DEPARTMENT : CIVIL ENGINEERING

YEAR & SEM : III B.TECH II SEM

SUBJECT : WATER RESOURCES ENGINEERING-I

B. Tech III-II Sem. (C.E) L T P C

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15A01605 WATER RESOURCES ENGINEERING-I

Course Objective:

To study the concepts of

i. Engineering Hydrology and its applications like Runoff estimation, estimation of design discharge and flood routing.

ii. Irrigation Engineering – Water utilization for Crop growth, canals and their designs.

UNIT – I

INTRODUCTION TO HYDROLOGY: Engineering hydrology and its applications; Hydrologic cycle; precipitation- types and forms, rainfall measurement, types of rain gauges, computation of average rainfall over a basin, presentation and interpretation of rainfall data.

DESCRIPTIVE HYDROLOGY: Evaporation- factors affecting evaporation, measurement of evaporation; Infiltration- factors affecting infiltration, measurement of infiltration, infiltration indices; Run off- Factors affecting run- off, Computation of run-off;

Design Flood; Estimation of maximum rate of run-off; separation of base flow.

UNIT – II

HYDROGRAPH ANALYSIS: Hydrograph; Unit Hydrograph- construction and limitations of Unit hydrograph, Application of the unit hydrograph to the construction of a flood hydrograph resulting from rainfall of unit duration; S-hydrograph.

GROUND WATER: Introduction; Aquifer; Aquiclude; Aquifuge; aquifer parametersporosity, Specific yield, Specific retention; Divisions of sub–surface water; Water table; Types of aquifers; storage coefficient-coefficient of permeability and transmissibility; well hydraulics-Darcy‟s law; Steady radial flow to a well –Dupuit‟s theory for confined and unconfined aquifers; Tube well; Open well; Yield of an open well–Constant level pumping test, Recuperation test.

UNIT – III

IRRIGATION: Introduction; Necessity and Importance of Irrigation; advantages and ill effects of Irrigation; types of Irrigation; methods of application of Irrigation water; quality for Irrigation water. Duty and delta; duty at various places; relation between duty and delta; factors affecting duty; methods of improving duty.

WATER REQUIREMENT OF CROPS: Types of soils, Indian agricultural soils,preparation of land for Irrigation; soil fertility; Soil-water-plant relationship; vertical distribution of soil moisture; soil moisture tension; soil moisture stress; various soil moisture constants; Limiting soil moisture conditions; Depth and frequency of irrigation; Gross command area; Culturable command area; Culturable cultivated and uncultivated area; Kor depth and Kor period; crop seasons and crop rotation; Irrigation efficiencies; Determination of irrigation requirements of crops; Assessment of Irrigation water. Consumptive use of water-factors affecting consumptive use, direct measurement and determination by use of equations (theory only)

UNIT – IV

CHANNELS – SILT THEORIES: Classification; Canal alignment; Inundation canals; Cross–section of an irrigation channel; Balancing depth; Borrow pit; Spoil bank; Land width; Silt theories–Kennedy‟s theory, Kennedy‟s method of channel design; Drawbacks in Kennedy‟s theory; Lacey‟s regime theory- Lacey‟s theory applied to channel design; Defects in Lacey‟s theory; Comparison of Kennedy‟s and Lacey‟s theory.

WATER LOGGING AND CANAL LINING: Water logging; Effects of water logging; Causes of water logging; Remedial measures; Saline and alkaline soils and their reclamation; Losses in canal; Lining of irrigation channels – necessity, advantages and disadvantages; Types of lining; Design of lined canal.

UNIT – V

DIVERSION HEAD WORKS: Types of diversion head works; Diversion and Storage head works; weirs and barrages; Layouts of diversion head works; components; Causes and failure of hydraulic structures on permeable foundations; Blighs creep
theory; Khoslas theory; Determination of uplift pressure, impervious floors using Blighs and Khoslas theory; Exit gradient.

CANALOUTLETS: Introduction; types of outlet; flexibility, proportionality, setting ,hyper proportional outlet, sub-proportional outlet, sensitivity, efficiency of an outlet, drowning ratio, modular limit; pipe outlet; Kennedy‟s gauge outlet; Gibb‟s module; canal escape.

TEXT BOOKS:

1. Irrigation And Water Power Engineering by Punmia&Lal, Laxmi Publications Pvt. Ltd., New Delhi
2. Irrigation Engineering and Hydraulic Structures by S. K. Garg; Khanna Publishers, Delhi.TEXT

REFERENCES:

1. Engineering Hydrology by K.Subramanya, The Tata Mcgraw Hill Company, Delhi
2. Engineering Hydrology by Jayarami Reddy, Laxmi publications Pvt. Ltd., New Delhi
3. Irrigation and Water Resources & Water Power by P.N.Modi, Standard Book House.

UNIT-I
INTRODUCTION TO HYDROLOGY

HYDROLOGY:-

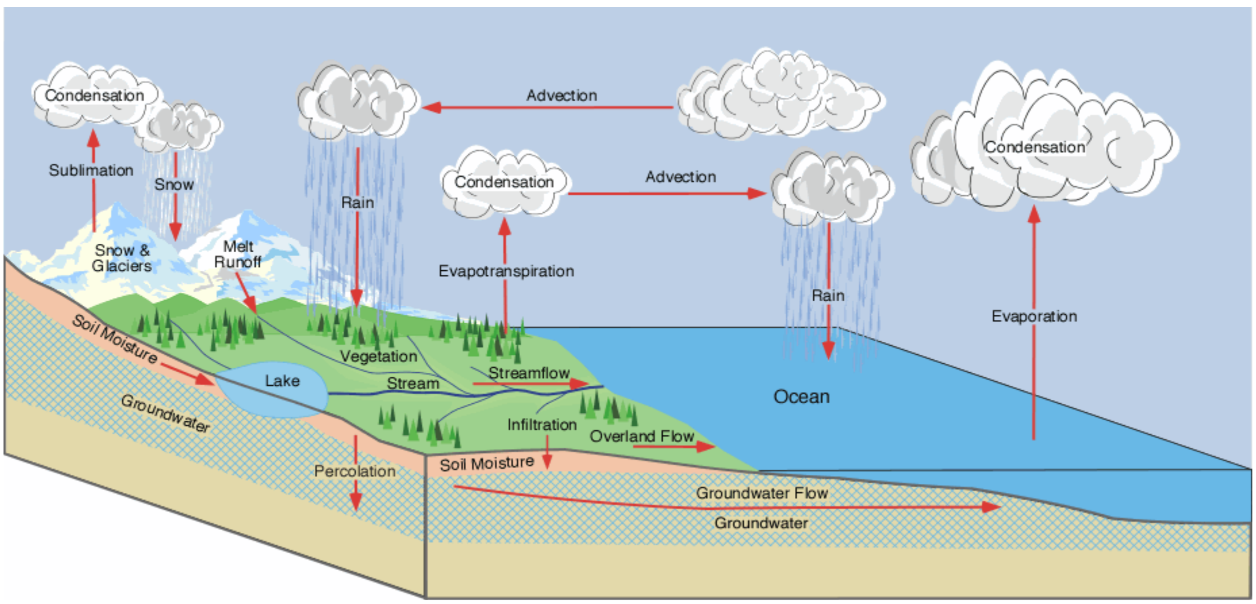
Hydrology is the science, which deals with the occurrence, distribution and disposal of water on the planet earth.

Hydro=Water Logy=Science

HYDROLOGIC CYCLE

Hydrologic cycle is the water transfer cycle, which occurs continuously in nature; the three important phases of the hydrologic cycle are: (a) Evaporation and evapotranspiration (b)precipitation and (c) runoff

Evaporation from the surfaces of ponds, lakes, reservoirs.ocean surfaces, etc. and transpiration from surface vegetation i.e., from plant leaves of cropped land and forests, etc. take place. These vapours rise to the sky and are condensed at higher altitudes by condensation nuclei and form clouds, resulting in droplet growth. The clouds melt and sometimes burst resulting in precipitation of different forms like rain, snow, hail, sleet, mist, dew and frost. A part of this precipitation flows over the land called runoff and part infilters into the soil which builds up the groundwater table. The surface runoff joins the streams and the water is stored in reservoirs. A portion of surface runoff and ground water flows back to ocean. Again evaporation starts from the surfaces of lakes, reservoirs and ocean, and the cycle repeats. Of these three phases of the hydrologic cycle, namely, evaporation, precipitation and runoff, it is the 'runoff phase', which is important to a civil engineer since he is concerned with the storage of surface runoff in tanks and reservoirs for the purposes of irrigation, municipal water supply hydroelectric power etc.



Hydrological Processes

1. Precipitation
2. Evaporation
3. Transpiration
4. Infiltration
5. Overland flow
6. Surface Runoff
7. Groundwater outflow

FORMS OF PRECIPITATION

Drizzle — a light steady rain in fine drops (0.5 mm) and intensity <1 mm/hr

Rain — the condensed water vapour of the atmosphere falling in drops (>0.5 mm, maximum size—6 mm) from the clouds.
Glaze — freezing of drizzle or rain when they come in contact with cold objects.
Sleet — frozen rain drops while falling through air at subfreezing temperature.
Snow — ice crystals resulting from sublimation (i.e., water vapour condenses to ice)
Snow flakes — ice crystals fused together.
Hail — small lumps of ice (>5 mm in diameter) formed by alternate freezing and melting, when they are carried up and down in highly turbulent air currents.
Dew — moisture condensed from the atmosphere in small drops upon cool surfaces.
Frost — a feathery deposit of ice formed on the ground or on the surface of exposed objects by dew or water vapour that has frozen
Fog — a thin cloud of varying size formed at the surface of the earth by condensation of atmospheric vapour(interfering with visibility)
Mist — a very thin fog

SCOPE OF HYDROLOGY

The study of hydrology helps us to know

(i)the maximum probable flood that may occur at a given site and its frequency; this is required for the safe design of drains and culverts, dams and reservoirs, channels and other flood control structures.

(ii) the water yield from a basin—its occurrence, quantity and frequency, etc; this is necessary for the design of dams, municipal water supply, water power, river navigation, etc.

(iii) the ground water development for which a knowledge of the hydrogeology of the area, i.e., of the formation soil, recharge facilities like streams and reservoirs, rainfall pattern, climate, cropping pattern, etc. are required.

(iv) the maximum intensity of storm and its frequency for the design of a drainage project in the area.

TYPES OF PRECIPITATION

The precipitation may be due to

(i) Thermal convection (convectional precipitation)

This type of precipiation is in the form of local whirling thunder storms and is typical of the tropics. The air close to the warm earth gets heated and rises due to its low density, cools adiabatically to form a cauliflower shaped cloud, which finally bursts into a thunder storm. When accompanied by destructive winds, they are called ‘tornados’.

(ii) Conflict between two air masses (frontal precipitation)

When two air masses due to contrasting temperatures and densities clash with each other, condensation and precipitation occur at the surface of contact, Fig. 2.1. This surface of contact is called a ‘front’ or ‘frontal surface’. If a cold air mass drives out a warm air mass’ it is called a ‘cold front’ and if a warm air mass replaces the retreating cold air mass, it is called a ‘warm front’. On the other hand, if the two air masses are drawn simultaneously towards a low pressure area, the front developed is stationary and is called a ‘stationary front’. Cold front causes intense precipitation on comparatively small areas, while the precipitation due to warm front is less intense but is spread over a comparatively larger area. Cold fronts move faster than warm fronts and usually overtake them, thefrontal surfaces of cold and warm air sliding against each other. This phenomenon is called ‘occlusion’and the resulting frontal surface is called an ‘occluded front’.

(iii) Orographic lifting (orographic precipitation)

The mechanical lifting of moist air over mountain barriers, causes heavy precipitation on the windward side (Fig. 2.2). For example Cherrapunji in the Himalayan range and Agumbe in the western Ghats of south India get very heavy orographic precipitation of 1250 cm and 900 cm (average annual rainfall), respectively.

(iv) Cyclonic (cyclonic precipitation)

This type of precipitation is due to lifting of moist air converging into a low pressure belt, i.e., due to pressure differences created by the unequal heating of the earth's surface. Here the winds blow spirally inward counterclockwise in the northern hemisphere and clockwise in the southern hemisphere. There are two main types of cyclones—tropical cyclone (also called hurricane or typhoon) of comparatively small diameter of 300-1500 km causing high wind velocity and heavy precipitation, and the extra-tropical cyclone of large diameter up to 3000 km causing wide spread frontal type precipitation.

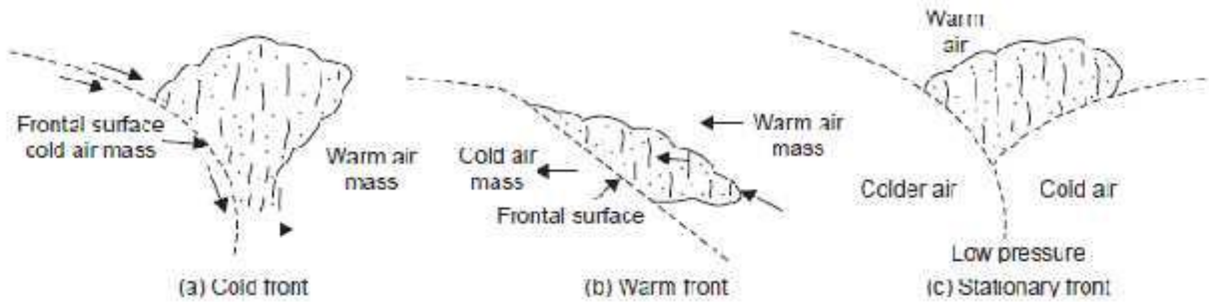


Fig. 2.1 Frontal precipitation

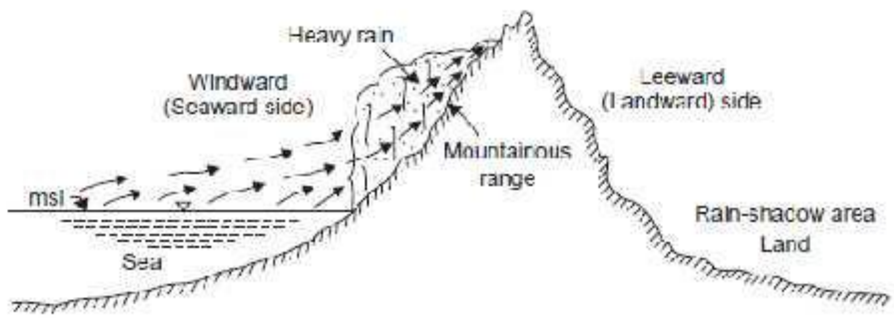
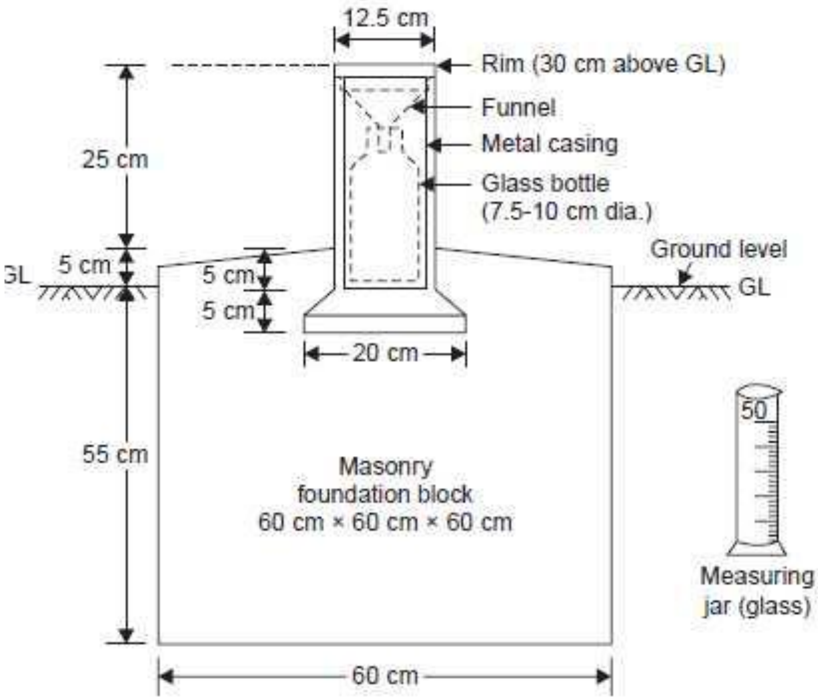


Fig. 2.2 Orographic precipitation

MEASUREMENT OF PRECIPITATION

Rainfall may be measured by a network of rain gauges which may either be of non-recording or recording type. The non-recording rain gauge used in India is the Symon's rain gauge (Fig. 2.3). 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. 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. 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 ofthe day in the register. Usually, rainfall measurements are made at 08.30 hr IST and sometimes at 17.30 hr IST also.Thus the non-recording or the Symon's 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. It is often desirable to protect the gauge from being damaged by cattle and for this purpose a barbed wire fence may be erected around it.



Recording Rain Gauge

This is also called self-recording, automatic or integrating rain gauge. This type of rain gauge Figs. 2.4, 2.5 and 2.6, 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 Fig. 2.7. 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. There are three types of recording rain gauges—tipping bucket gauge, weighing gauge and float gauge.

Tipping bucket rain gauge.

This consists of a cylindrical receiver 30 cm diameterwith a funnel inside (Fig. 2.4). Just below the funnel a pair of tipping buckets is pivoted such that when one of the bucket receives a rainfall of 0.25 mm it tips and empties into a tankbelow, while the other bucket takes its position and the process is repeated. The tipping of the bucket actuates on electric circuit which causes a pen to move on a chart wrapped round a drum which revolves by a clock mechanism. This type cannot record snow.

