RAJIV GANDHI PROUDYOGIKI VISHWAVIDYALAYA, BHOPAL

New Scheme Based On AICTE Flexible Curricula

Civil Engineering, VI-Semester

Departmental Elective CE 603(A) Water Resource Engineering

Unit - I

Irrigation water requirement and Soil-Water-Crop relationship: Irrigation, definition, necessity, advantages and disadvantages, types and methods. Irrigation development. Soils - types and their occurrence, suitability for irrigation purposes, wilting coefficient and field capacity, optimum water supply, consumptive use and its determination. Irrigation methods surface and subsurface, sprinkler and drip irrigation. Duty of water, factors affecting duty and methods to improve duty, suitability of water for irrigation, crops and crop seasons, principal crops and their water requirement, crop ratio and crop rotation, intensity of irrigation.

Unit - II

Ground Water and Well irrigation:

Confined and unconfined aquifers, aquifer properties, hydraulics of wells under steady flow conditions, infiltration galleries. Ground water recharge-necessity and methods of improving ground water storage. Water logging-causes, effects and its prevention. Salt efflorescence causes and effects. Reclamation of water logged and salt affected lands. Types of wells, well construction, yield tests, specific capacity and specific yield, advantages and disadvantages of well irrigation.

Unit-III

Hydrology: Hydrological cycle, precipitation and its measurement, recording and non recording rain gauges, estimating missing rainfall data, rain gauge net works, mean depth of precipitation over a drainage area, mass rainfall curves, intensity-duration curves, depth-area duration curves, Infiltration and infiltration indices, evaporation stream gauging, run off and its estimation, hydrograph analysis, unit hydrograph and its derivation from isolated and complex storms, S-curve hydrograph, synthetic unit hydrograph.

Unit - IV

Canals and Structures: Types of canals, alignment, design of unlined and lined canals, Kennedy's and Lacey's silt theories, typical canal sections, canal losses, lining-objectives, materials used, economics. Introductions to Hydraulic Structures viz.Dams,Spillways,Weirs ,Barrages,Canal Regulation Structures.

Unit-V

Floods: Types of floods and their estimation by different methods, probability and frequency analysis, flood routing through reservoirs and channels, flood control measures, economics of flood control.

Reference Books: -

1. Irrigation & Water Power Engg. by Punmia & Pandey B.B.Lal
2. Engg. Hydrology by K. Subhramanya - Tata Mc Graw Hills Publ. Co.
3. Engg. Hydrology - J.NEMEC - Prentice Hall
4. Hydrology for Engineers Linsley, Kohler, Paulnus - Tata Mc.Graw Hill.
5. Hydrology & Flood Control by Santosh Kumar - Khanna Publishers
6. Engg. Hydrology by H.M. Raghunath

RAJIV GANDHI PROUDYOGIKI VISHWAVIDYALAYA, BHOPAL

New Scheme Based On AICTE Flexible Curricula

Civil Engineering, VI-Semester

Departmental Elective CE 603(B) Precast & Modular Construction

Precast & Modular Construction

Unit – I
Introduction-Need for prefabrication – Principles – Materials – Modular coordination – Standardization –Systems – Production – Transportation – Erection.

Unit – II
Prefabricated components-Behavior of structural components – Large panel constructions – Construction of roof and floor slabs – Wall panels – Columns – Shear walls

Unit – III
DESIGN PRINCIPLES Disuniting of structures- Design of cross section based on efficiency of material used – Problems in design because of joint flexibility – Allowance for joint deformation.

Unit – IV
Joints in Structural Members-Joints for different structural connections – Dimensions and detailing – Design of expansion joints

Unit – V
Design of abnormal load: Progressive collapse – Code provisions – Equivalent design loads for considering abnormal effects such as earthquakes, cyclones, etc., – Importance of avoidance of progressive collapse.

Reference Books: -

1. CBRI, Building materials and components, India, 1990
2. Gerostiza C.Z., Hendrikson C. and Rehat D.R., "Knowledge based process planning for construction and manufacturing", Academic Press Inc., 1994

RAJIV GANDHI PROUDYOGIKI VISHWAVIDYALAYA, BHOPAL

New Scheme Based On AICTE Flexible Curricula

Civil Engineering, VI-Semester

Departmental Elective CE 603(C) Advance Pavement Design

Advance Pavement Design

Unit -I

Equivalent Single Wheels Load concepts and applications, Relationship between wheel arrangements and loading effects, tyre contact area, Effect of load repetition, Effect of transient loads, Impact of moving loading, Factors to be considered in Design of pavements, Design wheel load, soil, climatic factors, pavement component materials, Environmental factors, Special factors such as frost, Freezing and thawing.

Unit -II

Flexible Pavements : Component parts of the pavement structures and their functions, stresses in flexible pavements, Stress distribution through various layers, Boussinesque's theory , Burmister's two layered theory, methods of design, group index method, CBR method, Burmister's method and North Dakota cone method.

Unit -III

Rigid Pavements: Evaluation of subgrade, Modulus-K by plate bearing test and the test details, Westergaard's stress theory stresses in rigid pavements, Temperature stresses, warping stresses, frictional stresses, critical combination of stresses, critical loading positions.

Unit -IV

Rigid pavement design: IRC method, Fatigue analysis, PCA chart method. AASHTO Method, Reliability analysis. PAVEMENT JOINTS: Types of joints, contraction and warping joints, dowel bars and tie bars, Temperature reinforcements, filling and sealing of joints.

Unit -V

Evaluation and Strengthening of Existing Pavements: Benkleman beam method, Serviceability Index Method. Rigid and flexible overlays and their design procedures.

Reference Books:--

1. Principles of pavement design by E.J.Yoder & M.W. Witczak
2. AASHO, "AASHO Interim Guide for Design of Pavement Structures", Washington, D.C.
3. Portland Cement Association, Guidlines for Design of Rigid Pavements, Washington
4. DSIR, Conc. Roads Design & Construction
5. Srinivasan M. "Modern Permanent Way"

RAJIV GANDHI PROUDYOGIKI VISHWAVIDYALAYA, BHOPAL

New Scheme Based On AICTE Flexible Curricula

Civil Engineering, VI-Semester

Departmental Elective CE 603(D) Cost Effective & ECO-Friendly Structures

Cost Effective & ECO-Friendly Structures

Unit -I

Concepts of energy efficient & environment friendly materials and techniques. Cost effective materials :- Soil, Fly ash, Ferrocement, Lime, Fibres, Stone Dust, Red mud, Gypsum, Alternate Wood, Polymer.

Energy Efficient & Environment friendly building material products:- Walls - Stabilised and sun dried, soil blocks & bricks, Solid & Hollow concrete blocks, stone masonry blocks, Ferrocement partitions.

Roofs - Precast R.C. Plank & Joists roof, Precast channel roof, Precast L-panel roof, Precast Funicular shells, Ferrocement shells, Filler Slab, Seasal Fibre roof, Improved country tiles, Thatch roof, M.C.R. tile.

Unit -II

Cost effective construction techniques and equipments :-

(a) Techniques :- Rat trap bond construction, Energy Efficient roofings, Ferrocement technique, Mud Technology.
(b) Equipments :- Brick moulding machine, Stablilised soil block making machine and plants for the manufacturing of concrete blocks, M.C.R. tile making machine, Ferrocement wall panel & Roofing channel making machine, R.C.C. Chaukhat making m/c.

Unit -III

Cost effective sanitation :-

(a) Waste water disposal system
(b) Cost effective sanitation for rural and urban areas
(c) Ferrocement Drains

Unit -IV

Low Cost Road Construction:-

Cost effective road materials, stabilization, construction techniques tests, equipment used for construction, drainage, maintenance.

UNIT-V

Cost analysis and comparison :-

(a) All experimental materials
(b) All experimental techniques
Green Building rating systems

Reference books:-

1. Alternative Building Materials and Technologies – K S Jagadeesh, B V Venkatta Rama Reddy & K S NanjundaRao – New Age International Publishers
2. Integrated Life Cycle Design of Structures – AskoSarja –CRC Press
3. Non-conventional Energy Resources –D S Chauhan and S K Sreevasthava – New Age International Publishers
4. Buildings How to Reduce Cost – Laurie Backer - Cost Ford
5. Lynne Elizabeth, Cassandra Adams Alternative Construction : Contemporary Natural BuildingMethods ", Softcover, Wiley & Sons Australia, Limited, John,2005
6. Givoni, "Man, Climate, Architecture, Van Nostrand, New York, 1976.
7. Charles J. Kibert, Sustainable Construction: Green Building Design and Delivery,John Wiley & Sons,2005.
8. Eugene Eccli- Low Cost, Energy efficient shelter for owner & builder, Rodale Press, 1976

Unit - I

Irrigation water requirement and Soil-Water-Crop relationship:Irrigation, definition, necessity, advantages and disadvantages, types and methods. Irrigation development. Soils - types and their occurrence, suitability for irrigation purposes, wilting coefficient and field capacity, optimum water supply, consumptive use and its determination. Irrigation methods surface and subsurface, sprinkler and drip irrigation. Duty of water, factors affecting duty and methods to improve duty, suitability of water for irrigation, crops and crop seasons, principal crops and their water requirement, crop ratio and crop rotation, intensity of irrigation.

