to be in regime when the following conditions are satisfied.

1. The Channel is flowing in unlimited incoherent alluvium of the same character as that of the transported sediment. (Incoherent alluvium is a soil composed of loose granular material which can be scoured and deposited with the same ease.)
2. Silt grade (silt size) and silt charge (silt concentration) is the same throughout the channel.
3. Discharge in the canal is constant.

- The silt carried by the flowing water in the canal is kept in suspension by vertical eddies generated from the bed as well as from the sides of the canal.
- 3. The silt grade also plays an important role in controlling the regime conditions of the channel.
- The silt factor is given by the relationship $f = 1.76\sqrt{d}$ where d represents diameter of silt particle in mm.

LACEY'S PROCEDURES FOR DESIGNING UNLINED CANALS

- In Lacey's method for designing unlined canals in alluvial soils for a known discharge Q and a mean diameter of silt particle 'd', the required quantities are calculated as follows.

1. The mean velocity of flow is computed from the relation.

$$V=(Qf \div 140)^{1/6}$$

Where Q is discharge in m3/s, f is silt factor given by

f =1.76√d, d is diameter of silt particle in mm.

2. Calculate the cross sectional area of flow A = Q V
3. Knowing the side slope express 'A' in terms of B and D,
4. Determine the required wetted perimeter from the relationship

P= 4.75 Q -------(1)

5. Express the wetted perimeter in terms of B and D

$$P=B+2D\sqrt{1+K^2}\text{-------------}(2)$$

6. From equations 1 and 2 solve for values of B and D.

7. Calculate Hydraulic mean radius' (R) from the relationship

$$R = \frac{5}{2}\left[\frac{V^2}{f}\right] \text{-----}(3)$$

8. Also calculate hydraulic mean radius 'R' from the relationship

$$R = \frac{A}{P} = \frac{BD + K D^2}{B + 2D\sqrt{1+K^2}} \text{-----} (4)$$

9. If the values of hydraulic mean radius R worked out from equations 3 and 4 are the same then the design is OK.

10. Calculated the Bed slope from the equation

$$S = \left[\frac{f^{\frac{5}{3}}}{3340 Q^{\frac{1}{6}}}\right]$$

Draw backs in Lacey's theory

1. The theory does not give a clear description of physical aspects of the problem.
2. It does not define what actually governs the characteristics of an alluvial channel.
3. The derivation of various formulae depends upon a single factor f and dependence on single factor f is not adequate.
4. There are different phases of flow on bed and sides and hence different values of silt factor for bed and side should have been used.
5. Lacey's equations do not include a concentration of silt as variable.
6. Lacey did not take into account the silt left in channel by water that is lost in absorption which is as much as 12 to 15% of the total discharge of channel.

CANAL LINING

Canal lining :-

The impervious layer which protects the bed and sides of the canal from seepage is called canal lining.

Advantages of lining :-

- To save water for irrigation.
- To maintain the stability of section which reduces the change of shifting of outlets.
- To minimize the costs of maintenances.
- To carry water at higher velocities.
- To prevent canal's bank erosion.
- To increase in canal capacity.
- Removal of silt & plants from the sides of beds.
- Minimizing of flood dangers.

SCS CURVE NUMBER METHOD

- The SCS Runoff Curve Number method is developed by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS) and is a method of estimating rainfall excess from rainfall (Hjelmfelt, 1991).
- The **SCS curve number method** is a simple, widely used and efficient **method** for determining the approximate amount of runoff from a rainfall even in a particular area. Although the **method** is designed for a single storm event, it can be scaled to find average annual runoff values.

SCS CURVE NUMBER METHOD

- The major disadvantages of the method are sensitivity of the method to Curve Number (CN) values, fixing the initial abstraction ratio, and lack of clear guidance on how to vary Antecedent Moisture Conditions (AMC). However, the method is used widely and is accepted in numerous hydrologic studies.
- The SCS method originally was developed for agricultural watersheds in the mid-western United States; however it has been used throughout the world far beyond its original developers would have imagined.
- The basis of the curve number method is the empirical relationship between the retention (rainfall not converted into runoff) and runoff properties of the watershed and the rainfall.

SCS CURVE NUMBER METHOD

$$\frac{F}{S} = \frac{Q}{P}$$

where *F* = *P* – *Q* = actual retention after runoff begins;

Q = actual runoff

S = potential maximum retention after runoff begins (S ^{3} F)

P = potential maximum runoff (i.e., total rainfall if no initial abstraction).

FLOOD FREQUENCY ANALYSIS OF STREAM FLOW

- Flood frequency analyses are used to predict design floods for sites along a river.
- The technique involves using observed annual peak flow discharge data to calculate statistical information such as mean values, standard deviations, skewness, and recurrence intervals.
- These statistical data are then used to construct frequency distributions, which are graphs and tables that tell the likelihood of various discharges as a function of recurrence interval or exceedance probability.

FLOOD FREQUENCY ANALYSIS OF STREAM FLOW

- Flood frequency distributions can take on many forms according to the equations used to carry out the statistical analyses. Four of the common forms are:

1. Normal Distribution
2. Log-Normal Distribution
3. Gumbel Distribution
4. Log-Pearson Type III Distribution


Thank you