Weighing type rain gauge. In this type of rain-gauge, when a certain weight of rainfall is collected in a tank, which rests on a spring-lever balance, it makes a pen to move on a chart wrapped round a clockdriven drum (Fig. 2.5). Therotation of the drum sets the time scale while the vertical motion of the pen records the cumulative precipitation.

Float type rain gauge. 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 (Fig. 2.6). 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. This type of gauge is used by IMD.

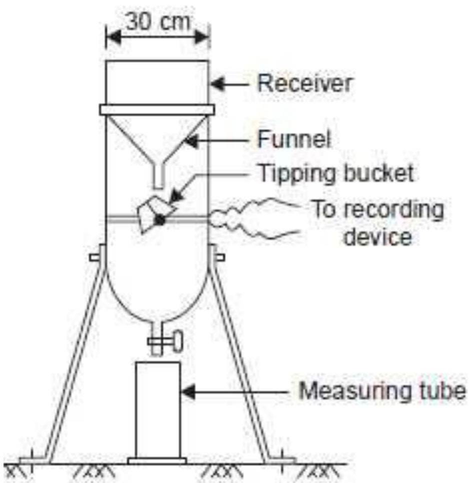


Fig. 2.4 Tipping bucket gauge

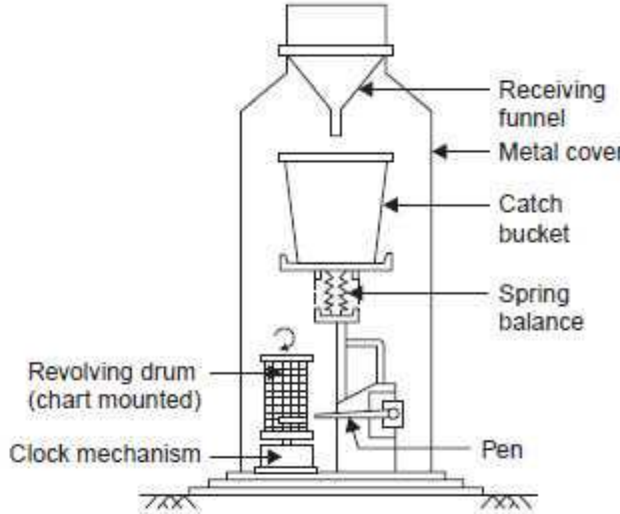


Fig. 2.5 Weighing type rain gauge

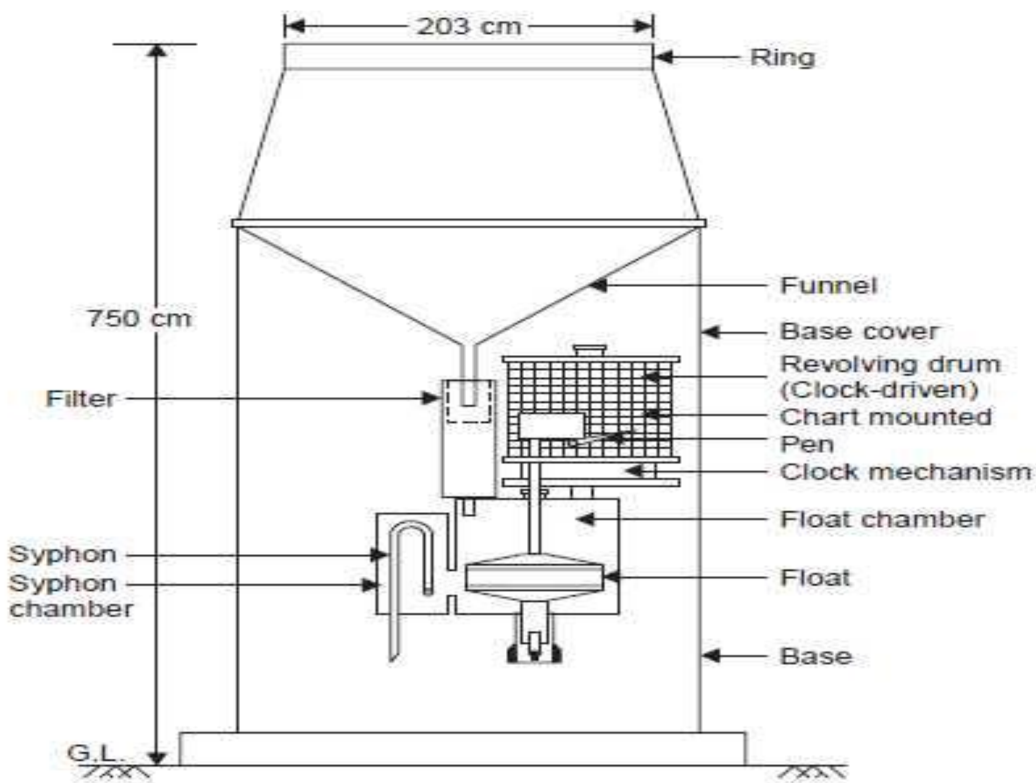


Fig. 2.6 Float type rain gauge

ESTIMATE OF MISSING RAINFALL DATA

(i) Station-year method

In this method, the records of two or more stations are combined into one long record provided station records are independent and the areas in which the stations are located are climatologically the same. The missing record at a station in a particular year may be found by the ratio of averages or by graphical comparison. For example, in a certain year the total rainfall of station A is 75 cm and for the neighbouring station B, there is no record. But if the a.a.r. at A and B are 70 cm and 80 cm, respectively, the missing year's rainfall at B (say, PB) can be found by simple proportion as: PB = 85.7 cm

This result may again be checked with reference to another neighbouring station C.

(ii) By simple proportion (normal ratio method)

(iii) Double-mass analysis

The trend of the rainfall records at a station may slightly change after some years due to a change in the environment (or exposure) of a station either due to coming of a new building, fence, planting of trees or cutting of forest nearby, which affect the catch of the gauge due to change in the wind pattern or exposure. The consistency of records at the station in question (say, X) is tested by a double mass curve by plottting the cumulative annual (or seasonal) rainfall at station X against the concurrent cumulative values of mean annual (or seasonal) rainfall for a group of surrounding stations, for the number of years of record (Fig. 2.9). From the plot, the year in which a change in regime (or environment) has occurred is indicated by the change in slope of the straight line plot. The rainfall records of the station x are adjusted by multiplying the recorded values of rainfall by the ratio of slopes of the straight lines before and after change in environment.

WATER LOSSES:

The hydrologic equation states that

Rainfall–Losses = Runoff

(i) Interception loss-due to surface vegetation, i.e., held by plant leaves.

(ii) Evaporation:

(a) from water surface, i.e., reservoirs, lakes, ponds, river channels, etc.

(b) from soil surface, appreciably when the ground water table is very near the soil surface.

(iii) Transpiration—from plant leaves.

(iv) Evapotranspiration for consumptive use—from irrigated or cropped land.

(v) Infiltration—into the soil at the ground surface.

(vi) Watershed leakage—ground water movement from one basin to another or into the sea.

The various water losses are discussed below:

Interception loss—

The precipitation intercepted by foliage (plant leaves, forests) and buildings and returned to atmosphere (by evaporation from plant leaves) without reaching the ground surface is called interception loss. Interception loss is high in the beginning of storms and gradually decreases; the loss is of the order of 0.5 to 2 mm per shower and it is greater in the case of light showers than when rain is continuous. Fig. 3.1 shows the Horton's mean curve of interception loss for different showers.

Effective rain = Rainfall – Interception loss

EVAPORATION:

Evaporation from free water surfaces and soil are of great importance in hydro-meterological studies.

Evaporation from water surfaces (Lake evaporation):

The factors affecting evaporation are air and water temperature, relative humidity, wind velocity, surface area(exposed), barometric pressure and salinity of the water, the last two having a minor effect. The rate of evaporation is a function of the differences in vapour pressure at the water surface and in the atmosphere, and the Dalton's law of evaporation is given by

$$E = K (e_w - e_a)$$

where E = daily evaporation

ew = saturated vapour pressure at the temperature of water

ea = vapour pressure of the air (about 2 m above)

K = a constant.

The Dalton's law states that the evaporation is proportional to the difference in vapour pressures ew and ea. A more general form of the Eq. (3.2) is given by

$$E = K' (e_w - e_a) (a + bV)$$

where K′, a, b = constantsand V = wind velocity.

EVAPORATION PANS:

(i) Floating pans (made of GI) of 90 cm square and 45 cm deep are mounted on a raft floating in water. The volume of water lost due to evaporation in the pan is determined by knowing the volume of water required to bring the level of water up to the original mark daily and after making allowance for rainfall, if there has been any.

(ii) Land pan. Evaporation pans are installed in the vicinity of the reservoir or lake to determine the lake evaporation. The IMD Land pan shown in Fig. 3.2 is 122 cm diameter and 25.5 cm deep,made of unpainted GI; and set on wood grillage 10 cm above ground to permit circulation of air under the pan. The pan has a stilling well, vernier point gauge, a thermometer with clip and may be covered with a wire screen. The amount of water lost by evaporation from the pan can be directly measured by the point gauge. Readings are taken twice daily at 08.30 and 17.30 hours I.S.T. The air temperature is determined by reading a dry bulb thermometer kept in the Stevenson's screen erected in the same enclosure of the pan. A totalising anemometer is normally mounted at the level of the instrument to provide the wind speed informationrequired. Allowance has to be made for rainfall, if there has been any. Water is added to the pan from a graduated cylinder to bring the water level to the original mark, i.e., 5 cm below the top of the pan. Experiments have shown that the unscreened pan evaporation is 1.144 times that of the screened one.

(iii) Colarado sunken pan. This is 92 cm square and 42-92 cm deep and is sunk in the ground such that only 5-15 cm depth projects above the ground surface and thus the water level is maintained almost at the ground level. The evaporation is measured by a point gauge

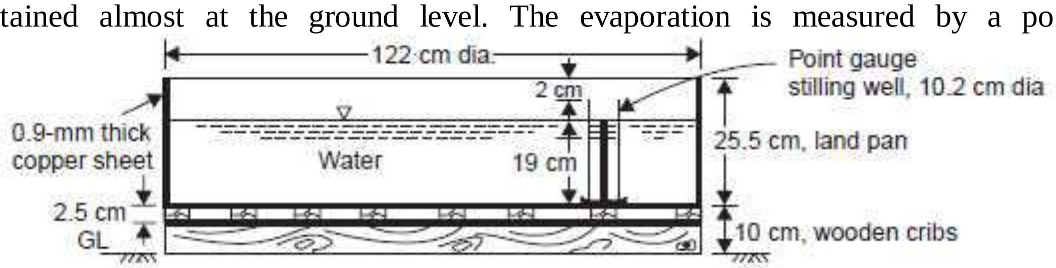


Fig. 3.2 IMD land pan

Pan coefficient—

Evaporation pan data cannot be applied to free water surfaces di- rectly but must be adjusted for the differences in physical and climatological factors. For ex- ample, a lake is larger and deeper and may be exposed to different wind speed, as compared to a pan. The small volume of water in the metallic pan is greatly affected by temperature fluc- tuations in the air or by solar raditions in contrast with large bodies of water (in the reservoir) with little temperature fluctuations. Thus the pan evaporation data have to be corrected to obtain the actual evaporation from water surfaces of lakes and reservoirs, i.e., by multiplying by a coefficient called pan coefficient

TRANSPIRATION:

Tanspiration is the process by which the water vapour escapes from the living plant leaves and enters the atmosphere. Various methods are devised by botanists for the measurement of transpiration and one of the widely used methods is by phytometer. It consists of a closed water tight tank with sufficient soil for plant growth with only the plant exposed; water is applied artificially till the plant growth is complete. The equipment is weighed in the begin- ning(W1) and at the end of the experiment (W2). Water applied during the growth (w) is measured and the water consumed by transpiration (Wt) is obtained as

$$Wt = (W1 + w) - W2$$

The experimental values (from the protected growth of the plant in the laboratory) have to be multiplied by a coefficient to obtain the possible field results. Transpiration ratio is the ratio of the weight of water absorbed (through the root system), conveyed through and transpired from a plant during the growing season to the weight of the dry matter produced exclusive of roots.

For the weight of dry matter produced, sometimes, the useful crop such as grains of wheat, gram, etc. are weighed. The values of transpiration ratio for different crops vary from 300 to 800 and for rice it varies from 600 to 800 the average being 700. Evaporation losses are high in arid regions where water is impounded while transpira- tionis the major water loss in humid regions.

EVAPOTRANSPIRATION

Evapotranspiration (Et) or consumptive use (U) is the total water lost from a cropped (or irrigated) land due to evaporation from the soil and transpiration by the plants or used by the plants in building up of plant tissue. Potential evapotranspiration (Ept) is the evapotranspiration from the short green vegetation when the roots are supplied with unlimited water covering the soil. It is usually expressed as a depth (cm, mm) over the area.

Estimation of Evapotranspiration

The following are some of the methods of estimating evapotranspiration:

(i) Tanks and lysimeter experiments

(ii) Field experimental plots

(iii) Installation of sunken (colarado) tanks

(iv) Evapotranspiration equations as developed by Lowry-Johnson, Penman, Thornthwaite, Blaney-Criddle, etc.

(v) Evaporation index method, i.e., from pan evaporation data as developed by Hargreaves and Christiansen.

Factors Affecting Evapotranspiration

From the above equations it can be seen that the following factors affect the evapotranspiration:

(i) Climatological factors like percentage sunshine hours, wind speed, mean monthly temperature and humidity.

(ii) Crop factors like the type of crop and the percentage growing season.

(iii) The moisture level in the soil.

INFILTRATION:

Water entering the soil at the ground surface is called infiltration. It replenishes the soil mois-turedeficiency and the excess moves downward by the force of gravity called deep seepage or percolation and builds up the ground water table. The maximum rate at which the soil in any given condition is capable of absorbing water is called its infiltration capacity (fp). Infiltration (f) often begins at a high rate (20 to 25 cm/hr) and decreases to a fairly steady state rate (fc) as the rain continues, called the ultimate fp (= 1.25 to 2.0 cm/hr) (Fig. 3.6). The infiltration rate (f) at any time t is given by Horton's equation.

$$f = fc + (fo - fc)\, e^{-kt}$$

where f0 = initial rate of infiltration capacity
fc = final constant rate of infiltration at saturation
k = a constant depending primarily upon soil and vegetation
e = base of the Napierian logarithm
Fc = shaded area in Fig. 3.6
t = time from beginning of t

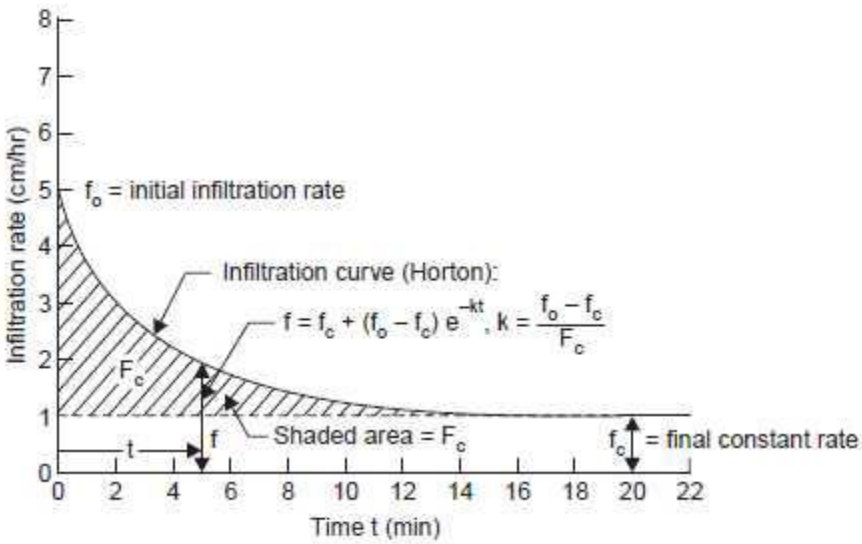


Fig. 3.6 Infiltration Curve (Horton)

The infiltration takes place at capacity rates only when the intensity of rainfall equals or exceeds fp; i.e., f = fp when i ≥ fp; but when i <fp, f <fp and the actual infiltration rates are approximately equal to the rainfall rates.

The infiltration depends upon the intensity and duration of rainfall, weather (temperature), soil characteristics, vegetal cover, land use, initial soil moisture content (initial wet- ness), entrapped air and depth of the ground water table. The vegetal cover provides protection against rain drop impact and helps to increase infiltration.

Methods of Determining Infiltration

The methods of determining infiltration are:

(i) Infiltrometers
(ii) Observation in pits and ponds
(iii) Placing a catch basin below a laboratory sample
(iv) Artificial rain simulators
(v) Hydrograph analysis

(i) Double-ring infiltrometer.

A double ring infiltrometer is shown in Fig. 3.7. The two rings (22.5 to 90 cm diameter) are driven into the ground by a driving plate and hammer, to penetrate into the soil uniformly without tilt or undue disturbance of the soil surface to a depth of 15 cm. After driving is over, any disturbed soil adjacent to the sides tamped with a metal tamper. Point gauges are fixed in the centre of the rings and in the annular space be- tween the two rings. Water is poured into the rings to maintain the desired depth (2.5 to 15 cm with a minimum of 5 mm) and the water added to maintain the original constant depth at regular time intervals (after the commencement of the experiment) of 5, 10, 15, 20, 30, 40, 60 min, etc. up to a period of atleast 6 hours is noted and the results are plotted as infiltration rate in cm/hr versus time in minutes as shown in Fig. 3.8. The purpose of the outer tube is to eliminate to some extent the edge effect of the surrounding drier soil and to prevent the water within the inner space from spreading over a larger area after penetrating below the bottom of the ring.