Irrigation-

Definition-Irrigation is the method in which a controlled amount of water is supplied to plants at regular intervals for agriculture. It is used to assist in the growing of agricultural crops, maintenance of landscapes, and re vegetation of disturbed soils in dry areas and during periods of inadequate rainfall.

Necessity-Water is necessary for plant growth and maturity. Irrigation, the artificial means of supplying water, becomes necessary for plant growth in the following cases. If rainfall is less than demand of plants, irrigation is necessary to fulfill the water requirement of plants.

Advantages and disadvantages-

Advantages of Irrigation:

1. For proper nourishment of crops certain amount of water is required. If rainfall is insufficient there will be deficiency in fulfillment of water requirement. Irrigation tries to remove this deficiency caused due to inadequate rainfall. Thus, irrigation comes to rescue in dry years.

2. Irrigation improves the yield of crops and makes people prosperous. The living standards of the people are thereby improved.

3. Irrigation also adds to the wealth of the country in two ways. Firstly as bumper crops are produced due to irrigation it makes country self-sufficient in food requirements. Secondly as the irrigation water is taxed when it is supplied to the cultivators, it adds to the revenue.

4. Irrigation makes it possible to grow cash crops which give good returns to the cultivators than the ordinary crops they might have grown in absence of irrigation. Fruit gardens, sugarcane, potato, tobacco etc., are the cash crops.

5. Sometimes large irrigation channels can be used as a means of communication.

6. The falls which come across the irrigation channels can be utilized for producing hydroelectric power.

7. Domestic advantages should not be overlooked. Irrigation facilitates bathing, cattle watering etc., and improves freshwater circulation.

8. Irrigation improves the groundwater storage as water lost due to seepage ads to the groundwater storage.

9. Along the banks of large irrigation channels plantation can be successfully done which not only helps introducing social forestry but also improves environmental status of the region.

10. New irrigation works are started at the time of famines to provide employment to a large number of populations. These works are called famine works or relief works.

11. When watering facility is provided to a barren land, the value of this land gets appreciated.

Disadvantages of Irrigation:

1. Excessive seepage and leakage of water forms marshes and ponds all along the channels. The marshes and the ponds in course of time become the colonies of the mosquito, which gives rise to a disease like malaria.

2. Excessive seepage into the ground raises the water-table and this in turn completely saturates the crop root-zone. It causes waterlogging of that area.

3. It lowers the temperature and makes the locality damp due to the presence of irrigation water.

4. Under irrigation canal system valuable residential and industrial land is lost.

5. Initial cost of irrigation project is very high and thereby the cultivators have to pay more taxes in the form of levy.

6. Irrigation works become obstacles in the way of free drainage of water during rainy season and thus results in submerging standing crops and even villages.

Types and methods-Surface irrigation Localized irrigation, Drip irrigation, Sprinkler irrigation, Center pivot irrigation, Lateral move irrigation, Sub-irrigation, Manual irrigation

Irrigation development- The irrigation potential through major, medium and minor irrigation projects has increased from 22.6 million hectares (mha) in 1951, to about 102.77 Mha at the end of 2006-07.

Year	Canal	Tank	Ground Water	Others	Net Irrigated Area (NIA)	Gross Irrigated Area (GIA)
1950-1	8.30	3.61	5.98	2.97	20.58	22.56
1960-1	10.37	4.56	7.29	2.44	24.66	27.98
1970-1	12.84	4.11	11.89	2.27	31.10	38.20
1980-1	15.29	3.18	17.70	2.55	37.72	49.78
1990-1	17.45	2.94	24.70	2.93	48.02	63.20
2002-3	16.34	2.26	34.50	2.73	55.85	78.33

Soils –

Types and their occurrence- Some of the major soil groups available in India are: 1) Alluvial Soils 2) Black Soils 3) Red Soils 4) Laterite and Lateritic Soils 5) Forest and Mountain Soils 6) Arid and Desert Soils 7) Saline and Alkaline Soils 8) Peaty and Marshy Soils.

Alluvial soil:

Mostly available soil in India (about 43%) which covers an area of 143 sq.km.

Widespread in northern plains and river valleys.

In peninsular-India, they are mostly found in deltas and estuaries.

Humus, lime and organic matters are present.

Highly fertile.

Indus-Ganga-Brahmaputra plain, Narmada-Tapi plain etc are examples.

They are depositional soil – transported and deposited by rivers, streams etc.

Sand content decreases from west to east of the country.

New alluvium is termed as Khadar and old alluvium is termed as Bhangar.

Colour: Light Grey to Ash Grey.

Texture: Sandy to Silty loam or clay.

Rich in: potash

Poor in: phosphorous.

Wheat, rice, maize, sugarcane, pulses, oilseed etc are cultivated mainly.

<u>Red soil</u>:

Major soil types in India

Seen mainly in low rainfall area.

Also known as Omnibus group.

Porous, friable structure.

Absence of lime, kankar (impure calcium carbonate).

Deficient in: lime, phosphate, manganese, nitrogen, humus and potash.

Colour: Red because of Ferric oxide. The lower layer is reddish yellow or yellow.

Texture: Sandy to clay and loamy.

Wheat, cotton, pulses, tobacco, oilseeds, potato etc are cultivated.

<u>Black soil / regur soil</u>:

Regur means cotton – best soil for cotton cultivation.

Most of the Deccan is occupied by Black soil.

Mature soil.

High water retaining capacity.

Swells and will become sticky when wet and shrink when dried.

Self-ploughing is a characteristic of the black soil as it develops wide cracks when dried.

Rich in: Iron, lime, calcium, potassium, aluminum and magnesium.

Deficient in: Nitrogen, Phosphorous and organic matter.

Colour: Deep black to light black.

Texture: Clayey.

Also read: Movements of ocean water: Waves, Tides and Ocean Currents

<u>Laterite soil</u>:

Name from Latin word 'Later' which means Brick.

Become so soft when wet and so hard when dried.

In the areas of high temperature and high rainfall.

Formed as a result of high leaching.

Lime and silica will be leached away from the soil.

Organic matters of the soil will be removed fast by the bacteria as it is high temperature and humus will be taken quickly by the trees and other plants. Thus, humus content is low.

Rich in: Iron and Aluminum

Deficient in: Nitrogen, Potash, Potassium, Lime, Humus
Colour: Red Colour due to iron oxide.
Rice, Ragi, Sugarcane and Cashew nuts are cultivated mainly.

Desert / arid soil:
Seen under Arid and Semi-Arid conditions.
Deposited mainly by wind activities.
High salt content.
Lack of moisture and Humus.
Kankar or Impure Calcium carbonate content is high which restricts the infiltration of water.
Nitrogen is insufficient and Phosphate is normal.
Texture: Sandy
Colour: Red to Brown.
Peaty / marshy soil:
Areas of heavy rainfall and high humidity.
Growth of vegetation is very less.
A large quantity of dead organic matter/humus which makes the soil alkaline.
Heavy soil with black Colour.

Forest soil:
Regions of high rainfall.
Humus content is less and thus the soil is acidic.

Mountain soil:
In the mountain regions of the country.
Immature soil with low humus and acidic.

Wilting coefficient-
The wilting coefficient is defined then as the percentage water content of a soil when the plants growing in that soil are first reduced to a wilted condition from which they cannot recover in an approximately saturated atmos- phere without the addition of water to the soil.

Field capacity:
Field Capacity is the amount of soil moisture or water content held in the soil after excess water has drained away and the rate of downward movement has decreased. This usually takes place 2–3 days after rain or irrigation in pervious soils of uniform structure and texture.

Consumptive use and its determination:
Definition:
It is the quantity of water used by the vegetation growth of a given area. It is the amount of water required by a crop for its vegetated growth to evapotranspiration and building of plant tissues plus evaporation from

soils and intercepted precipitation. It is expressed in terms of depth of water. Consumptive use varies with temperature, humidity, wind speed, topography, sunlight hours, method of irrigation, moisture availability.

Mathematically,

Consumptive Use = Evapotranspiration = Evaporation + transpiration It is expressed in terms of depth of water.

<u>Types of Consumptive Water Use</u>

Following are the types of consumptive use,

1. **Optimum Consumptive Use**
2. **Potential Consumptive Use**
3. **Seasonal Consumptive Use**

1. Optimum Consumptive Use: It is the consumptive use which produces a maximum crop yield.
2. Potential Consumptive Use: If sufficient moisture is always available to completely meet the needs of vegetation fully covering the entire area then resulting evapotranspiration is known as Potential Consumptive Use.
3. Seasonal Consumptive Use: The total amount of water used in the evapotranspiration by a cropped area during the entire growing season.

To measure or estimation the consumptive use there are two main methods:

1. **Direct Methods/Field Methods**
2. **Empirical Methods**
3. **Pan evaporation method**

1. Direct Methods:

In this method field observations are made and physical model is used for this purpose. This includes,

i. **Vapors Transfer Method/Soil Moisture Studies**
ii. **Field Plot Method**
iii. **Tanks and Lysimeter**
iv. **Integration Method/Summation Method**
v. **Irrigation Method**
vi. **Inflow Outflow Method**

1.1 Vapor Transfer Method:
In this method of estimation of water consumptive use, soil moisture measurements are taken before and after eachirrigation. The quantity of water extracted per day from soil is computed for each period. A curve is drawn by plotting the rate of use against time and from this curve, the seasonal use can be estimated. This method is suitable in those areas where soil is fairly uniform and ground water is deep enough so that it does not affect the fluctuations in the soil moisture within the root zone of the soil.It is expressed in terms of volume i.e. Acre-feet or Hectare-meter

1.2 Field Plot Method:

We select a representative plot of area and the accuracy depends upon the representativeness of plot (cropping intensity, exposure etc).It replicates the conditions of an actual sample field (field plot). Less seepage should be there.

Inflow + Rain + Outflow = Evapotranspiration

The drawback in this method is that lateral movement of water takes place although more representative to field condition. Also some correction has to be applied for deep percolation as it cannot be ascertained in the field.

1.3 Tanks and Lysimeter:

In this method of measurement of consumptive use of water, a watertight tank of cylindrical shape having diameter 2m and depth about 3m is placed vertically on the ground. The tank is filled with sample of soil. The bottom of the tank consists of a sand layer and a pan for collecting the surplus water. The plants grown in the Lysimeter should be the same as in the surrounding field. The consumptive use of water is estimated by measuring the amount of water required for the satisfactory growth of the plants within the tanks. Consumptive use of water is given by,

Cu = Wa - Wd

Where,

Cu=Consumptive use of water
Wa= Water Applied
Wd = Water drained off

Lysimeter studies are time consuming and expensive. Methods 1 and 2 are the more reliable methods as compare to this method.

1.4 Integration Method:

In this method, it is necessary to know the division of total area, i.e. under irrigated crops, natural native vegetation area, water surface area and bare land area. In this method, annual consumptive use for the whole area is found in terms of volume. It is expressed in Acre feet or Hectare meter.

***Mathematically*,**

Total Evapotranspiration = Total consumptive uses

Total Area Annual Consumptive Use = Total Evapotranspiration = A+B+C+D Where,
A = Unit consumptive use for each cropsits area
B = Unit consumptive use of native vegetation pits area
C = Water surface evaporationxits area
D = Bare land evaporationxits area

1.5 Irrigation Method:

In this method, unit consumption is multiplied by some factor. The multiplication values depend upon the type of crops in certain area. This method requires an Engineer judgment as these factors are to be investigated by the Engineers of certain area.

1.6 Inflow Outflow Method:

In this method annual consumptive use is found for large areas. If U is the valley consumptive use its value is given by,

U = (I+P) + (Gs - Ge) - R

Where,

U = Valley consumptive use (in acre feet or hectare meter)
I = Total inflow during a year
P = Yearly precipitation on valley floor
Gs = Ground Storage at the beginning of the year
Ge = Ground Storage at the end of the year
R = Yearly Outflow

All the above volumes are measured in acre-feet or hectare-meter.

2. Empirical Methods:

Empirical equations are given for the estimation of water requirement. These are,

2.1 Lowry Johnson Method:

The equation for this method is,

U = 0.0015 H + 0.9 (Over specified)

U = Consumptive Use
H = Accumulated degree days during the growing season computed from maximum temperature above 32 °F

2.2 Penman Equation:
According to this method,

U = ET = AH + 0.27 EaA - 0.27

ET = Evapotranspiration or consumptive use in mm Ea = Evaporation (mm/day)
H = Daily head budget at surface (mm/day)
H is a function of radiation, sunshine hours, wind speed, vapour pressure and other climatic factors.
A = Slope of saturated vapour pressure curve of air at absolute temperature in °F
2.3 Hargreaves's Method:

It is a very simple method. According to this method,

Cu = KEp

Where,

Cu = Consumptive Use coefficient (varies from crop to crop)
Ep = Evapotranspiration K = Coefficient

Irrigation methods

Surface- In surface (furrow, flood, or level basin) irrigation systems, water move across the surface of agricultural lands, in order to wet it and infiltrate into the soil. Surface irrigation can be subdivided into furrow, border strip or basin irrigation. It is often called flood irrigation when the irrigation results in flooding or near flooding of the cultivated land. Historically, this has been the most common method of irrigating agricultural land and still used in most parts of the world. Where water levels from the irrigation source permit, the levels are controlled by dikes, usually plugged by soil. This is often seen in terraced rice fields (rice paddies), where the method is used to flood or control the level of water in each distinct field. In some cases, the water is pumped, or lifted by human or animal power to the level of the land. The field water efficiency of surface irrigation is typically lower than other forms of irrigation but has the potential for efficiencies in the range of 70% - 90% under appropriate management.

Subsurface

Sprinkler - In sprinkler or overhead irrigation, water is piped to one or more central locations within the field and distributed by overhead high-pressure sprinklers or guns. A system utilizing sprinklers, sprays, or guns mounted overhead on permanently installed risers is often referred to as a solid-set irrigation system. Higher pressure sprinklers that rotate are called rotors are driven by a ball drive, gear drive, or impact mechanism. Rotors can be designed to rotate in a full or partial circle. Guns are similar to rotors, except that they generally operate at very high pressures of 40 to 130 lbf/in² (275 to 900 kPa) and flows of 50 to 1200 US gal/min (3 to 76 L/s), usually with nozzle diameters in the range of 0.5 to 1.9 inches (10 to 50 mm). Guns are used not only for irrigation, but also for industrial applications such as dust suppression and logging.

Sprinklers can also be mounted on moving platforms connected to the water source by a hose. Automatically moving wheeled systems known as traveling sprinklers may irrigate areas such as small farms, sports fields, parks, pastures, and cemeteries unattended. Most of these utilize a length of polyethylene tubing wound on a steel drum. As the tubing is wound on the drum powered by the irrigation water or a small gas engine, the sprinkler is pulled across the field. When the sprinkler arrives back at the reel the system shuts off. This type of system is known to most people as a "water reel" traveling irrigation sprinkler and they are used extensively for dust suppression, irrigation, and land application of waste water. Other travelers use a flat rubber hose that is dragged along behind while the sprinkler platform is pulled by a cable. These cable-type travelers are definitely old technology and their use is limited in today's modern irrigation projects.

Drip irrigation- Drip (or micro) irrigation, also known as trickle irrigation, functions as its name suggests. In this system water falls drop by drop just at the position of roots. Water is delivered at or near the root zone of plants, drop by drop. This method can be the most water-efficient method of irrigation,[29] if managed properly, since evaporation and runoff are minimized. The field water efficiency of drip irrigation is typically in the range of 80 to 90 percent when managed correctly. In modern agriculture, drip irrigation is often combined with plastic mulch, further reducing evaporation, and is also the means of delivery of fertilizer. The process is known as fustigation.

Deep percolation, where water moves below the root zone, can occur if a drip system is operated for too long or if the delivery rate is too high. Drip irrigation methods range from very high-tech and computerized to low-tech and labor-intensive. Lower water pressures are usually needed than for most other types of systems, with the exception of low energy center pivot systems and surface irrigation systems, and the system can be designed for uniformity throughout a field or for precise water delivery to individual plants in a landscape containing a mix of plant species. Although it is difficult to regulate pressure on steep slopes, pressure compensating emitters are available, so the field does not have to be level. High-tech solutions involve precisely calibrated emitters located along lines of tubing that extend from a computerized set of valves.

Duty of water-

The term duty means the area of land that can be irrigated with unit volume of irrigation water. Quantitatively, duty is defined as the area of land expressed in hectares that can be irrigated with unit discharge, that is, 1 cumec flowing throughout the base period, expressed in days.