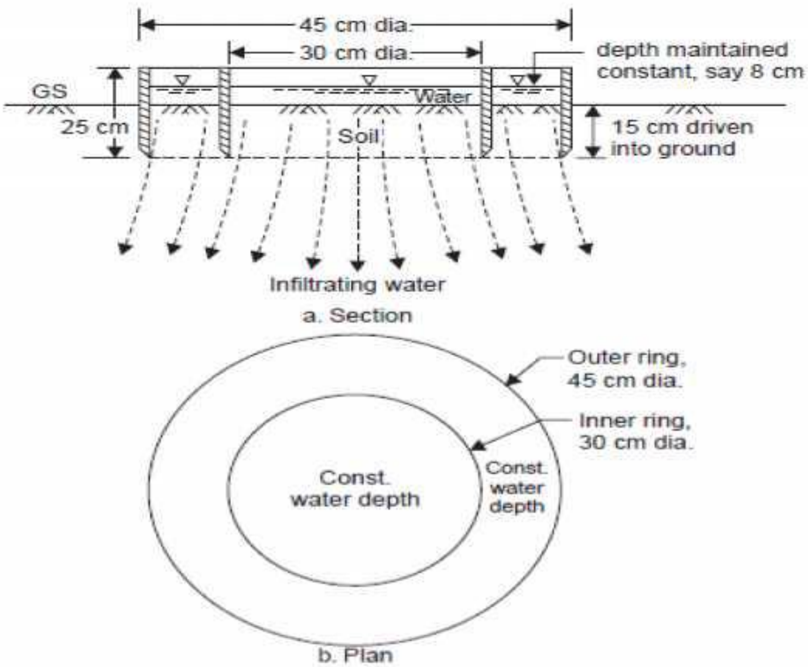


Fig. 3.7 Double ring infiltrometer

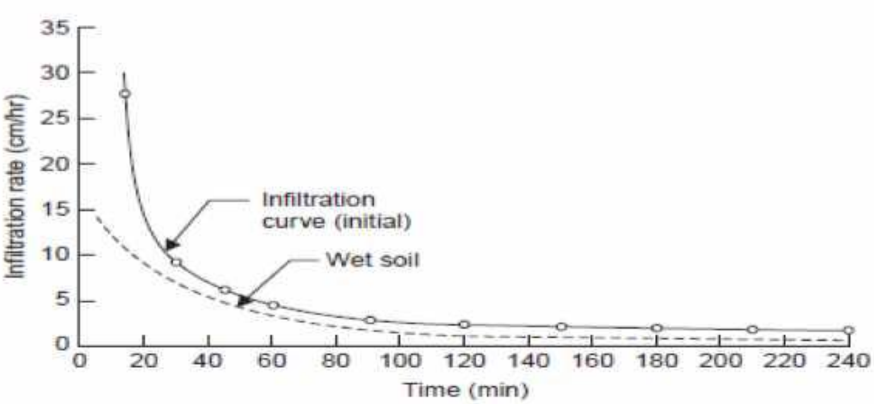


Fig. 3.8 Typical infiltration curve

Tube infiltrometer.

This consists of a single tube about 22.5 cm diameter and 45 to 60 cm long which is driven into the ground atleast to a depth up to which the water percolates during the experiment and thus no lateral spreading of water can occur (Fig. 3.9). The water added into the tube at regular timintervals to maintain a constant depth is noted from which the infiltration curve can be drawn.

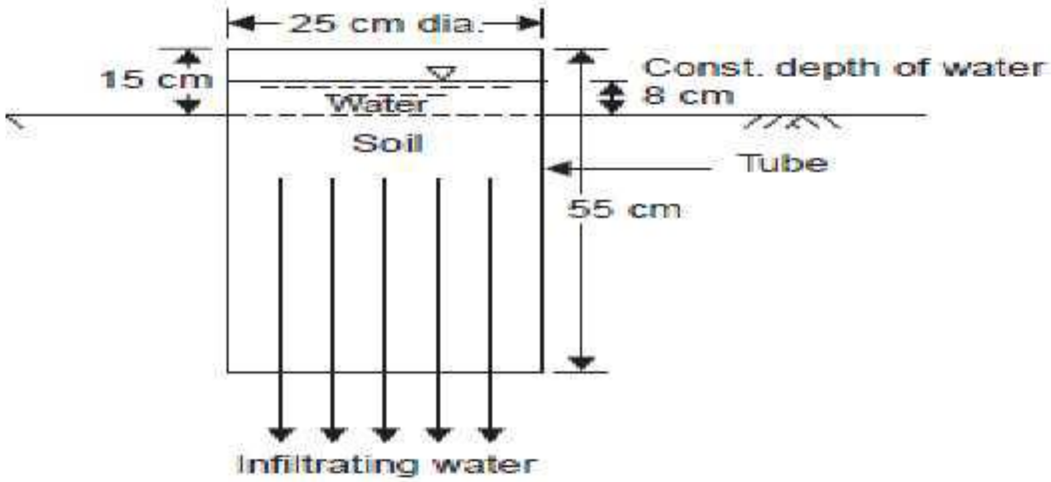


Fig. 3.9 Tube infiltrometer

INFILTRATION INDICES

The infiltration curve expresses the rate of infiltration (cm/hr) as a function of time. The area between the rainfall graph and the infiltration curve represents the rainfall excess, while the area under the infiltration curve gives the loss of rainfall due to infiltration. The rate of loss is greatest in the early part of the storm, but it may be rather uniform particularly with wet soil conditions from antecedent rainfall. Estimates of runoff volume from large areas are sometimes made by the use of infiltra- tionindices, which assume a constant average infiltration rate during a storm, although in actual practice the infiltration will be varying with time. This is also due to different states of wetness of the soil after the commencement of the rainfall. There are three types of infiltration indices:

(I) φ-index
(ii) W-index
(iii) fave-index

(i) φ-index—The φ-index is defined as that rate of rainfall above which the rainfall volume equals the runoff volume. The φ-index is relatively simple and all losses due to infiltration, interception and depression storage (i.e., storage in pits and ponds) are accounted for; hence,provided i > φ throughout the storm. The bar graph showing the time distribution of rainfall,
storm loss and rainfall excess (net rain or storm runoff) is called a hyetograph, Fig. 3.12. Thus, the φ- index divides the rainfall into net rain and storm loss.

$$\varphi\text{-index} = \frac{\text{basin recharge}}{\text{duration of rainfall}}$$

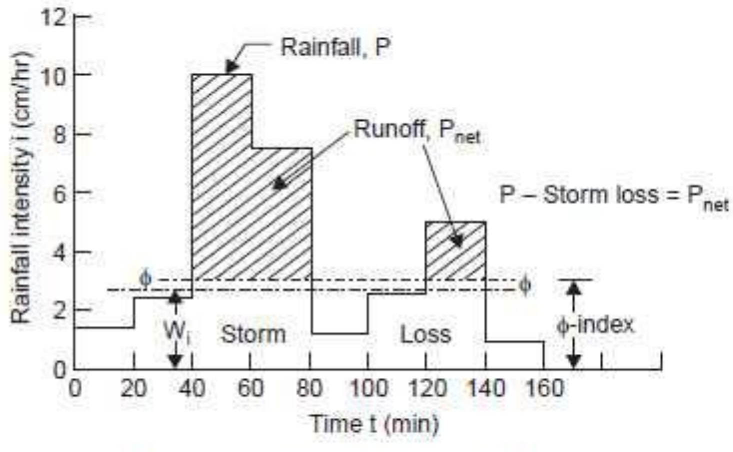


Fig. 3.12 Infiltration loss by ϕ-index

(ii) W-index—The W-index is the average infiltration rate during the time rainfall intensity exceeds the infiltration capacity rate, i.e.,

$$\text{W-index} = \frac{F_p}{t_R} = \frac{P - Q - S}{t_R}$$

where P = total rainfall
Q = surface runoff
S = effective surface retention
tR = duration of storm during which i >fp
Fp = total infiltration
The W-index attempts to allow for depression storage, short rainless periods during a storm and eliminates all rain periods during which i < fp. Thus, the W-index is essentially equal to the φ-index minus the average rate of retention by interception and depression storage, i.e., W < φ.Information on infiltration can be used to estimate the runoff coefficient C in computing the surface runoff as a percentage of rainfall i.e.,

$$Q = CP$$

$$C = \frac{i - W}{i}$$

(iii) fave-index—In this method, an average infiltration loss is assumed throughout the storm, for the period i > f.

RUNOFF

How does runoff occur?

When rainfall exceeds the infiltration rate at the surface, excess water begins to accumulate as surface storage in small depressions. As depression storage begins to fill, overland flow or sheet flow may begin to occur and this flow is called as “Surface runoff”

Runoff mainly depends on:

Amount of rainfall, soil type, evaporation capacity and land use :

- Amount of rainfall: The runoff is in direct proportion with the rainfall. i.e. as the rainfall increases, the chance of increase in runoff will also increases

- Soil type: Infiltration rate depends mainly on the soil type. If the soil is having more void space (porosity), than the infiltration rate will be more causing less surface runoff (eg. Laterite soil)
- Evaporation capacity: If the evaporation capacity is more, surface runoff will be reduced

Components of Runoff

1. Overland Flow or Surface Runoff: The water that travels over the ground surface to a channel. The amount of surface runoff flow may be small since it may only occur over a permeable soil surface when the rainfall rate exceeds the local infiltration capacity.
2. Interflow or Subsurface Storm Flow: The precipitation that infiltrates the soil surface and move laterally through the upper soil layers until it enters a stream channel.
3. Groundwater Flow or Base Flow: The portion of precipitation that percolates downward until it reaches the water table. This water accretion may eventually discharge into the streams if the water table intersects the stream channels of the basin. However, its contribution to stream flow cannot fluctuate rapidly because of its very low flow velocity

Data collection

The local flood control agencies are responsible for extensive hydrologic gaging networks within India, and data gathered on an hourly or daily basis can be plotted for a given watershed to relate rainfall to direct runoff for a given year.

Runoff Measurement

1. **Rational Method**

This method is the simplest form of rainfall-runoff estimation, which allows for the prediction of peak flow Qp(CFS) from the formula

$Qp = C \cdot i \cdot A$

where ,

C = runoff coefficient, variable with land use

i = intensity of rainfall of chosen frequency for a duration equal to time of concentration tc (in./hr)

tc = equilibrium time for rainfall occurring at the most remote portion of the basin to contribute flow at the outlet (min or hr).

A = area of watershed (acres) .

UNIT-II
HYDROGRAPH ANALYSIS

Hydrograph analysis

A hydrograph is a continuous plot of instantaneous discharge v/s time. It results from a combination of physiographic and meteorological conditions in a watershed and represents the integrated effects of climate, hydrologic losses, surface runoff, interflow, and ground water flow. Detailed analysis of hydrographs is usually important in flood damage mitigation, flood forecasting, or establishing design flows for structures that convey floodwaters.

Factors that influence the hydrograph shape and volume

- Meteorological factors
- Physiographic or watershed factors and
- Human factors

Meteorological factors include

- Rainfall intensity and pattern
- Areal distribution or rainfall over the basin and
- Size and duration of the storm event

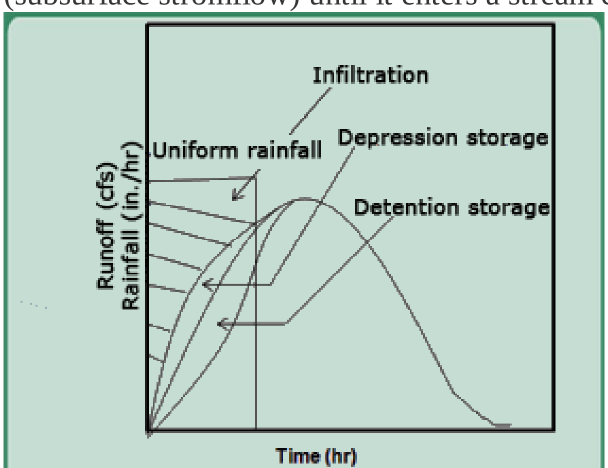
Physiographic or watershed factors include

- Size and shape of the drainage area
- Slope of the land surface and main channel
- Channel morphology and drainage type
- Soil types and distribution
- Storage detention in the watershed

Human factors include the effects of land use and land cover

Hydrograph analysis (contd..)

- During the rainfall, hydrologic losses such as infiltration, depression storage and detention storage must be satisfied prior to the onset of surface runoff
- As the depth of surface detention increases, overland flow may occur in portion if a basin
- Water eventually moves into small rivulets, small channels and finally the main stream of a watershed
- Some of the water that infiltrates the soil may move laterally through upper soil zones (subsurface stromflow) until it enters a stream channel



Distribution of uniform rainfall

Hydrograph relations

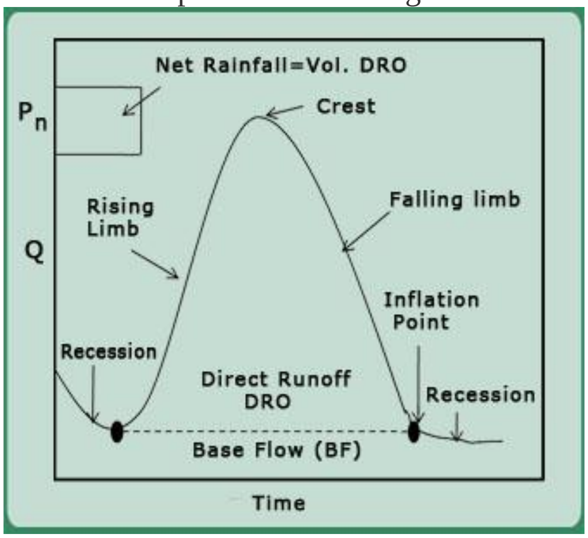
The typical hydrograph is characterized by a

1.Rising limb

2.Crest

3.Recession curve

The inflation point on the falling limb is often assumed to be the point where direct runoff ends



Recession and Base flow separation

- In this the hydrograph is divided into two parts
  1.Direct runoff (DRO) and
  2.Base flow (BF)
- DRO include some interflow whereas BF is considered to be mostly from contributing ground water
- Recession curve method is used to separate DRO from BF and can be expressed by an exponential depletion equation

  $q_t = q_o \cdot e^{-kt}$ where

  q_t = discharge at a later time t

  q_o = specified initial discharge

  k = recession constant

Baseflow Separation Methods

There are three types of baseflow separation techniques

1.Straight line method

2.Fixed base method

3.Constant slope method

1. Straight line method

Assume baseflow constant regardless of stream height (discharge).

Draw a horizontal line segment (A-D) from beginning of runoff to intersection with recession curve.

2. Constant slope method

Connect inflection point on receding limb of storm hydrograph to beginning of storm hydrograph Assumes flow from aquifers began prior to start of current storm, arbitrarily sets it to inflection point Draw a line connecting the point (A-C) connecting a point N time periods after the peak.

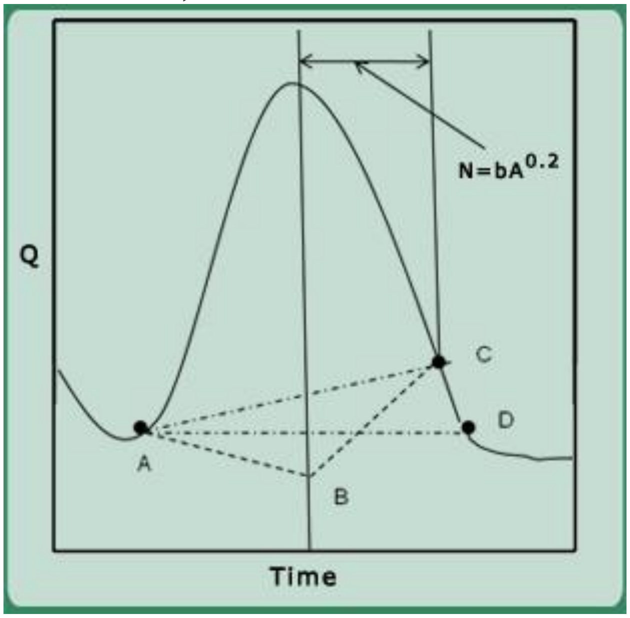
3. Fixed Base Method

Assume baseflow decreases while stream flow increases (i.e. to peak of storm hydrograph)

Draw line segment (A –B) from baseflow recession to a point directly below the hydrograph peak Draw line segment (B-C) connecting a point N time periods after the peak where

N = time in days where DRO is terminated, A= Discharge area in km2,

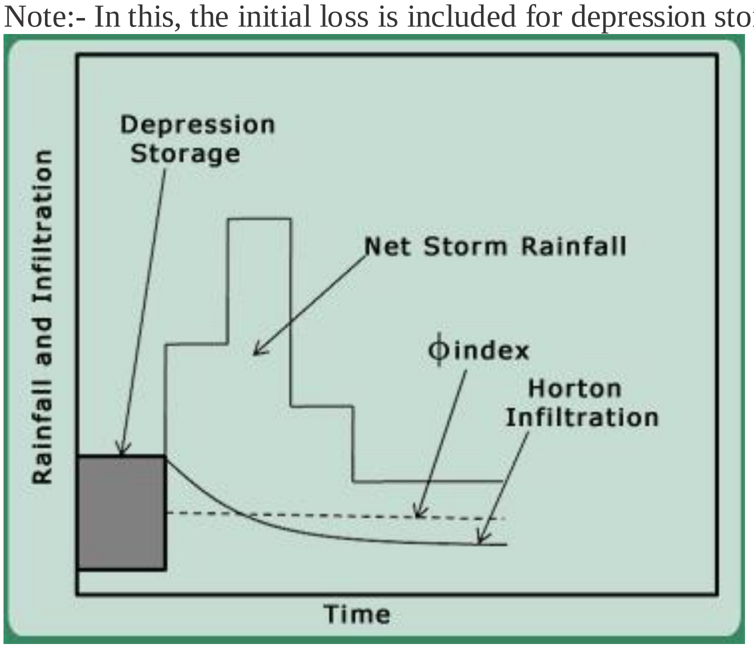
b= coefficient, taken as 0.827



Rainfall excess

- The distribution of gross rainfall can be given by the continuity equation as
  Gross rainfall = depression storage+ evaporation+ infiltration + surface runoff
- In case, where depression storage is small and evaporation can be neglected, we can compute rainfall excess which equals to direct runoff, DRO, by
  Rainfall excess (Pn) = DRO = gross rainfall – (infiltration + depression storage)
- The simpler method to determine rainfall excess include
  1.Horton infiltration method
  2.Ø index method

  Note:- In this, the initial loss is included for depression storage



Horton infiltration method

Horton method estimates infiltration with an exponential-type equation that slowly declines in time as rainfall continues and is given by

$$f = fc + (fo - fc)\, e^{-kt} \text{(when rainfall intensity } i>f)$$

where

f = infiltration capacity (in./hr)

fo = initial infiltration capacity (in./hr)

fc = final infiltration capacity (in./hr)

k = empirical constant (hr-1)

Ø index method

It is the simplest method and is calculated by finding the loss difference between gross precipitation and observed surface runoff measured as a hydrograph.