<u>Factors affecting duty:</u>

The factors that affect the duty are described below,

1. Soil Characteristics:

If the soil of the canal bed is porous and coarse grained, it leads to more seepage loss and consequently low duty. If it consists of alluvial soil, the percolation loss will be less and the soil retains the moisture for longer period and consequently the duty will be high.

2. Climatic Condition:

When the temperature of the command area is high the evaporation loss is more and the duty becomes low and vice versa.

3. Rainfall:

If rainfall is sufficient during the crop period, the duty will be more and vice versa.

4. Base Period:

When the base period is longer, the water requirement will be more and the duty will be low and vice versa.

5. Type of Crop:

The water requirement for various crops is different. So the duty varies from crop to crop.

6. Topography of Agricultural Land:
If the land is uneven the duty will be low. As the ground slope increases the duty decreases because there is wastage of water.

7. Method of Ploughing:
Proper deep ploughing which is done by tractors requires overall less quantity of water and hence the duty is high.

8. Methods of Irrigation:
The duty of water is high in case of perennial irrigation system as compared to that in inundation irrigation system.

9. Water Tax:
If some tax is imposed the farmer will use the water economically thus increasing the duty.

<u>Methods to improve duty</u>
Various methods of improving duty are:
(1) Proper Ploughing:
Ploughing should be done properly and deeply so that the moisture retaining capacity of soil is increased.

(2) Methods of supplying water:
The method of supplying water to the agriculture land should be decided according to the field and soil conditions. For example,

- **Furrow method For crops sown ion rows**
- **Contour method For hilly areas**
- **Basin For orchards**
- **Flooding For plain lands**

(3) Canal Lining:
It is provided to reduce percolation loss and evaporation loss due to high velocity.

(4) Minimum idle length of irrigation Canals:
The canal should be nearest to the command area so that idle length of the canal is minimum and hence reduced transmission losses.

(5) Quality of water:
Good quality of water should be used for irrigation. Pollution en route the canal should be avoided.

(6) Crop rotation:

The principle of crop rotation should be adopted to increase the moisture retaining capacity and fertility of the soil.

(7) Method of Assessment of water:
Particularly, the volumetric assessment would encourage the farmer to use the water carefully.

(8) Implementation of Tax:
The water tax should be imposed on the basis of volume of water consumption.

Crops and crop seasons

The agricultural crop year in India is from July to June. The Indian cropping season is classified into two main seasons-(i) Kharif and (ii) Rabi based on the monsoon. The kharif cropping season is from July –October during the south-west monsoon and the Rabi cropping season is from October-March (winter). The crops grown between March and June are summer crops. Pakistan and Bangladesh are two other countries that are using the term 'kharif' and 'rabi' to describe about their cropping patterns. The terms 'kharif' and 'rabi' originate from Arabic language where Kharif means autumn and Rabi means spring.

The kharif crops include rice, maize, sorghum, pearl millet/bajra, finger millet/ragi (cereals), arhar (pulses), soyabean, groundnut (oilseeds), cotton etc. The Rabi crops include wheat, barley, oats (cereals), chickpea/gram (pulses), linseed, mustard (oilseeds) etc.

Principal crops and their water requirement

Irrigation Water Requirement of Crops
It is defined as, "The quantity of water required by a crop in a given period of time for normal growth under field conditions." It includes evaporation and other unavoidable wastes. Usually water requirement for crop is expressed in water depth per unit area.

IRRIGATION WATER NEED = Crop water need — available rain fall
The first thing you need to consider when planning your garden is what growing zone you live in.
This is based on both the temperature range of your climate and the amount of precipitation. Take a close look at the area in which you are going to plant your garden. If the ground tends to be very moist, choose plants that can tolerate constantly wet soil, and even standing water.
If you live in an area that suffers from frequent droughts, however, select plants that can tolerate going long periods without water, especially in light of the frequent watering restrictions imposed on such areas.

Crop ratio and crop rotation:

Crop rotation is the practice of growing a series of dissimilar or different types of crops in the same area in sequenced seasons. It is done so that the soil of farms is not used for only one set of nutrients. It helps in reducing soil erosion and increases soil fertility and crop yield.
Growing the same crop in the same place for many years in a row disproportionately depletes the soil of certain nutrients. With rotation, a crop that leaches the soil of one kind of nutrient is followed during the next growing season by a dissimilar crop that returns that nutrient to the soil or draws a different ratio of

nutrients. In addition, crop rotation mitigates the buildup of pathogens and pests that often occurs when one species is continuously cropped, and can also improve soil structure and fertility by increasing biomass from varied root structures.

Intensity of irrigation:

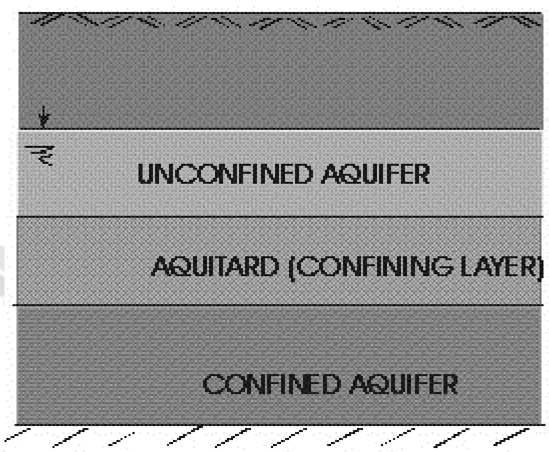
Intensity of irrigation is defined as the percentage of the irrigation proposed to be irrigated annually. Usually the areas irrigated during each crop season (Rabi, Kharif, etc) is expressed as a percentage of the CCA which represents the intensity of irrigation for the crop season.

Unit – II

Ground Water and Well irrigation: Confined and unconfined aquifers, aquifer properties, hydraulics of wells under steady flow conditions, infiltration galleries. Ground water recharge-necessity and methods of improving ground water storage. Water logging-causes, effects and its prevention. Salt efflorescence causes and effects. Reclamation of water logged and salt affected lands. Types of wells, well construction, yield tests, specific capacity and specific yield, advantages and disadvantages of well irrigation.

Confined and unconfined aquifers:

An unconfined aquifer is close to the land surface, being under the direct influence of the climatic factors (precipitations mainly, but temperature also). The groundwater fluctuations follow with a certain lag, depending on the depth and the nature of the unsaturated zone, the variation of the fallen precipitations. The unconfined aquifers extend from the *water table* to the base of the aquifer, represented by an impermeable boundary. Most of the unconfined aquifers are formed by highly permeable layers (gravel, coarse or medium sand) and less permeable formations (silt or clay) that do not cut the hydraulic continuity of the permeable layers on a regional level.



A confined aquifer is overlain by a confining layer (Figure 9.2), which is generally semi-pervious, allowing vertical fluxes between the adjacent layers.

Unconfined aquifer, confined aquifer and confining layer

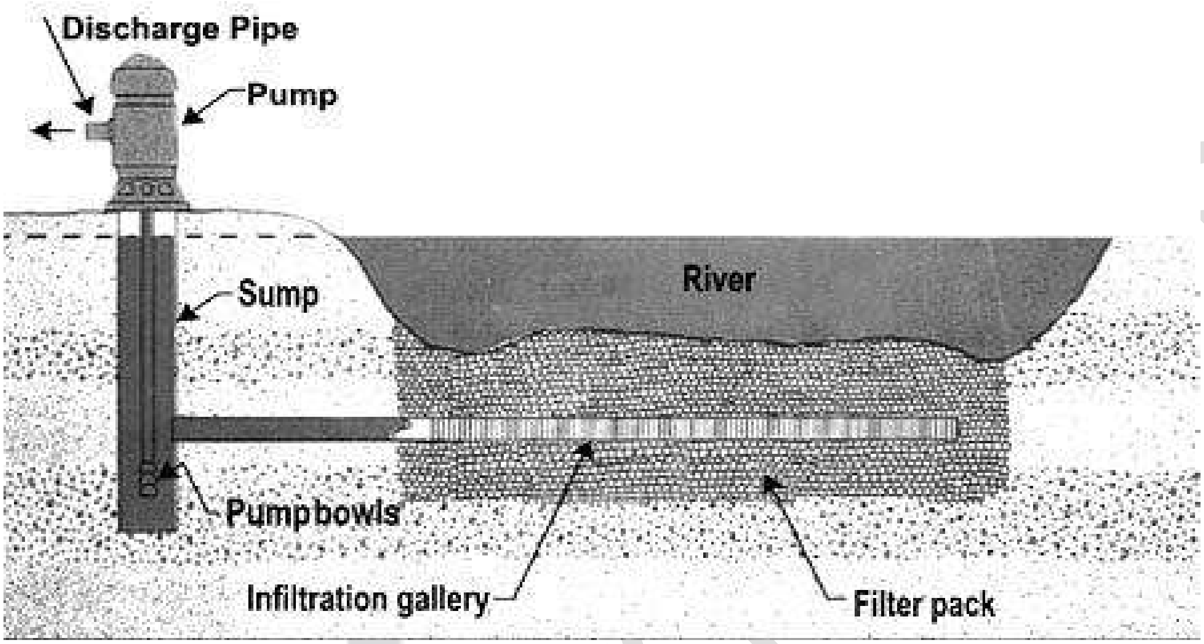
Unless an irrational abstraction, the confined aquifers are under pressure; this means that the water level in a piezometric well will rise above the top of the aquifer

Aquifer properties:

The levels to which the water from the confined aquifer rises define the piezometric or the potentiometric surface. The potentiometric surface can be under the top of the semi-pervious layer, above it but under the water table of the unconfined aquifer overlying it, or finally above the water table. A special case is when the potentiometric surface is above the ground level, the well penetrating the confined aquifer being artesian. The differences in hydraulic head between the unconfined and the confined aquifer lead to vertical fluxes directed from the aquifer having the upper value to the aquifer with the lower value of the hydraulic head. The vertical water transfer is called leakage and will thus be directed upward or downward.

Infiltration galleries:

An infiltration gallery is a structure including perforated conduits in gravel to expedite transfer of water to or from a soil aquifer.Infiltration galleries may be used to collect water from the aquifer underlying a river. Water from an infiltration gallery has the advantage of bank filtration to reduce the water treatment requirements for a surface withdrawal. An infiltration gallery may also be the best way to withdraw water from a thin aquifer or lens of fresh water overlying saline water.



Methods of improving ground water storage:

A variety of methods have been developed and applied to artificially recharge groundwater reservoirs in various parts of the world. Generally these methods are classified as surface and subsurface groundwater recharge.

Direct surface recharge techniques are among the simplest and most widely applied methods. Subsurface groundwater recharge conveys water directly into an aquifer without the filtration or oxidation that occurs when water percolates naturally through an unsaturated zone.

Direct Surface Groundwater Recharge

With direct groundwater recharge water moves from storage aboveground to the aquifer via soil percolation. Most of the existing large-scale artificial recharge schemes in Western countries make use of this technique,which typically employs infiltration basins (spreading basins) to enhance the natural percolation of water into the ground. Field studies of spreading techniques have shown that, of the many factors governing the amount of water that will enter the aquifer, the area of recharge and length of time that water is in contact with soil are the most important. In general direct surface recharge systems based on percolation have relatively low construction costs and are easy to operate and maintain.

Spreading Basins:

This method involves surface spreading of water in basins that are excavated in the existing terrain. For effective artificial recharge, highly permeable soils are required and maintenance of the water layer above the soil surface is necessary. Recharge in spreading basins is most effective where there are no impending layers between the land surface and the aquifer and where clear water is available for recharge. In addition this method tolerates more turbid water than any well recharge methods does.

Recharge Pits and Shafts:

Shafts can have circular, rectangular, or square cross sections and may be backfilled with porous material enhancing the percolation process and preventing the stagnation of the water (which can lead to insect breading). The shaft may end above the water table or reach below the water table and serve as hydraulic connector.

Ditches:

Ditches are similar to spreading basins but they have a different shape. A ditch can be described as a long narrow trench, its bottom width being less than its depth. A ditch system can be designed to suit the topographic and geologic conditions that exist at a given site (O'HARE et al. 1986). Water fills up in the ditches and percolates naturally through the soil.

Other Recharge Techniques:

Another method of artificially recharging groundwater is to use permeable pavements,which allows water surface runoff (e.g. storm water) to trickle underground, rather than allowing it to pool on the surface and evaporate.

Flood irrigation of surface water applied to surrounding farmlands is also a vital source of groundwater recharge. As agricultural land is converted to urban use, identifying sites for additional groundwater recharge is essential to keep water supplies balanced (water consumption of urban areas are generally lower, but impact of deep percolation from flood irrigation is lost.

Water logging-causes, effects and its prevention:

Definition:

When the conditions are so created that the crop root-zone gets deprived of proper aeration due to the presence of excessive moisture or water content, the tract is said to be waterlogged. To create such conditions it is not always necessary that under groundwater table should enter the crop root-zone. Sometimes even if water table is below the root-zone depth the capillary water zone may extend in the root-zone depth and makes the air circulation impossible by filling the pores in the soil.

The waterlogging may be defined as rendering the soil unproductive and infertile due to excessive moisture and creation of anaerobic conditions. The phenomenon of waterlogging can be best understood with the help of a hydrologic equation, which states that

Inflow = Outflow -I- Storage

Here inflow represents that amount of water which enters the subsoil in various processes. It includes seepage from the canals, infiltration of rainwater, percolation from irrigated fields and subsoil flow. Thus although it is loss or us, it represents the amount of water flowing into the soil.

The term outflow represents mainly evaporation from soil, transpiration from plants and underground drainage of the tract. The term storage represents the change in the groundwater reservoir.

Causes of Waterlogging:

After studying the phenomenon of waterlogging in the light of hydrologic equation main factors which help in raising the water-table may be recognised correctly.

They are:

i. **Inadequate drainage of over-land run-off increases the rate of percolation and in turn helps in raising the water table.**

ii. **The water from rivers may infiltrate into the soil.**

iii. **Seepage of water from earthen canals also adds significant quantity of water to the underground reservoir continuously.**

iv. **Sometimes subsoil does not permit free flow of subsoil water which may accentuate the process of raising the water table.**

v. **Irrigation water is used to flood the fields. If it is used in excess it may help appreciably in raising the water table. Good drainage facility is very essential.**

Effects of Waterlogging:

The waterlogging affects the land in various ways. The various after effects are the following:

1. Creation of Anaerobic Condition in the Crop Root-Zone:

When the aeration of the soil is satisfactory bacteriological activities produce the required nitrates from the nitrogenous compounds present in the soil. It helps the crop growth. Excessive moisture content creates anaerobic condition in the soil. The plant roots do not get the required nourishing food or nutrients. As a result crop growth is badly affected.

2. Growth of Water Loving Wild Plants:

When the soil is waterlogged water loving wild plant life grows abundantly. The growth of wild plants totally prevent the growth of useful crops.

3. Impossibility of Tillage Operations:

Waterlogged fields cannot be tilled properly. The reason is that the soil contains excessive moisture content and it does not give proper tilth.

4. Accumulation of Harmful Salts:

The upward water movement brings the toxic salts in the crop root-zone. Excess accumulation of these salts may turn the soil alkaline. It may hamper the crop growth.

5. Lowering of Soil Temperature:

The presence of excessive moisture content lowers the temperature of the soil. In low temperature the bacteriological activities are retarded which affects the crop growth badly.

6. Reduction in Time of Maturity:

Untimely maturity of the crops is the characteristic of waterlogged lands. Due to this shortening of crop period the crop yield is reduced considerably.

Salt efflorescence causes and effects:

Efflorescence is purely the result of natural laws, and is the direct outcome of the situation of the brickwork, which causes large irregular shaped patches of a whitish mould, formed on the surface of the wall, and thus disfigures its appearance. Efflorescence is produced by the entrance of moisture to the interior of the brickwork, which usually contains various soluble salts.

These salts are dissolved by the water and issuing from the pores of the bricks, they crystallise on its surface and or within the bricks in the form of mould, causing disintegration of the brickwork which persists until in time it becomes exhausted and gradually dries away. The only means by which this can be remedied is to prevent water or moisture soaking into the brickwork and dissolving the salts.

Causes of Efflorescence:

Causes of efflorescence are the entering of moisture into the brickwork and soaking it to saturation. The moisture, once finding its way into the brick, travels upwards due to capillary action till it is prevented by any water proofing barrier.

Reclamation of water logged and salt affected lands

Water logged areas can be reclaimed by following certain techniques.

1. Proper Drainage System

Farmers should have adequate surface drainage facilities to remove excess water from their fields. The surface runoff and subsoil drainage of water should not be so slow. During rainy season efforts should be made not to retain water on soil surface.

2. Using Tube Wells

A tube well is an ideal device to lower the level of water in water logged areas. Tube wells have the capability to draw out of the earth large quantities of water continuously. It is a good technique to reclaim water logged areas by installing tube wells.

3. Lining of Canals

In order to minimize water logging, concrete lining of canals and other water channels should be done. It will be helpful not only in controlling water logging but also in saving useful irrigation water.