Unit hydrograph (UH)

- The unit hydrograph is the unit pulse response function of a linear hydrologic system.
- First proposed by Sherman (1932), the unit hydrograph (originally named unit-graph) of a watershed is defined as a direct runoff hydrograph (DRH) resulting from 1 in (usually taken as 1 cm in SI units) of excess rainfall generated uniformly over the drainage area at a constant rate for an effective duration.
- Sherman originally used the word “unit” to denote a unit of time. But since that time it has often been interpreted as a unit depth of excess rainfall.
- Sherman classified runoff into surface runoff and groundwater runoff and defined the unit hydrograph for use only with surface runoff.

The unit hydrograph is a simple linear model that can be used to derive the hydrograph resulting from any amount of excess rainfall. The following basic assumptions are inherent in this model :

- Rainfall excess of equal duration are assumed to produce hydrographs with equivalent time bases regardless of the intensity of the rain.
- Direct runoff ordinates for a storm of given duration are assumed directly proportional to rainfall excess volumes.
- The time distribution of direct runoff is assumed independent of antecedent precipitation.
- Rainfall distribution is assumed to be the same for all storms of equal duration, both spatially and temporally.

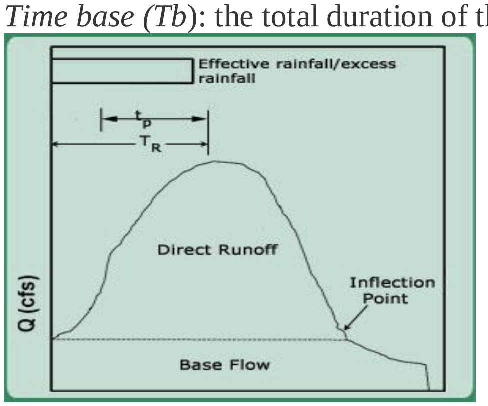
Terminologies

Duration of effective rainfall : the time from start to finish of effective rainfall

Lag time (L or tp): the time from the center of mass of rainfall excess to the peak of the hydrograph

Time of rise (TR): the time from the start of rainfall excess to the peak of the hydrograph

Time base (Tb): the total duration of the DRO hydrograph



Rules to be observed in developing UH from gaged watersheds

- ✓ Storms should be selected with a simple structure with relatively uniform spatial and temporal distributions .
- ✓ Watershed sizes should generally fall between 1.0 and 100 mi2 in modern watershed analysis .
- ✓ Direct runoff should range 0.5 to 2 in.
- ✓ Duration of rainfall excess D should be approximately 25% to 30% of lag time tp
- ✓ A number of storms of similar duration should be analyzed to obtain an average UH for that duration .
- ✓ Step 5 should be repeated for several rainfall of different durations .

Essential steps for developing UH from single storm hydrograph

- Analyze the hydrograph and separate base flow .
- Measure the total volume of DRO under the hydrograph and convert time to inches (mm) over the watershed.
- Convert total rainfall to rainfall excess through infiltration methods, such that rainfall excess = DRO, and evaluate duration D of the rainfall excess that produced the DRO hydrograph.
- Divide the ordinates of the DRO hydrograph by the volume in inches (mm) and plot these results as the UH for the basin. Time base Tb is assumed constant for storms of equal duration and thus it will not change.
- Check the volume of the UH to make sure it is 1.0 in.(1.0mm), and graphically adjust ordinates as required.

S – Curve method

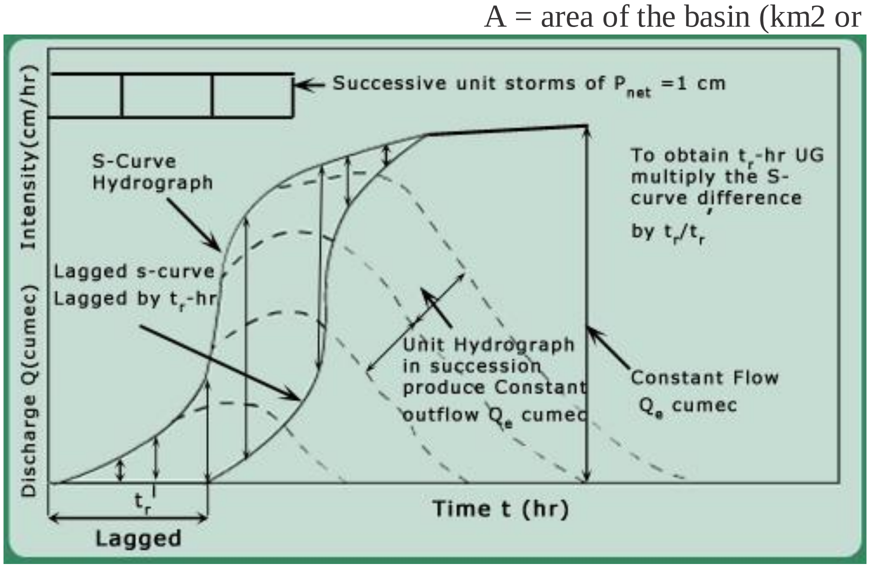
It is the hydrograph of direct surface discharge that would result from a continuous succession of unit storms producing 1cm(in.)in tr –hr

If the time base of the unit hydrograph is Tb hr, it reaches constant outflow (Qe) at T hr, since 1 cm of net rain on the catchment is being supplied and removed every tr hour and only T/tr unit graphs are necessary to produce an S-curve and develop constant outflow given by,

Qe = (2.78·A) /tr

where

Qe = constant outflow (cumec)
tr =duration of the unit graph (hr)
A = area of the basin (km2 or acres)



Introduction to groundwater hydrology

A major component of precipitation that falls on the earth surface eventually enters into the ground by the process of infiltration. The infiltrated water is stored in the pores of the underground soil strata. The water which is stored in the pores of the soil strata is known as groundwater. Therefore, the groundwater may be defined as all the water present below the earth surface and the groundwater hydrology is defined as the science of occurrence, distribution and movement of water below the earth surface.

Classification of ground water

There are various classifications of groundwater given by different researchers. However, as per the most popular classification given by Meinzer (1923), the groundwater has been divided mainly in two groups: interstitial water and internal water. The interstitial water is again subdivided into two divisions. They are vadose water present in the zone of aeration and groundwater present in the zone of saturation. The vadose water is further subdivided into three zones, i.e., soil water zone, intermediate zone and capillary zone. Fig. 1.2 shows the classification of groundwater. The soil water zone is adjacent to the ground surface. The intermediate zone is between the lower edge of the soil water zone and the upper edge of the capillary zone. The capillary zone extends from the bottom edge of the intermediate zone to the upper edge of the saturated zone. The thickness of the capillary zone depends on the properties of the soil and also on the homogeneity of the soil. The depth of capillary zone is varying from few centimeters to few meters. In capillary zone, all the pores are field up with water. However, we cannot draw water by inserting a well up to that depth. This is because of the negative pressure developed at this zone due to surface tension effect. Groundwater zone starts from the bottom edge of the capillary zone. In this zone, all the pores of the soil matrix are filled with water. This zone is also known as zone of saturation. The top surface of the zone of saturation or groundwater is known as phreatic surface. This phreatic surface is also known as water table.

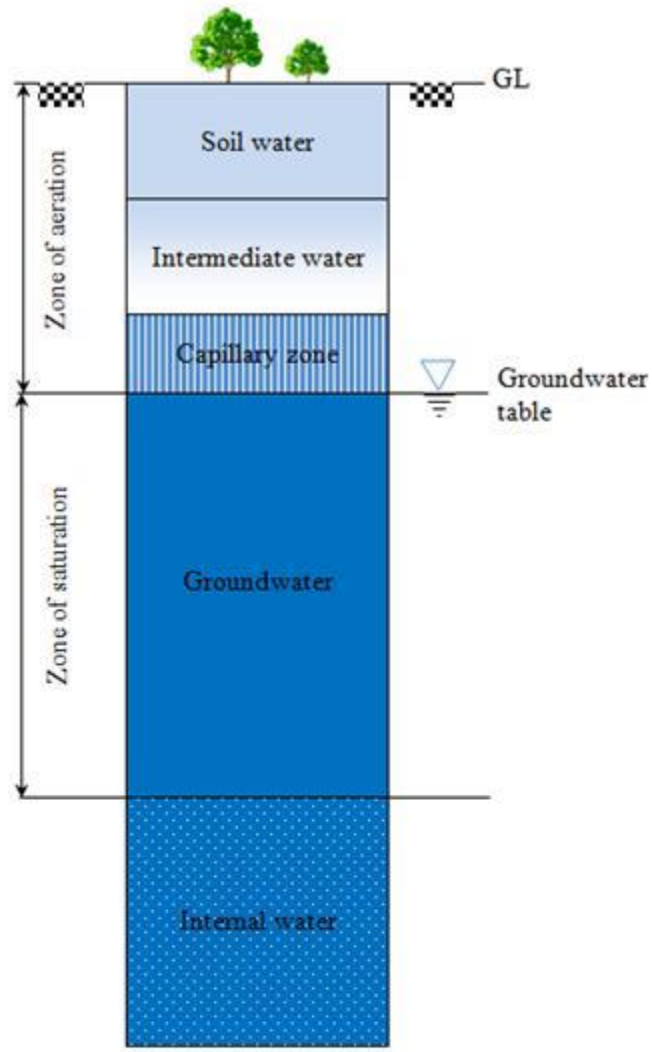


Fig. 1.2 Classification of groundwater

The degree of saturation for the soil below the water table is equal to 1, i.e. the soil is fully saturated. As a groundwater hydrologist, we are primarily interested for the water below the groundwater table, i.e. the water available in the zone of saturation . For the soil above the water table, the degree of saturation of the soil is varying between 0 and 1 . However, the degree of saturation will never be 0 due of the presence of hygroscopic water. The hygroscopic water is the water that held tightly on the surface of the soil colloidal particle. Hygroscopic water can be removed from the soil by oven drying. Fig. 1.3 shows the moisture distribution in soil column.

Approximation of Groundwater Table

The water table acts as a boundary between saturated zone and unsaturated zone. The soil matrix is fully saturated below the water table. At the same time, the soil just above the water table is also saturated due to the capillary effect. The depth of capillary rise may be from few centimeters to few meters. A suggested by SilinBekchurin (1958), capillary rise may be around 2-5 cm in case of course sand, may be around 12-35 cm in case of sand, around 35-70 cm in case of fine sand, around 70-150 cm in case of silt and around 2-4 m and more in case of clay soil. Fig.1.4 shows the actual and approximate distribution of the moisture content. The actual distribution can be approximate by a step function which is necessary to approximate the elevation of the groundwater table. The step defines the depth of the capillary rise, h_c.

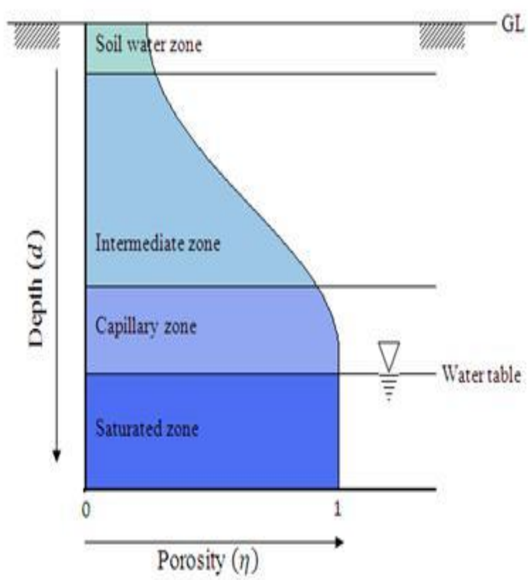


Fig. 1.3 Moisture distribution in a soil column

It can be assumed that up to the distance of h_c, above the phreatic surface, the aquifer is fully saturated. The aquifer above h_c line is completely dry, *i.e.* no moisture is present. The upper end of the capillary fringe may be taken as the groundwater table. However, when depth of capillary fringe, h_c is much smaller than the thickness of the aquifer below the water table, the capillary fringe may be neglected in solving real world problems. The depth of the capillary fringe can be approximated as (Mavis and Tsui 1939)

$$h_c = \frac{2.2}{dm}\left(\frac{1-n}{n}\right)^{3/2}$$

where d_m is the mean diameter of the soil grain, n is the porosity. Polubarinova - Kochina (1952, 1962) approximated the capillary fringe as

$$h_c = \frac{0.45}{d_{10}}\left(\frac{1-n}{n}\right) \quad (1.4)$$

where d_{10} is the partical size at which 10% of the total partical is finer than that size.

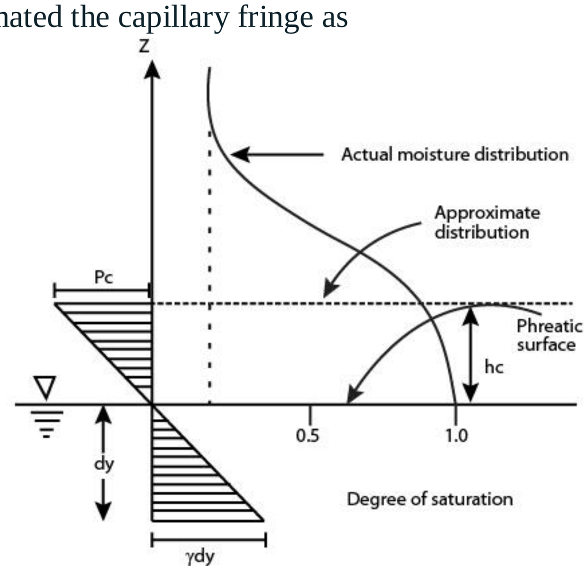


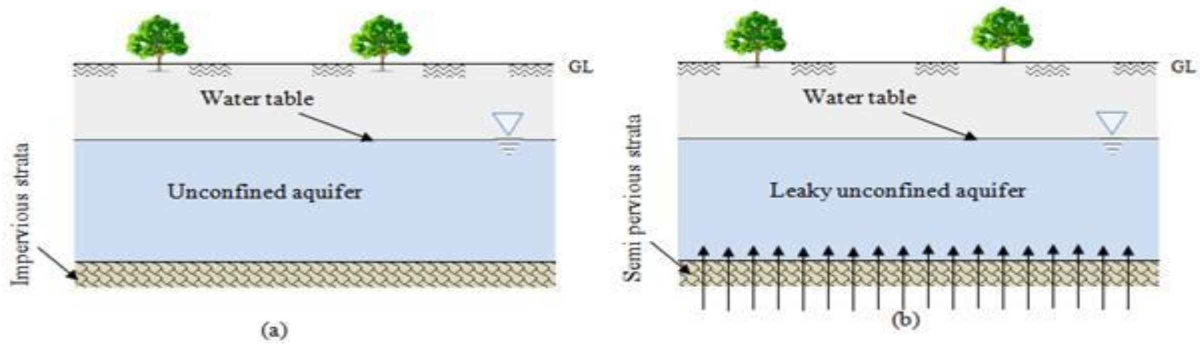
Fig. 1.4: Approximation of groundwater table

Geological formations and their classification

Aquifer

An aquifer is an underground geological formation which contains water and sufficient amount of water can be extracted economically using water wells. Aquifers comprise generally layers of sand and gravel and fracture bedrock.

When water table serves as the upper boundary of the aquifer, the aquifer is known as unconfined aquifer (Fig. 1.5 (a)). As discussed in the earlier section, there exists a capillary zone above the water table. However, in most of the analysis, the capillary zone is neglected and water table is considered as the upper boundary of the aquifer. The unconfined aquifer is also known as water table aquifer and phreatic aquifer. An impervious layer is generally served as the bottom boundary of an unconfined aquifer. Sometime, the bottom of an unconfined aquifer may be semipervious and water may gain and lose through the semipervious bottom layer. The aquifer is then known as leaky unconfined aquifer (Fig. 1.5 (b)).



An aquifer which is bounded by two impervious layers at top and bottom of the aquifer is called confined aquifer (Fig. 1.6 (a)). In case of confined aquifer, if we insert a piezometer into the aquifer, the water level will rise above the top impervious layer as the pressure in the aquifer is more than the atmospheric pressure. As such, the confined aquifer is also known as pressure aquifer. Top and bottom layer of a confined aquifer is generally impervious. However, sometimes these layers may be semipervious in nature. In such a situation, the water may gain or lose through these semipervious layers. The aquifer is then called leaky confined aquifer (Fig. 1.6 (b)).

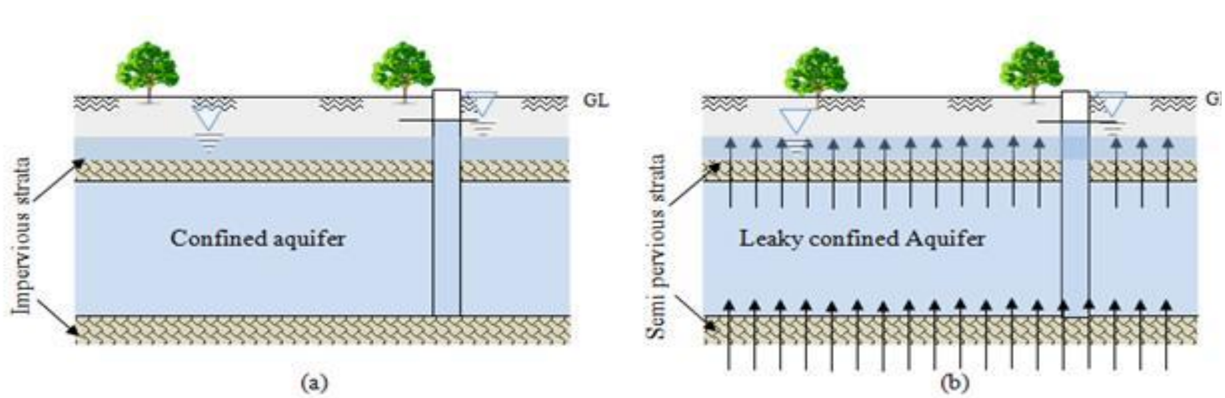


Fig. 1.6 (a) Confined aquifer (b) Leaky confined aquifer

When piezometric surface of a confined aquifer is above the ground level, the confined aquifer is then called an artesian aquifer. For artesian aquifer, if you put a well, the water will come out of the well automatically.

Aquitard

An aquitard is an underground geological formation which contains water but significant amount of water cannot be extracted using water wells. Aquitard comprises of generally layers of clay soil with low hydraulic conductivity.

Aquifuge

It is a geological formation which is incapable to absorb or transmit water through it. Thus it is an impermeable formation.

Homogeneous and isotropic medium

A porous medium is called homogeneous when aquifer parameters are constant throughout the medium, i.e. the properties of the medium are independent of space (Fig. 1.7(a)). The medium will be called non-homogeneous when aquifer properties are varying with space (Fig. 1.7(b)).

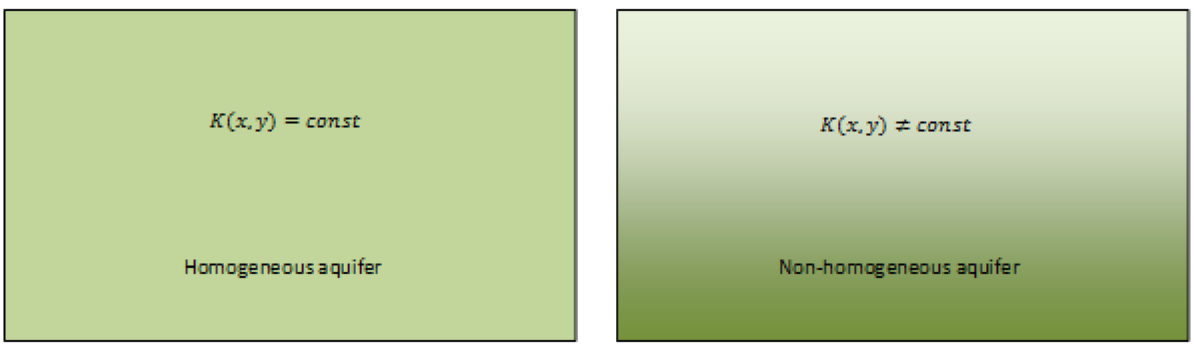


Fig. 1.7 (a) Homogeneous aquifer (b) Non-homogeneous aquifer

A porous medium will be called isotropic when medium parameters are constant in all the directions, i.e. the parameters are independent of direction (Fig. 1.8(a)). The medium will be called an anisotropic when the parameters are different in different directions (Fig. 1.8(b)).

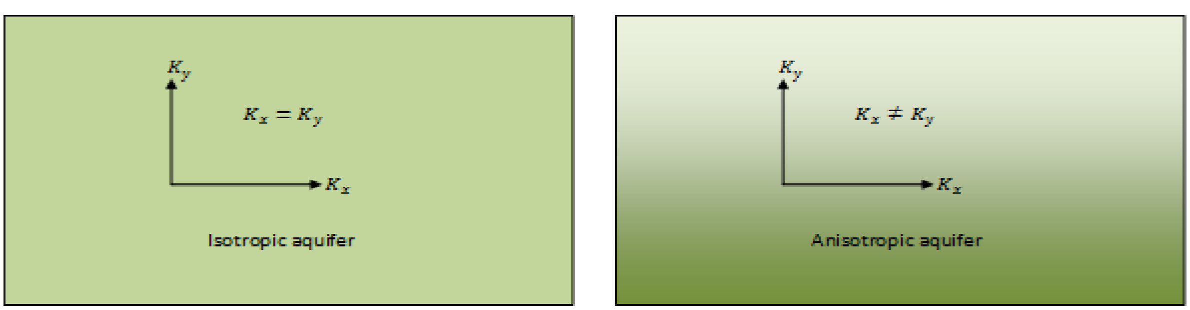
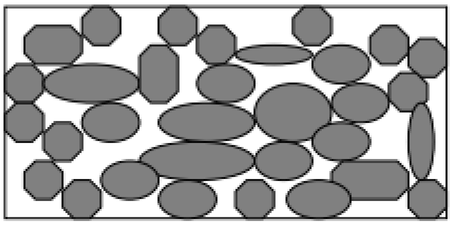


Fig. 1.8 (a) Isotropic aquifer (b) Anisotropic aquifer

Aquifer Properties

- **Porosity** – Percentage volume occupied by voids. Porosity is independent of scale. For example, a pile of marbles and a pile of beach balls have spherical shape and differing sizes; the porosities are identical due to the similar shaping.



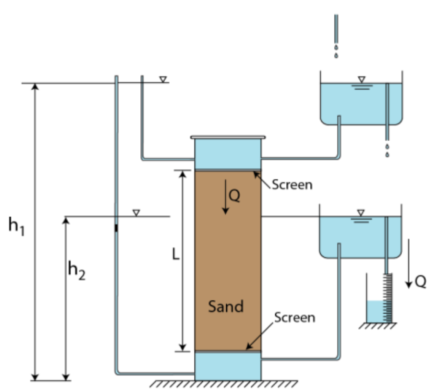
- **Permeability** – Measures the transmission property of the media and the interconnection of the pores. Related to hydraulic conductivity and transmissivity. (more later)

  Good aquifer – High porosity + High permeability • Sand and gravel, sandstone, limestone, fractured rock, basalt

  Aqiuiclude, Confining bed, Aquitard – "impermeable" unit forming a barrier to groundwater flow. • Granite, shale, clay

Darcy's Experiment

In the year 1856, Henry Darcy, a French hydraulic engineer investigated the flow of water through a vertical homogeneous sand filter. Based on his experiments, he concluded that the rate flow through the porous media is proportional to the head loss and is inversely proportional to the length of the flow path. Figure 3.1 shows the setup of Darcy's experiment. As shown in the figure, the length of the vertical sand filter is L, the cross sectional area of the filter is A, the piezometric heads at top and bottom of the filter are h_1 and h_2. Thus the head loss is (h_1 - h_2). The piezometric heads are measured with respect to an arbitrary datum. As per the conclusions made by Darcy, the flow rate Q is



- proportional to the cross sectional area *(A)* of the filter
- proportional to the difference in piezometric heads
- inversely proportional to the length *(L)* of the filter

After combining these conclusions, we have

$$Q = KA\left(\frac{h_1 - h_2}{L}\right) \qquad (3.1)$$

Where,
Q is the flow rate, *i.e.* the volume of water flows through the sand filter per unit time.
K is the coefficient of proportionality and is termed as hydraulic conductivity of the medium. It is a measure of the permeability of the porous medium. It is also known as coefficient of permeability. h_1 and h_2 are the piezometric heads.
Now, defining $J = \frac{h_1 - h_2}{L}$ and $q = \frac{Q}{A}$
Where J is the hydraulic gradient and q is the specific discharge, *i.e.* the discharge per unit area.
The equation 3.1 can also be written as,
q = KJ (3.2)

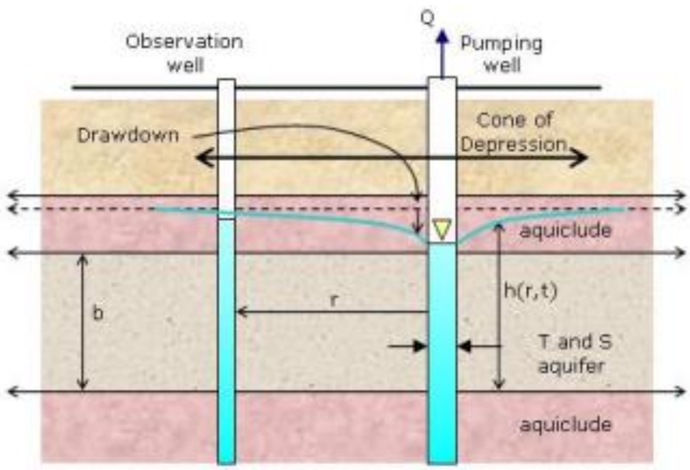
Validity of Darcy's Law

Darcy's law stated that the relation between specific discharge (*q*) and hydraulic gradient (*J*) is linear. However in real world situation, the relation becomes non-linear for higher values of specific discharge. As such, the Darcy's law is not valid for higher specific discharge. The relation is generally linear as long as the Reynolds number does not exceed some value between 1 and 10. The Reynolds number, which is expressed as the ratio between inertial force and viscous force acting on the fluid.

Steady Radial Flow in a Confined Aquifer

Assumptions:

- Aquifer is confined (top and bottom)
- Well is pumped at a constant rate
- Equilibrium is reached (no drawdown change with time)
- Wells are fully screened and is only one pumping



Consider Darcy's law through a cylinder, radius r, with flow toward well.

$Q = K\frac{dh}{dr}2\pi rb$ and rearrange as $dh = \frac{Q}{2\pi Kb}\frac{dr}{r}$

Integrate from r_1, h_1 to r_2, h_2

Integrate from r_1, h_1 to r_2, h_2

$$\int_{h_1}^{h_2} dh = \frac{Q}{2\pi Kb}\int_{r_1}^{r_2}\frac{dr}{r}$$

$$h_2 - h_1 = \frac{Q}{2\pi Kb}\frac{r_2}{r_1}$$ or noting that T = Kb

$$\boxed{T = \frac{Q}{2\pi(h_2 - h_1)}\ln\frac{r_2}{r_1}}$$ this is the Thiem equation

Notes on the Thiem equation:

- Good with any self consistent units L and t
- If drawdown has stabilized can use any two observation wells
- Water is not coming from storage (S doesn't appear) cannot get S from this test
- Commonly used in USGS units and $\log_{10}$, T in gpd/ft (gallons per day per foot), Q in gpm (gallons per minute), r and h in ft.

$$T = \frac{527.7Q}{(h_2 - h_1)}\log\frac{r_2}{r_1}$$

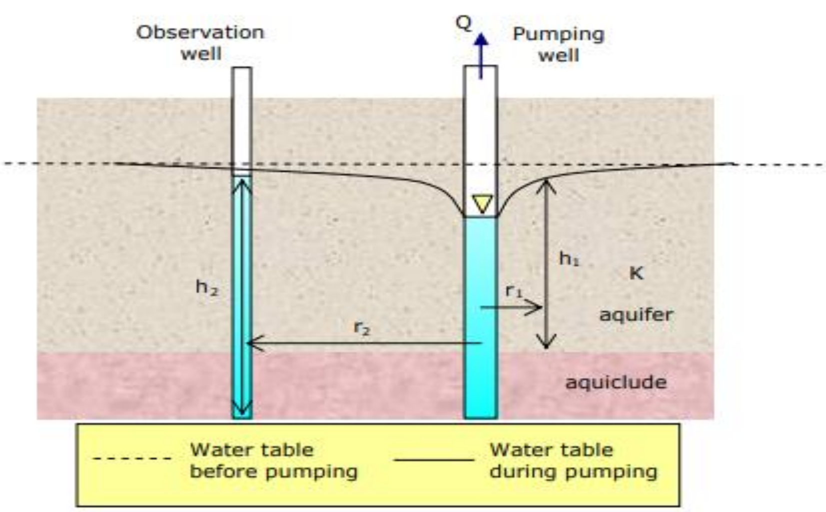
Specific Capacity of a Well – Roughly estimating T

Specific Capacity = Discharge Rate/Drawdown in the well

Steady Radial Flow in an Unconfined Aquifer

Assume:

- Aquifer is unconfined but underlain by an impermeable horizontal unit.
- Well is pumped at a constant rate
- Equilibrium is reached (no drawdown change with time)
- Wells are fully screened and
- There is only one pumping well



Radial flow in the unconfined aquifer is given by

$$Q = K(2\pi r h)\frac{dh}{dr} \text{ and rearrange as } hdh = \frac{Q}{2\pi K}\frac{dr}{r}$$

Integrate from r_1, h_1 to r_2, h_2

$$\int_{h_1}^{h_2} jdh = \frac{Q}{2\pi K}\int_{r_1}^{r_2}\frac{dr}{r}$$

$$\frac{h_2^{\,2} - h_1^{\,2}}{2} = \frac{Q}{2\pi K}\ln\frac{r_2}{r_1}$$ or noting that T = Kb

$$\boxed{K = \frac{Q}{\pi(h_2^{\,2} - h_1^{\,2})}\ln\frac{r_2}{r_1}}$$

this is the Thiem equation for unconfined conditions (K not T, h^2 not h, no 2)

Yield of Wells:

It is well known that under the favourable condition water tries to maintain its own level. Hence, it is obvious that the level of water in a well approximately indicates the level of waters table under normal conditions of no withdrawal. As the water is pumped out or withdrawn from the well the level of water in the well falls more quickly than the ground water level and consequently if forms a cone of depression. The difference of level of waters table and the water level in the well now is called a head of depression.

Actually under this head water percolates into the well through soil pores. Naturally when depression head is more the rate of water contribution to the well will also be more. If the depression head goes on increasing, due to continued water withdrawal from the well then a time may come when the increased velocity will dislodge the soil particles. At this stage the percolating water brings soil particles with it in the well.

Naturally this stage is critical and hence various terms, for example, depression head, rate of percolation, (it is also termed yield of well and is expressed in cubic metres per hour or in litres per minute) velocity of percolation are prefixed with the term critical.

It is very essential that the critical depression head should not be allowed to reach or be allowed to exceed for a particular well withdrawal as after that it may create unstable conditions for the well structure. Sufficient margin of safety or a factor of safety should be provided (Generally factor of safety is 3 to 4).

It should be noted now that whenever “yield of well” is referred to, its means maximum safe yield unless otherwise stated. Yield of well is the rate at which water percolates into the well under the safe maximum working head or critical depression head. It is expressed in m3/hr or It/min. The yield of open well can be determined by any one of the two methods, namely, pumping test and recuperation test.

Pumping Test:

In this method water is withdrawn from the well freely till a critical depression head or a safe maximum head is created. Once this stage is reached the rate of pumping is so adjusted as to maintain the constant water level in the well. Thus the depression head remains constant. Naturally at his stage the rate at which water is pumped out of the well will be equal to the rate at which water percolates into the well. This rate is expressed in m3/hr or It/min and will be obviously the yield of the well.

Recuperation Test:

In this method water level in the well is depressed by pumping to any level below the normal level. Then the pumping is stopped and time taken by the percolating water to fill the well to any particular level is noted. Total quantity of water percolated into the well is calculated by knowing cross-sectional area and rise in the water level after stoppage of pumping. The rate of percolation or the yield of well can be arrived at by dividing the quantity of water by the time. This test is carried out generally in a driest period to take worst condition into account.
Now it can be inferred that the actual pumping test of determining available yield is most reliable but it is difficult to conduct the test accurately. Whereas recuperation test is very simple to perform but it does not give the maximum safe yield. The reason is as the water level in the well rises the safe maximum working head is not maintained throughout the period of observation.

Specific Yield of Wells:

Rate of water percolation in the well or yield of a well in m3/hr under a head of one metre is called the specific yield of the well. From the above definition it is clear that the specific yield depends on: (i) position of the water-table, (ii) permeability and porosity of the soil formation, (iii) the rate of water withdrawal from the well, and (iv) quantity of water storage in the well. Specific yield of the well is also called specific capacity of the well.

It can be calculated from the following formula:

K = 2.303 [A/T log H1/H2]

Where K is specific yield of a well in m3/hr under depression head of one metre.

A is area of well in plan in m2.