4. Water Management

Farmers should be educated about water management. Use of excessive irrigation water for cultivation of certain crops should be avoided. Modern irrigation techniques like drip irrigation should be adopted.

5. Tolerant Crops

Crops like rice, oats, etc should be preferred in water logged areas. Because rice require more moisture for its growth.

6. Tolerant Trees

Trees like Eucalyptus, willows, etc should be planted in water logged areas because of its high moisture requirement.

Reclaiming of salt affected land:

Salt leaching

The amount of crop yield reduction depends on such factors as crop growth, the salt content of the soil, climatic conditions, etc. In extreme cases where the concentration of salts in the root zone is very high, crop growth may be entirely prevented. To improve crop growth in such soils the excess salts must be removed from the root zone. The term reclamation of saline soils refers to the methods used to remove soluble salts from the root zone. Methods commonly adopted or proposed to accomplish this include the following:

Scraping: Removing the salts that have accumulated on the soil surface by mechanical means has had only a limited success although many farmers have resorted to this procedure. Although this method might temporarily improve crop growth, the ultimate disposal of salts still poses a major problem.

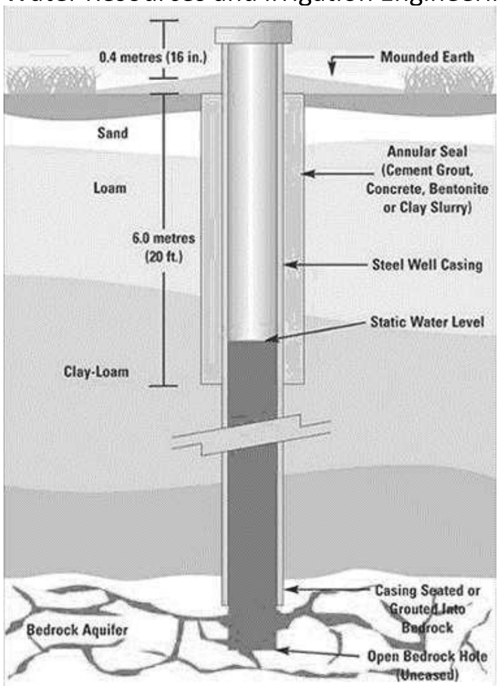
Flushing: Washing away the surface accumulated salts by flushing water over the surface is sometimes used to desalinize soils having surface salt crusts. Because the amount of salts that can be flushed from a soil is rather small, this method does not have much practical significance.

Leaching: This is by far the most effective procedure for removing salts from the root zone of soils. Leaching is most often accomplished by ponding fresh water on the soil surface and allowing it to infiltrate. Leaching is effective when the salty drainage water is discharged through subsurface drains that carry the leached salts out of the area under reclamation. Leaching may reduce salinity levels in the absence of artificial drains when there is sufficient natural drainage, i.e. the ponded water drains without raising the water table. Leaching should preferably be done when the soil moisture content is low and the groundwater table is deep. Leaching during the summer months is, as a rule, less effective because large quantities of water are lost by evaporation. The actual choice will however depend on the availability of water and other considerations. In some parts of India for example, leaching is best accomplished during the summer months because this is the time when the water table is deepest and the soil is dry. This is also the only time when large quantities of fresh water can be diverted for reclamation purposes.

Types of wells:

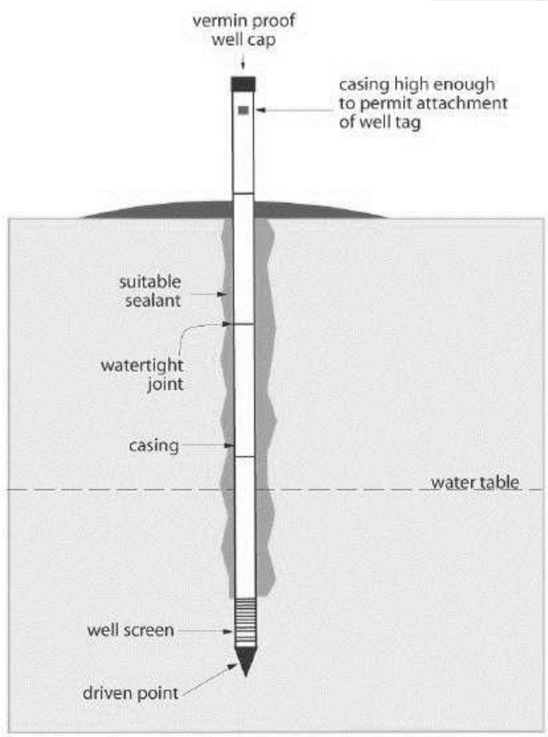
Drilled wells:

Drilled wells are constructed by either cable tool (percussion) or rotary-drilling machines. Drilled wells that penetrate unconsolidated material require installation of casing and a screen to prevent inflow of sediment and collapse. They can be drilled more than 1,000 feet deep. The space around the casing must be sealed with grouting material of either neat cement or bentonite clay to prevent contamination by water draining from the surface downward around the outside of the casing.



Driven wells:

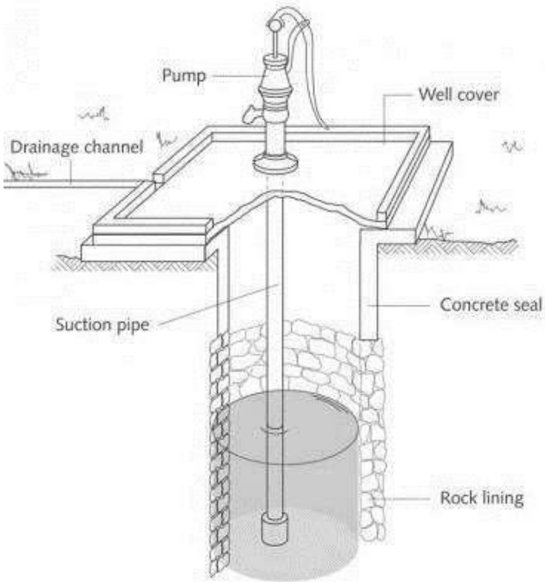
Driven wells are constructed by driving a small-diameter pipe into shallow water-bearing sand or gravel. Usually a screened well point is attached to the bottom of the casing before driving. These wells are relatively simple and economical to construct, but they can tap only shallow water and are easily contaminated from nearby surface sources because they are not sealed with grouting material. Hand-driven wells usually are only around 30 feet deep; machine-driven wells can be 50 feet deep or more.



Dug wells:

Historically, dug wells were excavated by hand shovel to below the water table until incoming water exceeded the digger's bailing rate. The well was lined with stones, bricks, tile, or other material to prevent

collapse, and was covered with a cap of wood, stone, or concrete tile. Because of the type of construction, bored wells can go deeper beneath the water table than can hand-dug wells. Dug and bored wells have a large diameter and expose a large area to the aquifer. These wells are able to obtain water from less-permeable materials such as very fine sand, silt, or clay. Disadvantages of this type of well are that they are shallow and lack continuous casing and grouting, making them subject to contamination from nearby surface sources, and they go dry during periods of drought if the water table drops below the well bottom.



<u>Well construction:</u>

The initial investment for a properly designed and constructed well pays off by ensuring:

- **A reliable and sustainable water supply consistent with your needs and the capability of the aquifer**
- **Good quality water that is free of sediment and contaminants**
- **Increased life expectancy of the well**
- **Reduced operating and maintenance costs**
- **Ease of monitoring well performance.**

Choosing a Well Site

- **The well is accessible for cleaning, testing, monitoring, maintenance and repair**
- **The ground surrounding the well is sloped away from the well to prevent any surface run off from collecting or ponding**
- **The well is up-slope and as far as possible from potential contamination sources such as septic systems, barnyards or surface water bodies**
- **The well is not housed in any building other than a bona fide pump house.**

Well Design Considerations

Well design and construction details are determined after a test hole has been completed and the geological zones have been logged. There are many components to well design the driller must take into account. Decisions will be made about:

- **Type of well**

- **Intended use**
- **Well depth**
- **Casing material, size and wall thickness**
- **Intake design**
- **Annular seal**
- **Monitoring and preventive maintenance provisions.**

Well Depth

During the test hole drilling, the licensed water well contractor will complete a lithological or formation log. Soil and rock samples are taken at various depths and the type of geologic material is recorded. This allows the driller to identify zones with the best potential for water supply. Some drillers also run a geophysical (electric) log in the test hole to further define the geology. This gives them more accurate information about aquifer location. Generally a well is completed to the bottom of the aquifer. This allows more of the aquifer to be utilized and ensures the highest possible production from the well.

Types of Wells

There are two main types of wells, each distinguished by the diameter of the bore hole. The two types are bored wells and drilled wells.