T is total time of recuperation to bring water level from depth H1 to H2

H1 is difference of water level in the well just after stoppage of pumping and the normal water level of the well

H2 is difference of water level in the well after time T and normal water level of the well.

$$Q \propto H$$

$$Q = K \cdot H \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

K is a constant or specific yield of the well.

O – O represents normal or original water level in the well.

m — m represents the water level in the well after pumping.

n – n represents the water level in the well at time T after stoppage of pumping.

q – q represents the water level in the well at any time t after stoppage of pumping.

p – p represents the water level in well at time t + dt after stoppage of pumping.

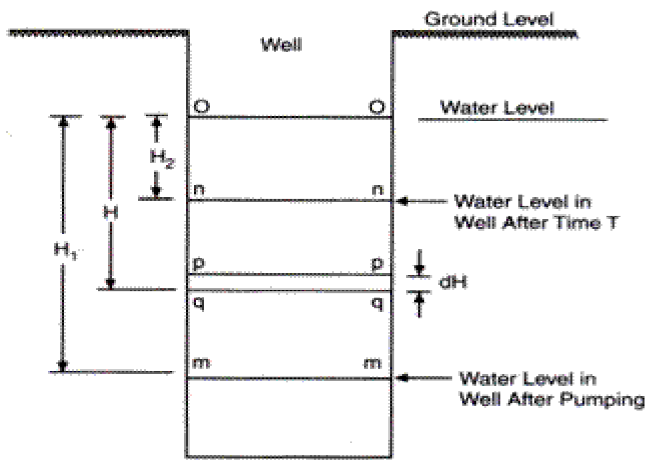


Fig. 17.13.

The amount of water percolated into the well in short time δt is given by

$$q = A \times dH$$

where dH is the rise in water level in the short time δt.

Also $$q = Q \times \delta t$$

$\therefore$ $$Q \times dt = A \times dH$$

Substituting for Q from (1)

$$K \times H \times \delta t = A \times dH$$

Separating the variables

$$\frac{K}{A}\delta t = \frac{dH}{H} \quad \text{... (2)}$$

Now integrating the equation (2) between limits

$$t = 0 \quad \text{and} \quad t = T$$

and $$H = H_1 \quad \text{and} H = H_2$$

As the time increases depression head decreases hence negative sign will be taken for limits of H.

$$-\log_e H \Big|_{H_1}^{H_2} = \frac{K}{A} t \Big|_0^T$$

Taking limits

$$\log_e \frac{H_1}{H_2} = \frac{K}{A}.T$$

Converting into common logarithm

$$2.303 \log_{10} \frac{H_1}{H_2} = \frac{K}{A}.T$$

or $$K = 2.303 \frac{A}{T} \log_{10} \frac{H_1}{H_2} \quad \text{... (3)}$$

The equation (3) can also be written in the from

$$\frac{K}{A} = 2.303 \frac{1}{T} \log_{10} \frac{H_1}{H_2}$$

K/A is the specific yield of well per unit area of the well and expressed in $m^3/hr/m^2$.

When the limit of critical velocity is not exceeded it may be rightly assumed that K/A is constant for a well. For several types of subsoil formations Marriot has given the following Table 17.3.

Table 17.3. Marriot's Table of Specification

Type of subsoil	*K/A*
Clay	0.25
Fine sand	0.50
Coarse sand	1.0

UNIT-III
IRRIGATION

Water is the most important element for the growth of plants. Different types of plants require different quantities of water at different times during their growing period. Water is supplied to the plants through direct rain or flood waters of the rivers which inundate large land areas during floods. As these are natural processes, there may be heavy rain and damaging the crops or creating a scarcity of supplying water for the crops. So an artificial method is needed by which water can be collected and stored so that it can be used when necessary. This method of science is termed as “irrigation”. There are various types of irrigation methods. Irrigation system definition, irrigation history, irrigation scheduling approaches, irrigation examples are briefly described below.

What is Irrigation System?

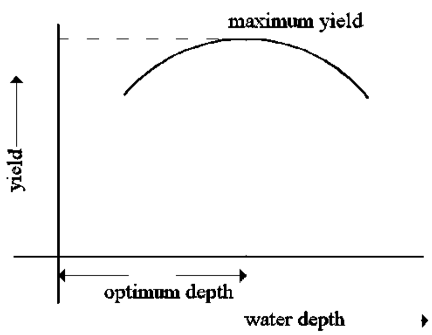
Irrigation may be defined as the science of the artificial application of water to the land in order to fulfill the water requirements of the crops throughout the *crop period* for the full nourishment of the crops. Nutrients to the crops may also be applied through irrigation.

Irrigation Synonym: rinse, wash, wash out, inundate, flow, soak, etc.

Irrigation antonym: Dry, drought, drainage.

Crop period: The time period between the instant of sowing seeds to the instant of harvesting the plants is called crop period.

Irrigation water should be supplied as soon as the moisture falls up to the optimum level. The quantity of water that produces the maximum yield of the crops is termed as optimum water level. More or less than the optimum level results in the reduction of the yield.



Necessity of Irrigation

India is basically an agricultural country, and all its resources depend on the agricultural output. Water is evidently the most vital element in the plant life. Water is normally supplied to the plants by nature through rains. However, the total rainfall in a particular area may be either insufficient, or ill-timed. In order to get maximum yield, it is essential to supply the optimum quantity of water, and to maintain correct timing of water, this is possible only through a systematic irrigation system. Thus, the necessity of irrigation is as follows:

1. Less Rainfall

When the total rainfall is less than needed for the crop, artificial supply is necessary. In such case, irrigation works may be constructed at a place where more water is available, and then to convey the water to the area where there is deficiency of water. Rajasthan canal is one such example. It conveys water to the arid zones of Rajasthan, where the annual rainfall is hardly 100-200 mm.

2. Non-uniform Rainfall

The rainfall in a particular area may not be uniform over the crop period. During the early periods of the crops, rains may be there, but no rainwater may be available at the end, with the result that either the yield may be less, or the crop may die altogether. By collection of water during the excess rainfall period, water may be supplied to the crop during the period when there may be no rainfall. Most of the irrigation projects in India are based on this premise.

3. Growing a number of crops during a year

The rainfall in an area may be sufficient to raise only one type of crop during the rainy season (i.e. Kharif crops), for which no irrigation may be required. However, with the provision of irrigation facilities in that area, crops can be raised in other season also (i.e. Rabi crops).

4. Growing perennial crops

Perennial crops such as sugar cane etc, which need water throughout the year, can be raised only through the provision of irrigation facilities in the area.

5. Commercial crop with additional water

The rainfall in a particular area may be sufficient to raise usual crops, but more water may be necessary for raising commercial and cash crops.

6. Controlled water supply

By construction of proper distribution system, the yield of the crop may be increased because of controlled supply of water.

Advantages of irrigation

- ***Increase in food production*** – timely and optimum supply of water to the fields helps in increasing crop yield. This solves food problem of the country.

- ***Elimination of mixed cropping*** - means sowing together of two or more crops in the same field. If the weather conditions are not favorable for one crop the famer will at least gets yield from the other. If irrigation is assured mixed cropping can be eliminated or reduced.

- ***General prosperity of the region***- Due to assured supply of water cash crops like sugarcane, cotton, tobacco can be grown by which prosperous and their standard of living improves.

- ***Revenue to state***- Increased food production saves foreign exchange spent on import. Also water charges levied increase revenue of the state.

- ***Generation of hydroelectric power*** – same projects designed for irrigation can be used for hydro electric power generation at cheaper cost.

- ***Domestic water supply*** – irrigation structures constructed can be used for town water supply schemes.

- ***Famine protection*** – Irrigation works helps during famine and drought in two ways. During construction, employment is carried to the people and after construction continuous water supply is maintained.

- ***Transportation***– Larger irrigation channels can be used for inland navigation purposes also embankments and inspection roads make pathway for commuters.

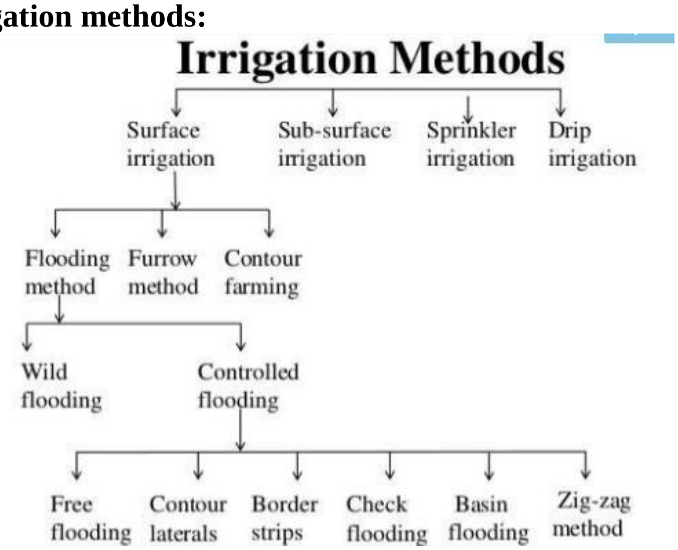
- ***Recreation*** – Irrigation structures like reservoirs, canals etc are used for boating, bathing, swimming, water games and other recreations.

- ***Afforestation***– Due to percolation of water along the banks of canal trees are grown along the banks of canals which increases timber wealth and reduces soil erosion.

Disadvantages of excessive irrigation

- Due to over irrigation water table rises up to ground level causing water logging and self efflorescence making the field unsuitable for cultivation.
- Due to excessive irrigation all pools and depressions around the canals are filled up with water causing creation of breeding places for mosquitoes
- Number of cross drainage works is required to be for natural drainages.
- Large amount of country income is spent on irrigation projects
- Irrigation water becomes cause of quarrels in villages.
- Seepage of water makes the environment unhealthy for living.

Classification of irrigation methods:



Surfaceirrigation

- Surface irrigation method is most widely practiced.
- In this method water is conveyed to the point of infiltration directly the soil surface in channels that vary in shape, size and hydraulic characteristics.
- The channels may vary from corrugation to long narrow strips or large fields where water is impounded.

On the basis of their conveyance size and shape, surface irrigation may be of following types.

A. Methods involving complete flooding of the soil surface

a.Wildflooding

- In this method water flows from the ditch directly to the field without much control on either side of the flow. It covers the entire field and moves almost unguided.
- The rate of advancing front is controlled by the topography of the field.
- Land leveling is not precisely followed.
- The depth of water sheet at different points may not be same, somewhere deep causing water logging and somewhere very shallow leading to water scarcity a few days after drying.
- Uneven distribution of water and low water application efficiency are the common drawbacks of this method. But the method is easy and inexpensive.
- Close growing crops are generally irrigated by this method.

b.BorderIrrigation

- Borders are usually long, uniformly graded strips of land, separated by earthen bunds. The bunds so formed are not to contain the water from ponding but to guide it as it flows down the field.
- Border irrigation is generally best suited to the larger mechanized farms as it is designed to produce long uninterrupted field lengths for ease of machine operations. Borders can be upto 800 m or more in length and 3-30 m wide depending on a variety of factors. It is less suited to small-scale farms involving hand labour or animal powered cultivation methods.
- Border slopes should be uniform, with minimum slope of 0.05% to provide adequate drainage and a maximum slope of 2% to limit problems of soil erosion. Deep homogenous loam or clay soil with medium infiltration rates is preferred. Close growing crops such as pasture, alfalfa are preferred. Borders may be either laid along the slope (straight) or across the slope(contour)

c.CheckorCheckBasinIrrigation

- Check method consists of dividing the field into several relatively level plots called checks surrounded by low bunds. They are irrigated with comparatively large flow of water. Small checks are levelled while bigger ones are slightly sloping along the length. A check is also termed as check basin. There are two methods of check irrigation, rectangular check method and contour method

i.Rectangularcheckirrigation

- In a relatively uniform land with a gentle slope, checks may be rectangular and sometimes square. They may be a few square meters in size for vegetable crops. The size of a check is a function of the water intake rate of soil, land slope and the available stream size. In lighter soils the size of a check may necessarily be small to achieve uniform wetting and in heavier soils the size may be large.
- Water is conveyed to checks by a system of supply channel, laterals and field channels. Laterals or field channels are laid out in such a way that a channel passes through a set of two rows of checks. Such a channel
- is used to irrigate checks on both the sides. A supply channel is constructed on the upper reach of the field and laterals usually follow the slope, if there is any.

- Check method is adopted for irrigating row crops as well as closely spaced grain crops, fodder and vegetables in a wide range of soils having moderate to slow infiltration rates.

Advantages and limitations

- Advantages of the method are that

(i)variable size of streams can be effectively used
(ii) it can be adopted for wide range of soils
(iii)water application efficiency is high

Principallimitationsare

1. Precise land leveling is necessary,
2. Considerable land is wasted by bunds and channels,
3. Labour requirement is high for preparing the land for irrigation
4. Movements of farm animals, implements and machinery are often restricted by bunds and channels.

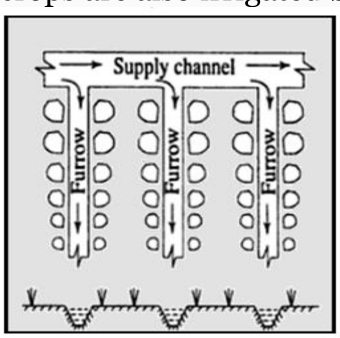
ii.Contourcheckirrigation

- In slopping and rolling lands contour checks are constructed by rising bunds or ridges along contours having vertical intervals of 15 to 30 cm.
- Checks at the end of the adjoining contours may sometimes be joined at suitable places to make them continuous.
- They are almost uniformly level or gently sloping and are often small.
- A contour checks is also termed contour check basin. Contour checks are suitable for growing vegetables.

B. Methods involving partial flooding of the soil surface

a.FurrowIrrigationMethods

- Furrow irrigation refers to irrigating land by constructing furrows between two rows of crops or alternately after every two rows of crops. It wets the land surface only partly and water in the furrow moves laterally by capillarity to the unwetted areas below the ridge and also downward to wet the root zone of soil. Furrow irrigation is adopted to irrigate all row crop such as potato and vegetable crops on ridges. Plantation and fruit crops are also irrigated by furrow method.



Principal limitations of the method are:
(i) land requires precise grading to a uniform slope
(ii) labour is necessary to control water in furrows
(iii) this method is unsuitable for light irrigation.

Classificationoffurrowirrigationmethods

- Furrow irrigation methods may be classified based on the types of furrows employed and the pattern of irrigation adopted. The methods are: (a) straight graded furrow irrigation (b) straight level furrow irrigation (c) contour furrow irrigation (d) alternate furrow irrigation and (e) raised bed and furrow irrigation.
- The first two types are formed as explained earlier (Furrow methods), with or without slopes for easy flow of water. The other types are as follows.

i.Contourfurrowirrigation

- Contour furrow method of irrigation is adopted in an uneven and rolling topography. When the longitudinal slope exceeds the safe limits for graded furrow, furrows are constructed along the contour.

ii.Alternatefurrowirrigation

- When the supply of water is limited, irrigation is applied through alternate furrows. Besides, this alternate furrow method is adopted where salt is a problem. Water is discharged in alternate furrows keeping the in-between furrow dry. In the subsequent irrigation, water is allowed to flow through the alternate furrows that had been kept dry on the previous occasion. This method saves quite a good amount of water and is very useful and crucial in areas of water scarcity and salt problems.

iii.Raisedbedandfurrowirrigation

- Raised beds of 1 to 1.5m width alternating with furrows are often constructed for growing vegetables crops, particularly those vegetable crops that creep on soil surface. Fruits of such vegetables get damaged on coming in contact with the moist soil. Two rows of plants are usually raised on two sides of a bed or ridge. A furrow runs between two rows of the adjacent ridges of beds and supplies water to the plant rows. The method assures saving of a large amount of water. The surface soil of beds or ridges remains dry and the creeping plants and their fruits are not damaged. Water from furrow moves laterally into the soil below the bed or ridge to meet the crop need.
- It prevents accumulation of salts at the base of plants and reduces the salt injury to crop in areas where salt is a problem.

iv.Corrugationirrigation

- Corrugations are miniature furrow adopted for irrigating close growing crops such as grain, forage and pasture crops. Crops may be line sown or broadcast and corrugations may bear any definite relation to crop rows. This method is used for fine to moderately coarse soils, especially soils that forms crust. Corrugations reduce crusting as they wet only a part of the land surface. They are not suitable for sandy soils as corrugations get smooth quickly due to collapse of ridges, particularly in moderate to high rainfall areas. The method is advantageous when the available stream is small.

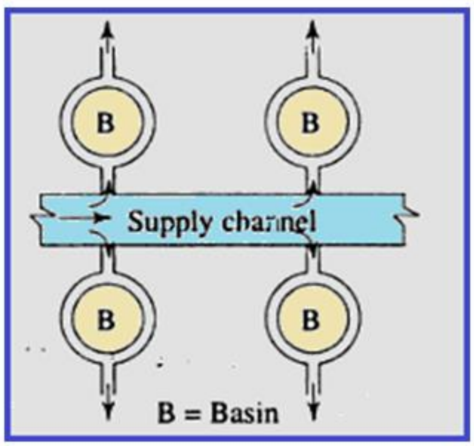
- Principal advantages of the methods are that (i) it saves quite a good amount of water (ii) small supply stream is used (iii) used for soils with crusting problems and (iv) high water application efficiency.

b.)Basinandringirrigation

- Fruit crops in orchards are irrigated by constructing basins or rings around trees. Basins are usually used for small trees, while rings are used in bigger trees which are widely spaced.