Casing Size and Type

Decisions about the diameter and type of well casing are made after the driller considers the following:

- **Aquifer characteristics**
- **Hydraulic factors that influence well performance**
- **Drilling method**
- **Well depth**
- **Cost (in discussion with the well owner).**

The casing must be large enough to house the pump and allow sufficient clearance for installation and efficient operation.

<u>Yield tests:</u>

A Well Yield Test is a timed-test to determine how many gallons per minute a well system can produce. A Well Yield Test will show: A functioning well pump and pressure tank. If a well is running dry or lacks sufficient recuperation.It is well known that under the favorable 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 lt/min. The yield of open well can be determined by any one of the two methods, namely, pumping test and recuperation test.

<u>Specific capacity</u>
The amount of water furnished under a standard unit head: the amount of water that is furnished under unit lowering of the surface of the water in a well by pumping.
Specific capacity is a quantity that which a water well can produce per unit of drawdown. It is normally obtained from a step drawdown test. Specific capacity is expressed as:

$$Sc = Q/ho-h$$

Where

Sc is the specific capacity ($[L^2T^{-1}]$; m²/day or USgal/day/ft)
Q is the pumping rate ($[L^3T^{-1}]$; m³/day or USgal/day), and
ho-h is the drawdown ([L]; m or ft)
The specific capacity of a well is also a function of the pumping rate it is determined at. Due to non-linear well losses the specific capacity will decrease with higher pumping rates. This complication makes the absolute value of specific capacity of little use; though it is useful for comparing the efficiency of the same well through time

<u>Specific yield:</u>
Specific yield is defined as the volume of water released from storage by an unconfined aquifer per unit surface area of aquifer per unit decline of the water table.

<u>Advantages and disadvantages of well irrigation:</u>
Advantages:
1. Whenever necessity is felt, in any tract locally, well may be sunk to start open well irrigation. Much consideration need not be given to any of the other factors which are given proper weightage while introducing canal irrigation.
2. There is no need of constructing many and expensive hydraulic structures. The cost of well irrigation project is therefore much less.
3. When the water is withdrawn from the subsoil formation by means of wells the waters table obviously lowers and water-logging of the land is prevented.
4. The water is used more economically as cultivator has to put in labour for lifting water.

5. The water can be used at any time depending upon the choice of cultivator and water needs of crops.

6. As the water is assured for whole of the year, provided groundwater conditions are favorable, two to three corps can be grown on the same field in one year.

7. Maintenance cost of a well is less. Also as the well is situated usually in the middle of the field water losses in transit are less.

8. By constructing number of wells in any tract intensive irrigation of some valuable crops can be done.

9. In well irrigation duty realized is higher.

10. Well water irrigates the un-commanded patches of the culturable land in the canal irrigated tract. Thus it assists the canal irrigation.

11. Well water is cooler in summer season and warmer in winter season. This water when applied to the crops, tries to neutralize the bad effects of the hot or cold season.

Disadvantages:

1. To make the water available for irrigation purposes it is necessary to lift it from underground. For lifting the water power is required. Thus the well irrigation is much dependent on the availability of power or trouble free working of the machinery which is very rare thing.

2. Sometimes cost of well water is so high that the returns obtained from it are not justifiable.

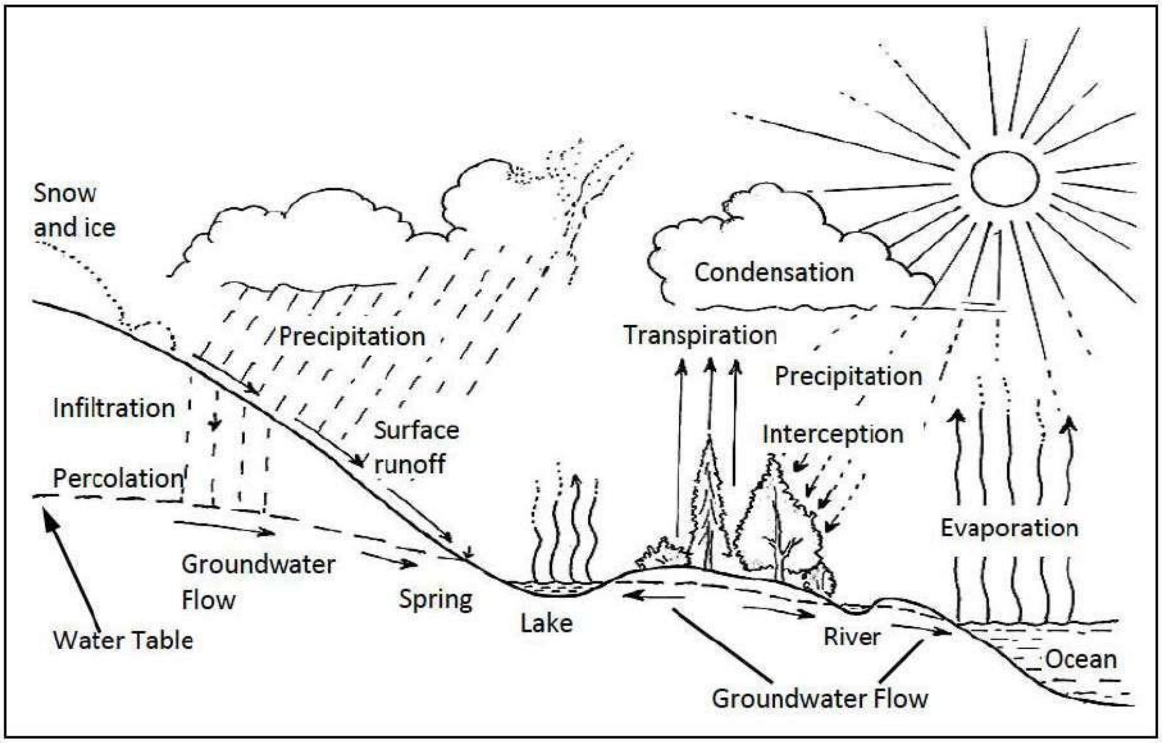
3. Availability of water from the wells depends on groundwater storage. The discharge from well is low and area commanded is less.

4. The water in well is static and therefore it is free of suspended silt. Water carrying silt together with some useful suspended salts is very beneficial to the crops. Well water thus lacks in this respect.

Unit-III

Hydrology:Hydrological cycle, precipitation and its measurement, recording and non recording rain gauges, estimating missing rainfall data, rain gauge net works, mean depth of precipitation over a drainage area, mass rainfall curves, intensity-duration curves, depth-area duration curves, Infiltration and infiltration indices, evaporation stream gauging, run off and its estimation, hydrograph analysis, unit hydrograph and its derivation from isolated and complex storms, Scurve hydrograph, synthetic unit hydrograph.

Hydrological cycle:



The hydrologic cycle begins with the evaporation of water from the surface of the ocean. As moist air is lifted, it cools and water vapour condenses to form clouds. Moisture is transported around the globe until it returns to the surface as precipitation. Once the water reaches the ground, one of two processes may occur; 1) some of the water may evaporate back into the atmosphere or

2) The water may penetrate the surface and become groundwater. Groundwater either seeps its way to into the oceans, rivers, and streams, or is released back into the atmosphere through transpiration. The balance of water that remains on the earth's surface is runoff, which empties into lakes, rivers and streams and is carried back to the oceans, where the cycle begins again.

Lake effect snowfall is good example of the hydrologic cycle at work. Below is a vertical cross-section summarizing the processes of the hydrologic cycle that contribute to the production of lake effect snow. The

cycle begins as cold winds (horizontal blue arrows) blow across a large lake, phenomena that occurs frequently in the late fall and winter months around the Great Lakes.

Evaporation of warm surface water increases the amount of moisture in the colder, drier air flowing immediately above the lake surface. With continued evaporation, water vapor in the cold air condenses to form ice-crystal clouds, which are transported toward shore.

By the time these clouds reach the shoreline, they are filled with snowflakes too large to remain suspended in the air and consequently, they fall along the shoreline as precipitation. The intensity of lake effect snowfall can be enhanced by additional lifting due to the topographical features (hills) along the shoreline. Once the snow begins to melt, the water is either absorbed by the ground and becomes groundwater, or goes returns back to the lake as runoff.

Lake effect snow events can produce tremendous amounts of snow. One such event was the Cleveland, Ohio Veteran's Day Snowstorm from November of 1996, where local storm snowfall totals exceeded 50 inches over two to three days.