Basinirrigation

- A basin is usually made for one tree sapling but it may include more than one tree sapling when they are not spaced very wide. Basins may be square, circular or rectangular.
- Basins are made longer and wider as saplings grow in size. The land inside basins is flat with the base area of trees kept little raised so that the sapling stems do not come in direct contact with water. Only a part of the total land surface is flooded. Water is supplied through laterals and each basin may be connected with another one by a small furrow to get the water supply. A lateral or field channel passes between two rows of trees alternately supplying water to individual basins on both sides. A basin usually covers the complete area under the tree canopy. Desired quantity of water is allowed into a basin for complete infiltration.



Advantagesandlimitations

- Advantages are that (i) a considerable amount of irrigation water is saved (ii)water application efficiency is very high (iii) entire area excepting the basin area does not require precise land leveling, (iv) the labour requirement and the cost of making basins are low and (v) no land is wasted. This method is adaptable for fruit trees or shrubs in orchards and plantations. The principal disadvantage is that working with implements and machineries is prevented.

Ringirrigation

- Ring method consists of irrigating fruit trees in orchards by constructing circular trenches around trees. Ring trenches are smaller in both depth and width around small trees and are larger around bigger trees. Usually a ring is laid out at the periphery of the tree canopy. The ring trenches are usually made 30 to 50 cm wide and narrow furrows. Laterals pass through a set of two rows of trees supplying water into rings on both sides. Water supply process is essentially the same as with the basin irrigation. Water in desired quantity is allowed to stand in the trenches for infiltration.

c.)SurgeIrrigation

- Surge irrigation is defined as the intermittent application of water to field surface under gravity flow which results in a series of "on and off" modes of constant or variable time spans. Large intermittent flows rather than continuous ones are used in two sets of furrows and gated pipes laid in the "Tee" configuration. Water is switched alternatively from one set of furrows to the other by a valve and automatic time controller until irrigation is completed. The cycle time (irrigation period plus the rest period) can be made to vary from 30 minute to several hours.

2. Subsurface irrigation methods

- Subsurface irrigation, also designated as sub irrigation, involve irrigation to crops by applying water from beneath the soil surface either by constructing trenches or installing underground perforated pipe lines or tile lines. Water is discharged into trenches and allowed to stand during the whole period of irrigation for lateral and upward movement of water by capillarity to the soil between trenches.
- Underground perforated pipe or tiles in which water is forced , trickle out water through perforations in pipes or gaps in between the tiles. Water moves laterally and upward to moist the root zone soil under capillary tensions. Pipelines remain filled with water during the period of irrigation. The upper layers of soil remain relatively dry owing to constant evaporation while lower layers remain moist. The essential pre-requisite for sub-irrigation are: (1)existence of a high water table or an impervious sub-soil above which an artificial water table can be created (2) highly permeable root zone soil with reasonably uniform texture permitting good lateral and upward movement of water (3) irrigation water is scarce and costly and (4) soil should not have any salinity problem.
  - It might be ensured that no water is lost by deep percolation. The artificial water table is created to a depth of 30 to 120 cm depending on crops to be grown, nature of soil capillarity and the depth of impervious soil layer. Uniform topographic conditions and moderate slope favour sub-irrigation. In places where sprinkler irrigation is expensive, sub irrigation is adopted. Sub-irrigation is made by constructing a series of ditches or trenches 60 to 100 cm deep and 30 cm wide, the two sides of which are made vertical. Ditches are spaced 15 to 30 m.
  - The crops, particularly with shallow root system are well adapted to sub irrigation. Sometimes, sub irrigation is made to high priced vegetable crops by installing a perforated pipe distribution system below the soil surface but within the crop root zone. This is often termed the artificial irrigation. A good quality water supply must be available throughout the growing season and an outlet for drainage is provided, particularly in high rainfall areas.

Advantagesandlimitations

- Advantages of this method of irrigation are (i) soil water can be maintained at a suitable tension favorable for good plant growth and high yields (ii) evaporation loss from soil surface is minimized (iii) cost of water application is very low and (iv) it can be used for soils having a low water holding capacity and a high infiltration rate where surface method cannot be adopted and the sprinkler irrigation is expensive.

Quality of Irrigation water

1. Sediment:

• Effect of Sediment on the quality of irrigation water depends on the nature of sediment and characteristics of the soil receiving the water.

• If sediment contains large amount of plant nutrition and it comes from fertile area then it is quite beneficial, particularly for agriculture area which has low content of plant nutrient and a very low water holding capacity

• If a sediment is not rich in plant nutrient and it is deposited on the surface, it will reduce permeability of the soil and will make irrigation more difficult

2. Concentration of Salt:

• Salts present in water increases osmotic pressure of the soil solution causing high soil moisture stress in the root zone which affects the growth of crops and yield of the crops

• Bad effects of the salts depends upon the salt concentration left in the soil

$$C_s = \frac{CQ}{Q-(Cu-Reff)} \quad (ppm\ or\ mg/L)$$

Cs= salinity concentration of the soil solution

• C= concentration of the salts

• Q= amount of water applied

• Cu= consumptive use of water by crops

• Reff= effective rainfall/ amount of water in root zone

• If Cs >700 ppm-harmful to some crops

• If Cs>2000 ppm, harmful to all crops

Concentration of Salt

Sr No.	Classification	Electrical conductivity $\mu Mho/cm$	Uses
1	Low saline water	<250	For all crops
2	Medium Saline water	250-750	Normal salt tolerant plants can be grown if leaching is done
3	High saline water	750-2250	High salt tolerant plants can be grown with special measures
4	Very high saline water	>2250	Not suitable

3. Proportion of Sodium Ion concentration

• When percentage of Na ions in the total exchangeable cations exceed to 10%, aggregation of soil grains breakdown and hence soil becomes less permeable and of poor tilth

• Proportion of Na ion concentration is generally measured by SAR(Sodium absorption ratio):

$$SAR = \frac{[Na^{+}]}{\sqrt{\frac{[Mg^{+2}] + [Ca^{+2}]}{2}}}$$

$concentration\ [\quad] is\ expressed\ in\ equivalence\ per\ million$

$$Equivalency\ per\ million = \frac{concentration\ in\ ppm}{Equivalent\ weight}$$

SOIL MOISTURE AND PLANT RELATIONSHIP

Soil Moisture:

→ Water held in the voids of the soil above the water table is called as ‘’Soil Moisture’’

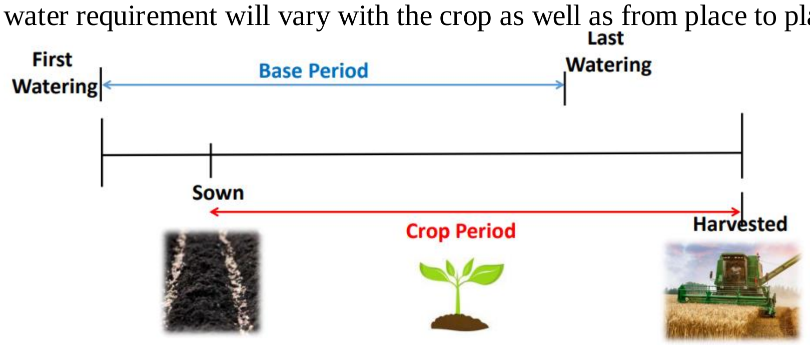
→ Water holding capacity of the soil

→water holding capacity of the soil mainly depends on (i) Porosity of soil n = $\boldsymbol{n} = \boldsymbol{VvV}$

→ Which is physical property of soil (ii) Size of voids: Moisture holding capacity of the soil largely depends on size of the voids.

Water Requirement of Crop

Water requirement of a crop is the total water required by it from the time it is sown to the time it is harvested. • Note:→ Depending on type of climate type of soil, method of cultivation, rain fall and etc, water requirement will vary with the crop as well as from place to place



Crop period: it is the time interval between instant of sowing to the instant of harvesting. It represents the total time during which crop was present in the field.

Base period: it is time interval between first watering before sowing the last watering before harvesting. • Note:→ In reality, crop period > Base period, but theoretically they are approximate taken same and even terms are used interchangeably

Delta (∆):- ∆ is defined as total depth of water in cm required by a crop during the base period.

Duty (D): Duty is defined as area irrigated in hectare by 1 cumec of water flowing continuously for the duration of base period. Duty is expressed as, D = 300 ha/cumec • By knowing Duty of water & area to be irrigated for growing a particular crop, required discharge can be calculated. • Also by knowing total available discharge and duty of water, area which can be irrigated can be determined.

Relationship between Duty (D) and Delta ∆

- Let ‘D’ hectare area is irrigated by supplying 1 m3/sec of water for the base period of ‘B’ days such that total water stored in the root zone is ∆ m
- Therefore, volume of water supplied = B Days x 1 m3/sec = B x 24x60x60 sec x 1 m3/sec
  = 68400 B m3 … (1)
- Amount of water stored = D (ha) x ∆ (m) = D x 104 m2 x ∆ m =D x ∆ 104 m3 …..(2)
  Equating (1) and (2), D x ∆ 104 m3 = 68400 B m3 => D x ∆ = 8.64 B
  D =ha/cumec ∆ = m B= days

UNIT-IV
CHANNELS – SILT THEORIES

Classification of Soil Water :

Water in the voids of the soil can be divided into 3 parts;

1. *Gravity Water* •
   → It is that water which is not held by the soil but drain out under the action of gravity •
   → it remains in the soil for a short time period (1 to 3 days) till the time it is required to drain out
   →it prevents circulation of air in the soil hence it is harmful to the crops if present for longer duration
2. *Capillary Water* •
   → It is that pat of water which is retained in the soil after gravity water is drained off and it can be absorbed by the plant roots.
   → This water held in the soil by surface tension between the soil particles plant roots gradually absorb capillary water hence it is main source of water for plant growth, these fore it is also called as 'Available water'
3. Hygroscopic Water •
   → Hygroscopic water is that water which is absorbed by the soil particles from the atmosphere and it is held very tightly by the soil particles, therefore if cannot be extracted by plant roots.

Soil Moisture Tension & Soil Moisture Stress

→ Soil moisture tension is defined as force per unit area that must be exerted in order to extract water from the soil. •

→ Soil moisture tension is usually expressed in terms of Atmosphere (i.g. pressure) •

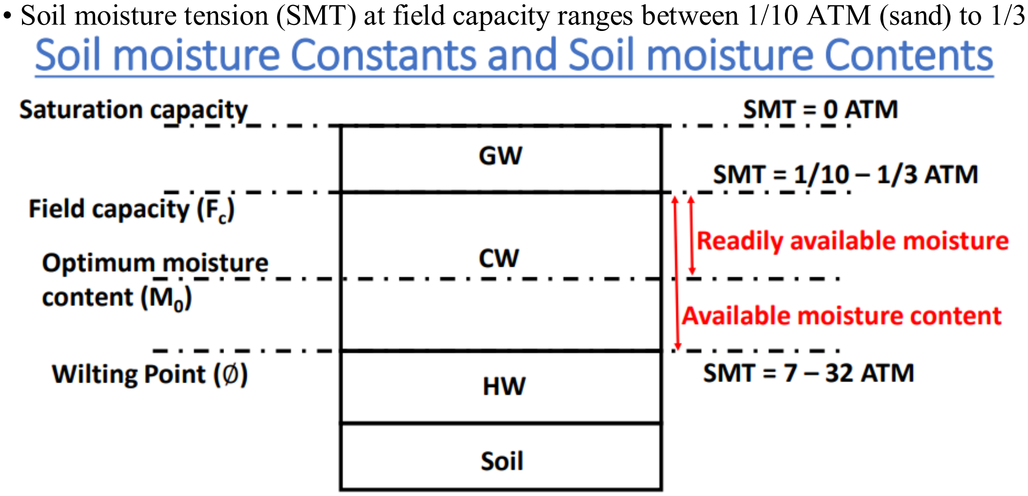
$$Soilmoisturetension \propto 1/moisturecontent$$

• For a given soil, soil moisture tension SMT is inversely proportional to moisture content

• If we know, SMT at various moisture content then we can determine how much water is available for plants and what amount of water must be added to the soil for the purpose of irrigation

• Soil Moisture Stress is sum of soil moisture tension (SMT) & osmotic pressure

• Soil moisture tension (SMT) at field capacity ranges between 1/10 ATM (sand) to 1/3 ATM (clay)



Crops and Seasons of India

1. Khareef crops/Summer Crops: • (April – September)& 'Summer Crop' • Rice, Jowar, Bajra, Maize, Ground nut, cotton
2. Rabi Crops: • (October – March) &' winter crop' • Wheat, Gram, Mustard, Potato, Barley
3. Perennial Crops: • (300-360) days
4. Zaid Crops • Fruits and vegetables (March-June)

Important Definition

1. Crop ratio/Rabi-Kharif ratio

Crop = $\boldsymbol{AreairrigatedinRabiseason} / \boldsymbol{AreairrigatedinKharifseason}$ = 2 (approx)

2. Paleo irrigation

• It is defined as watering done prior to the sowing of crops.

• It is done to make area suitable for sowing as it becomes very dry and to add sufficient moisture to the soil which would be required for initial growth

3. Kor watering, Kor depth, Kor Period:

• Kor Watering is the first watering after sowing of crops when crop is few 'cm' high

• This irrigation depth is the maximum of all the waterings and this depth is called as KOR depth

• The portion of Base period in which KOR watering is needed is called as 'Kor period'

4. Capacity factor: = **Meansupplydischargeforacanalforacertainduration /Maximumdischagecarryingcapacityofcanal**

= **Qrequired /Qdesigne**d

5. Time Factor Time Factor = No.of days canal has actually run / No.of days of irrigation period

6. Crop Calendar Crop calendar is a tool that provides information about planting, sowing, and harvesting period of locally adopted crops in an area.



Select State : RAJASTHAN   Select Crop : Wheat

State	Crop	Season	From	To	Period
RAJASTHAN	Wheat	Kharif	November (Beg)	May (Mid)	Sowing
		Kharif	November (Beg)	May (Mid)	Sowing
		Kharif	January (Beg)	April (Beg)	Harvesting
		Kharif	January (Beg)	April (Beg)	Harvesting
		Kharif	July (Mid)	October (End)	Harvesting
		Rabi	November (Beg)	March (Beg)	Sowing
		Rabi	November (Beg)	December (End)	Sowing
		Rabi	March (Beg)	May (End)	Harvesting

7. Gross Command Area (GCA) • It is the total area with in the limit of an irrigation project. • It includes cultivable as well as non-cultivable area like road, Building, Pond etc.

8. Cultivable Command Area (CCA); • It is that portion of GCA which is cultivable and it denotes the area on which actually cultivation is to be done. • In absence of data we may assume, CCA = 80% of GCA.

9. Intensity Of Irrigation /Annual Intensity Of Irrigation • Intensity of Irrigation = sum of seasonal intensity of irrigation in a year. • Seasonal intensity of Irrigation is that percentage of CCA on which actually the irrigation is done in a particular season.

10. Irrigation efficiency; • In general, irrigation efficiency = Water available for use /water applied

a) Water conveyance efficiency (n_c)

$$N_C = \frac{w_f}{w_r} \times 100$$

where,

w_r is water released from river reservoir for the field.

w_f is water given to the field

This efficiency account for water which possess seepage loss & evaporating loss during conveyance from river (or) reservoir to the field.

b) Water application efficiency (n_a)

$$N_a = \frac{w_s}{w_f} \times 100$$

where,

w_s is the water stored in the field i.e, in the root zone

w_f is the water given to the field

This efficiency accounts for water losses such as surface run off (R_f) & Deep Percolation (D_f) which occurs during application of water in the field.

$$W_f = W_S + R_f + D_F$$

c) Water use efficiency (n_u)

$$N_u = \frac{W_u}{w_f} \times 100$$

where,

w_f is the water given to the field

w_u water use consumptively

w_u = leaching requirement + presowing requirement + water stored

d) Water storage efficiency (n_s)

$$N_s = \frac{w_s}{w_n} \times 100$$

where,

w_s is the water stored in the field, i.e, in the root zone

w_n is the amount of water to be stored in the field such that moisture content is raised to field capacity (F_C)

w_n is the total water required up to F_c i.e., available moisture content before irrigation.

CONSUMPTIVE IRRIGATION REQUIREMENT ➢It is the amount of water required to meet evapotranspiration needs of crop during its full growth ➢It is denoted by CIR CIR = CU – Reff

NET IRRIGATION REQUIREMENT ➢It is the amount of water required to be delivered at the field to meet CIR, i.e. evapotranspiration as well as water required for presowing and leaching.

➢It is denoted by NIR

NIR = CIR + PRESOWING REQUIREMENT + LEACHING REQUIREMENT

• **FIELD IRRIGATION REQUIREMENT** ➢It is the amount of water required by the crop in the field plus amount of water lost in application.

➢It is denoted by FIR

FIR = Net Irrigation Requirement /Water application efficiency
FIR = NIR/na

GROSS IRRIGATION REQUIREMENT ➢It is the amount of water to be released in canals.

➢It is denoted by GIR

GIR = Field Irrigation requirement /Water conveyance efficiency
GIR = FIR/ nc

CANAL DESIGN • On account of erosion in catchment and drainage basin, rivers receive huge quantity of sediment having fine silt, coarse sand , a portion of which enters into a canal also. • Design of canal mainly depends on quantity of silt in the water and type of boundary surface of the channel.

1. Rigid boundary channel

• In this the surface of channel is lined.

• Quantity of silt transported by such channels remains more or less same that has entered at the head of the channel.

• In such channel velocity of flow is high which does not allows deposition of silt.

• Therefore, these channels do not have problem of silt transport.

2. Unlined channels

• In this the quantity of silt varies from section to section due to scouring of bed and sides of the channels as well as due to silting.

• If velocity is too low then silting may take place whereas if velocity is very high scouring may take place.

3. Unlined Alluvial Channels

• These should be designed for such a velocity such that neither bed and sides are scoured nor silt is deposited and a stable channel section is obtained such channels are called as stable channels or regime.

• The velocity of flow which will keep silt in suspension & will not scour the bed and sides of the channel, it is called as non silting and non- scouring velocity.

DESIGN OF REGIME CHANNEL

Basically two methods are used for design of Regime channel

1. Kennedy's Theory (1595)
2. Lacey's theory

KENNEDY'S THEORY

According to Kennedy,

1. Eddies are generated due to friction between water and channel surface.
2. Silt supporting power of a channel depends on eddies generated from the bed of the channel. The vertical component of these eddies tries to more than sediment upwards, while weight of the sediment tries to bring it down, Hence sediment remains in suspension.
3. Eddies generated from the sides were neglected because they are horizontal for the greater part and hence they have very little silt supporting power. • Kennedy introduced the term critical velocity (Vo) which will keep channel free from silting & scouring.

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

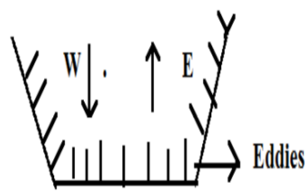
V_o → critical velocity in m/sec

y → depth of flow in m

m → critical velocity ratio, whose value will depend on type of soil

m > I → for coarse soil (1-1.2)

m < I → for fine soil (0.7-1)



Drawbacks Of Kennedy's Theory

1. Kutter's equation is used to determine the mean velocity of flow hence limitation of Kutter's equation are also incorporated in Kennedy's theory.
2. This theory involves trial & error which is time consuming.
3. Silt concentration and silt grade is not considered.
4. This theory is not universally accepted.
5. Value of 'm' is decided arbitrarily
6. There is no equation for bed slope or b/d ratio without which it is not possible to obtain a unique section.

LACEY'S THEORY

• Lacey carried out extensive investigation on the design of stable channel in alluvium.

• He found many drawbacks in Kennedy's theory.

• He elaborated regime concept and found that even if a channel is showing no silting and no scouring, it may not be in regime actually. He therefore differentiated between three regime conditions.

• True Regime
• Initial Regime
• Final Regime

1. True Regime Condition • An artificially constructed channel having certain fixed section and a certain fixed slope can behave in regime only if following conditions are satisfied.

a) Discharge is constant

b) Flow is uniform

c) Silt charge & silt grade is constant

d) Canal is flowing through an incoherent alluvium which is of the same grade as that of alluvium transported.

e) In practice all these conditions can never be satisfied, therefore an artificial channel can never be in True Regime.

2. Initial Regime Condition • It is first stage of regime attained by a channel after it is in service.

• If a channel is excavated with smaller width and flatter bed slope, then as the flow takes place in the channel, bed slope of the channel is increased due to deposition of silt on the bed to develop increased flow velocity, hence the given discharge is allowed to flow through the channel of smaller width and sides of such channel are subjected to lateral restrain and could have scoured if the bank soil would have been in true alluvium.

• But in practice they may be grassed or may be of clayey soil, therefore they may not get eroded.

• Hence such channels will appear to be in Regime.

• They have achieved only a working stability due to rigidity of their banks, such channel are termed as 'Channels in Initial Regime'.

• Lacey's Theory is not applicable in initial Regime condition

3. Final Regime Condition:

• It is the ultimate state of Regime attained by a channel when bed slope, depth of flow & width are adjusted in order to obtain a stable channel section. This condition is called as 'Final Regime Condition'.

• Such a channel in which all the variables are equally free to vary has the tendency to attain a semi elliptical section.

• When a channel is protected on the bed and sides with some kind of protecting material, Channel section could not be scoured and there is no possibility of change in longitudinal slope. These channel sections are said to be in 'permanent regime'

DESIGN STEPS FOR LACEY'S THEORY

For a given discharge, Q mean particle size d_{50} in mm

- **Determine silt factor,** $f = 1.76\sqrt{d_{mm}}$
- **Determine velocity** $v = \left(\frac{Qf^2}{140}\right)^{1/6}$
- **Determine Area** $A = \frac{Q}{v}$
- **Assuming, side slope** 1/2H : 1v
- **Determine Perimeter** $P = 4.75\sqrt{Q}$ (Q in m³/sec)
- **Determine Bed slope;**
- $S = \frac{1}{3340} \times \frac{f^{5/3}}{Q^{1/6}}$

Drawbacks OfLacey's Theory

1. Lacey said that a Regime channel has a semi elliptical shape but same is not supported by his equation.
2. Regime relations do not account for amount of sediment transported by flowing water.
3. Characteristics of Regime channel are not precisely defined.

COMPARISON OF KENNEDY'S AND LACEY'S THEORY

KENNEDY'S THEORY	LACEY'S THEORY
Trapezoidal channel	Semi elliptical channel
Silt is kept in suspension due to eddies generated from bottom	Silt is kept in suspension, due to eddies generated both from side slope & the bottom i.e, throughout the perimeter.
Recommended Kutter's equation for finding velocity.	Gave his own velocity equation.
No equation for bed slope.	Gave eq^n to calculate bed slope
Trial & error procedure	Direct procedure
Applicable for alluvial channel	Applicable for alluvial channel as well as for rivers.

UNIT-V
DIVERSION HEAD WORKS

CANAL HEAD WORKS

• In order to divert water from the river into the canal, it is necessary to construct certain works on structures across the river & at the head of the off taking canal. These works are termed as 'Canal Head works (or) Head works'.

• Canal Headworks are classified into 2 types;

1. Storage Headworks
2. Diversion Headworks

TYPES OF DIVERSION HEADWORKS

a) Temporary diversion Headwork:

• It consists of a spur (or) bund constructed across the river to raise the water level in the river and divert it into the canal.

• These bunds are constructed almost every year after the floods, because they may be damaged by the floods.

b) Permanent diversion Headwork:

• It consist of a permanent structure such as weir (or) barrage constructed across the river to raise the water level in the river and divert it into the canal.

• In our country, most of the diversion head works for important canal system are Permanent diversion headwork.

LOCATION OF CANAL HEADWORK

*1. Rocky stage (**or**) Hilly stage:*

• In this state, the river is in the hills.

• The bed slope and velocities are high in this stage.

• Not suitable for canal headworks.

2. Boulder stage:

• From the rocky stage, the river passes on to the boulder stage.

• In this stage, the bed slope and velocity are less than those in the rocky stage.

• There is large subsoil flow in the boulder region because of high permeability.

• Suitable for canal headworks.

3. Through stage or Alluvial stage:

• From Boulder stage, the river passes on to the alluvial plain created by itself.

• The bed slope & the velocity are small in this stage.

• Suitable for canal headworks.

4. Delta stage:

• From through stage, the river passes on to the delta stage as it approaches the ocean.

• It drops down the sediment and gets divided into channels on either side of the deposit resulting in the formation of a delta.

• Not suitable for canal headworks.

COMPONENTS OF DIVERSION HEADWORK

1. Weir

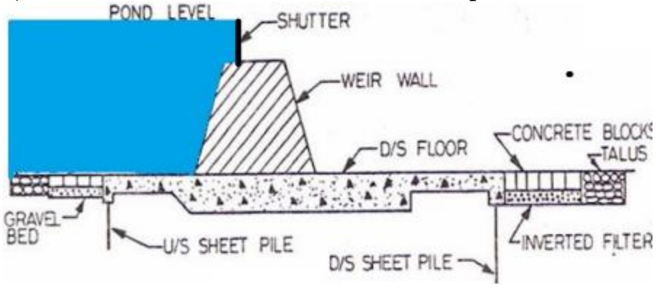
• A weir is an obstruction constructed across a river to rise its water level and divert the water into the canal.

• Shutters are usually provided on the crest and only small part of the ponding of water is carried out by shutters.

• Weirs are usually aligned at right angles to the direction of flow of the river.

• Weirs are classified into 3 types:

a) Masonry weir with vertical drop
b) Rockfill weir with sloping aprons
c) Concrete weir with a downstream slope



a) Masonry weir with vertical drop

• This type of weir is suitable for any type of foundation.

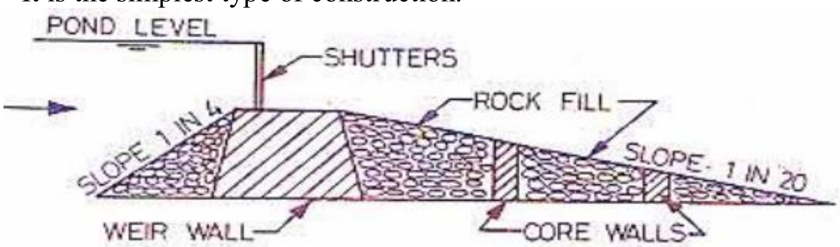
• This is an old type of weir for which floor design was usually based on Bligh's theory

b) Rockfill weir with sloping aprons

• It consist of a masonry weir wall and dry packed boulders laid in the form of glacis

• Glacis (*or*) sloping aprons are on the upstream and downstream sides of the weir wall with a few intervening corewalls.

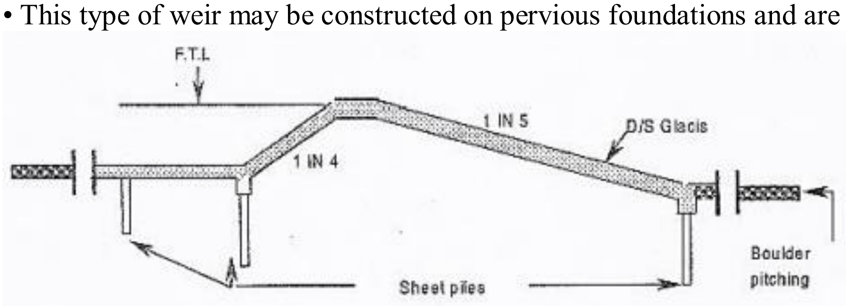
• It is the simplest type of construction.



c) Concrete weir with a downstream glacis

• This type of weir is of recent origin based in the design concepts of Khosla's theory for subsoil flow.

• This type of weir may be constructed on pervious foundations and are commonly adopted these days.



2. Barrage:

• Barrage is a structure similar to weir with the only difference that crest is kept at a low level and the ponding of water is accomplished mainly by means of gates.

• It is also known as 'River regulator'

• The difference between a barrage and weir is only qualitative. In the former, gates provide the larger part of the ponding while in the latter the crest carries outmost of the ponding.

• Afflux is the rise in the maximum flood level upstream of the weir caused due to construction of the weir across the river.

3. Undersluices / Scouring sluices:

• The undersluices are the openings provided in the weir wall with their crest at a low level.
• These openings are fully controlled by gates.
• They are located on the same side as the off taking canal.
• The discharging capacity of the undersluices is provided as the maximum of following.

I. Two times the maximum discharge of the off taking canal
II. Maximum – winter discharge
III. 20% of the maximum flood discharge.

4. Divide Wall:

• A divide wall is a long masonry ($\boldsymbol{or}$) concrete wall which is constructed at right angles to the axis of the weir to separate the undersluicesfrom the rest of the weir ($\boldsymbol{or}$) weir proper.
• The divide walls can be designed as cantilever retaining walls subjected to silt resume and water pressure from the undersluice side.

5. Fish Ladder:

• A Fish ladder is generally provided to enable the fish ascend the head waters of the river and thus reach their spawning grounds for breeding or to follow their migratory habits in search of food.
• In our country generally, anadromous fish move from upstream to downstream in the beginning of winter in search of warmth and return upstream before monsoon for clearer water.
• Fish ladder is a device by which the flow energy can be dissipated in such manner so as to provide smooth flow at sufficiently low velocity around 5 m/sec.
• Various types of Fish ladders are; • Pool type • Steep channel type • Fish lock.

6. Canal Head Regulator:

• A canal head regular is a structure constructed at the head of a canal taking off from the upstream of a weir (or) a barrage.
• It consists of a number of spans separated by pies which support the gates vided for regulation of flow into the canal.

CANAL HEAD REGULATOR

Breast Wall:

• Breast wall is a RCC wall provided from the pond level upto river HFL (Highest Flood level) to avoid spilling of the water over the canal regulator gates.
• Breast wall spans for the entire length of the regulator & will rest over the piers of the regulator bays.
• Breast wall is subjected to vertical self weight and horizontal water pressure acting against it from the upstream side.

Weir or Barrage Regulation:

• The silt can be removed from the entering water by operating the undersluices of the barrage or weir.
• The supplies entering the canal which takes off from the upstream of a weir (or) a barrage can be regulated in the following two ways; 1) Still pond regulation 2) Semi open flow regulation

1. Still pond regulation

• In this method of regulation, all the gates of the undersluices are kept closed while the canal is running. Hence the undersluice pocket draws only as much discharge as is required for the canal.
• This is very useful method to control the amount of silt entering the canal.
• This method is possible only when the crest of the canal head regulator is high above the upstream floor of the undersluices.

2. Semi open flow regulation

• This method does not provide proper control on entry of silt into the canal because turbulence created in the pocket tend to raise the coarser material upwards and enter the canal.

SILT CONTROL DEVICES

1. Silt excluder • These devices are constructed on the river bed in front of the head regulator. • A minimum velocity of 2-3 m/sec must be maintained through the tunnels to keep them free from silt deposit.

2. Silt extractors (or) silt ejectors • Silt extractors are those silt control devices which remove the silt which has already entered the canal from the head. • These devices are provided in the canal a little distance downstream from the head regulator.

FAILURE OF WEIRS ON PERMEABLE FOUNDATION

1. Due to seepage (or) sub surface flow:

I. By piping (*or*) undermining: ➢Remedies: • Provide sufficient length of the impervious floor so that the path of percolation is increased and exit gradient is reduced • Provided piles at the upstream and the downstream ends of the impervious floor

II. By uplift pressure: ➢Remedies • Provide sufficient thickness of the impervious floor • Provide pile at the upstream end of the impervious floor (up lift pressure is reduced in the downstream side)

2. Due to surface flow

I. By suction due to standing wave (*or*) Hydraulic jump: ➢Remedies: • Provide additional thickness of the impervious floor to counter balance the suction pressure due to standing wave. • Construct floor as monolithic concrete mass instead of in different layers of masonry

II. By scour on the upstream & downstream of the weir: ➢Remedies: • Provide deep piles both at upstream & downstream ends of the impervious floor. The piles are to be driven up to a depth much below the calculated scour depth. • Provide launching aprons of suitable length and thickness at upstream & downstream ends of the impervious

CROSS DRAINAGE WORKS

• A cross drainage work is a structure constructed for carrying a canal across a natural drain (*or*) river intercepting the canal so as to dispose the drainage water without interrupting the continuous canal supplies.

• These are unavoidable in any type of canal system.

• In order to minimize the no. of cross drainage works, the alignment of canals should be generally along the watershed so that we have less no. of natural drains.

TYPES OF CROSS DRAINAGE WORKS

1. Cross drainage works carrying the canal over the natural drain

i. AQUEDUCT • An Aqueduct is a hydraulic structure which carries a canal (through a trough (or) a duct) across and above the drainage similar to a bridge in which instead of road (*or*) a railway, a canal is carried over a natural drain. • In the case of an aqueduct, HFL (Highest flood level) of the drainage should main lower than the level of the underside of the canal trough. • The canal water is taken across the drain in a trough supported on piers

ii. SYPHON AQUEDUCT • A syphon aqueduct is a cross drainage structure similar to an aqueduct except that the stream bed is depressed locally where it passes under the trough of the canal and the barrels discharges the stream flow under pressure. • A syphon aqueduct is constructed where the water surface level of the train at high flood is higher than the canal bed.

2. Cross drainage works carrying the natural drain over canal

i. SUPER PASSAGE • A super passage is also similar to a bridge in which the natural drain is carried over the canal. • A super passage is reverse of an aqueduct.

ii. SYPHON • A syphon is similar to a syphon aqueduct with the difference that in the case of a syphon, the canal water is carried through the barrelsunder the drain. • The barrels in this case also act as inverted syphons through which the canal water flows under pressure.

3. Cross drainage works admitting the drain water into the canal • In this type of cross drainage works, the canal water and the drain water are allowed to intermingle with each other. • This may be achieved by the following two types of the Crossdrainage works: i. Level Crossing ii. Inlet and Outlet

i. Level Crossing – • A level crossing is a cross drainage work in which the drainage and the canal meet each other at approximately the same level. • It consists of a regular with quick falling shutters across the drain at its downstream junction with the canal. • Such an arrangement is adopted when both the canal and the drainage carry considerable discharge, the latter during the high flood season when syphoning either the canal ($\boldsymbol{or}$) the stream proves to be extremely costly or else the head loss through the syphon barrels is very high. Arrangement is practically similar to that provided on a canal head work. • In this arrangement, the perennial discharge is used advantageously in order to increase the canal supplies.

ii. Inlet And Outlet - • An inlet is an open cut ($\boldsymbol{or}$) a pipe which is provided in a canal bank suitably protected by pitching to pass the drain water into the canal. • This arrangement is provided only where the silt load of the drainage is suitable. • An inlet may be provided for a small drain coming across a canal it the bed level of drain is slightly higher ($\boldsymbol{or}$) lower than the canal F.S.L • It is not necessary that the no of inlets & outlets should be the same. • Inlet is a non-regulating structure • Outlet is another open cut in the canal bank with bed & sides of the cut properly pitched.