Precipitation and its measurement:

Precipitation is the falling of water from the sky in different forms. They all form from the clouds which are raised about 8 to 16 kilometers (4 to 11 miles) above the ground in the earth's troposphere. Precipitation takes place whenever any or all forms of water particles fall from these high levels of the atmosphere and reach the earth surface. The drop to the ground is caused by frictional drag and gravity. When one falling particle drops from the cloud, it leaves behind a turbulent wake, causing faster and continued drops.Precipitation falls in many forms, or phases. They can be subdivided into:

- **Liquid precipitation:**
    - **Drizzle**
    - **Rain**
    - **Fog condensation on vegetation foliage, dripping on forest soil**
- **Freezing precipitation:**
    - **Freezing drizzle**
    - **Freezing rain**
    - **Rain and snow mixed / "Snain"**
    - **Sun Shower**
- **Frozen precipitation:**
    - **Snow**

- **Snow grains**
- **Ice pellets / Sleet**
- **Hail**
- **Snow pellets / Graupel**
- **Ice crystals**

Recording and non-recording rain gauges:

1. Non-Recording Type Rain-Gauge:

It gives only total rainfall occurred during particular time period. Recording type rain- gauge gives hourly rainfall. Under non-recording type rain-gauges, one most commonly used in Symon's rain-gauge. This type is mentioned below. It is the simplest in principle, construction and working.

Principle:

From the definition of unit rainfall it is clear that the definition is independent of extent of area. So far as only measurement of rainfall is concerned area under consideration may be large or small.

Now taking smallest possible area, if the water, which comes down as rainfall, is collected before the losses take place or water runs off then the depth of this water over the small area can be quite accurately determined to give the amount of rainfall occurred in proper units (centimetres). The small area should be selected in such a way that its meteorological characteristics are similar to that particular large area which it represents.

Construction:

It consists of a funnel and a receiver mainly. The receiver is a cylindrical (zinc) metal bottle. The diameter of the bottle and the topmost diameter of funnel is 127 mm. The funnel is fitted in the neck of the bottle. Both are then placed in a metal casing with suitable packing's. The base of the metal casing is enlarged to 210 mm.

The capacity of the bottle is such as to measure extremes of rainfall likely to occur in 24 hours. Zinc receivers hold 175 mm to 1000 mm according to size. Gauge is provided with one measuring graduated jar which measures the water in mm. The smallest division on the jar is 0.2 mm. The rainfall should be estimated to the nearest 0.1 mm. See Fig. 2.4.

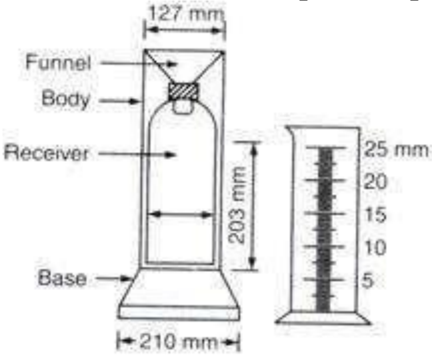


Fig. 2.4. Symons non-recording type rain-gauge

At the site where rainfall is to be measured concrete block us constructed. The base of the gauge is permanently fixed in the block in such a way that the top of the casing is about 30 cm above natural surface level. While fixing the base of the gauge precaution is taken to level it perfectly. The rain-gauging station is protected by barbed wire fencing with a gate. The size of the concrete foundation block should be 60 cm x 60 cm.

The necessity to keep the rim of the funnel above the natural surface by 30 cm is twofold:

(i) It prevents splashing of water into the funnel almost to a negligible amount.

(ii) If the height is kept more than 30 cm the amount of rain water collected decreases owing to wind eddies set up by the gauge itself.

Working:

The gauge is adjusted every day for measurement of rainfall. When rainfall occurs the rainwater covering area of the funnel passes to the receiver before any sort of loss takes place. After every 24 hours the rainfall is measured. Usually the measurement is taken at 0830 hr. I.S.T. The received water is poured carefully in the measuring jar to measure daily rainfall. If it is raining at the time of observation, it is necessary to do the measurements very quickly.

If found essential spare receiver may be placed immediately in the body after previous receiver is taken out. The total amount of rainfall measured during the previous 24 hours should invariably be entered against the date of measurement irrespective of the fact whether the rainfall was received on the date of measurement or on the previous date after yesterday's measurement.

Totaliser:

Sometimes unavoidably rain-gauge is to be installed at such a location which is not easily accessible in un-favourable climate. Then it is not possible to measure the rainfall every day at 0830 hr. I.S.T. In such cases a different type of non- recording gauge is used. It is called totaliser. It is in the form of a can.

To accommodate 1220 mm of rain upper and lower diameter of the can is kept 203 mm and 610 mm respectively. Since, the observer goes at a longer interval it is essential to provide some arrangement to

minimise evaporation loss. Generally a wind screen is mounted on the can to stop evaporation loss. Sometimes a thin layer of oil is also kept floating at the water surface in the can to reduce evaporation loss.

2. Recording Type Rain-Gauge:

The recording gauge consists of a funnel 127 mm in diameter fixed on one side of a rectangular box. It is called receiver also. In the rectangular box a float is adjusted. The float is connected by means of a float rod to a pin point (or a recording pen). The pin point touches a graph paper mounted on a rotating drum.

The drum is mounted on the top of the receiver on the other side. A clockwork arrangement revolves the drum once in 24 hours. At the bottom the box is connected to a siphon. The siphon comes into action and releases the water as soon as box is filled to a certain level. Figure 2.5 shows complete arrangement; it is called natural siphon type recording rain-gauge.

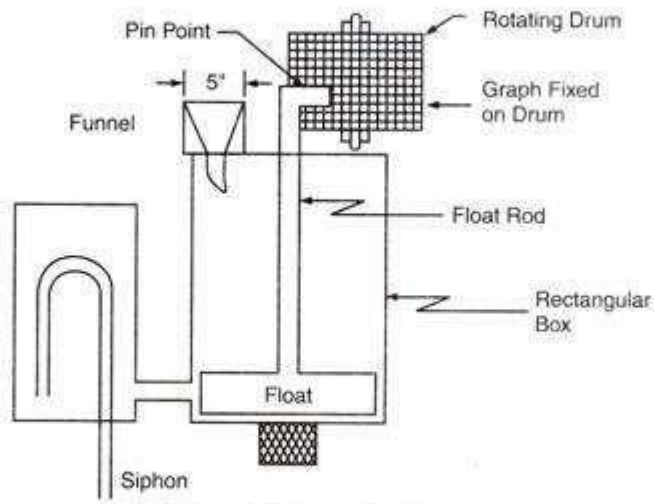


Fig. 2.5. Recording type rain-gauge

As the rainfall starts rain water passes through the funnel into the box. As the water level in the box rises the float is also raised. In turn the pin point moves on the graph to plot a mass curve of rainfall. When the box is filled to such an extent that the float touches the top, the siphon starts working and the rainwater collected in the box is drained out.

Mass Curve Principle of Integrating Rain-Gauge:

The recording type rain-gauge is also called integrating rain-gauge. The reason is that the curve obtained on the graph is a cumulative curve in respect of rainfall. On y-axis we get accumulated or integrated rainfall and on x-axis we have equal time increment. This type of curve in which one ordinate gives accumulated values is called a mass curve. On the graph mounted on the rotating drum we get the mass curve of rainfall (Fig. 2.6).

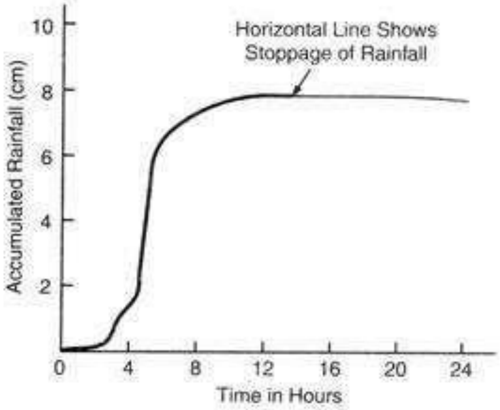


Fig. 2.6. Mass curve of rainfall

Tipping Bucket Type Rain-Gauge for Remote Recording:

To facilitate remote recording of rainfall a new type of rain-gauge is used. It is called tipping bucket type rain-gauge. In this type a pair of tipping buckets is placed below a funnel. The bucket gets filled up by 0.25 mm of rainfall and immediately it tips and empties the water into a chamber below. At that very instant other bucket comes below the funnel to receive rainwater. The tipping of the bucket actuates an electrical circuit which moves a pointer to register the rainfall on a graph. The water collected in the chamber below could also be measured by a measuring jar.

<u>Estimating missing rainfall data:</u>

1. **Arithmetic Mean Method**
2. **Normal Ratio Method**

1. Simple Arithmetic Mean Method

According to the arithmetic mean method the missing precipitation 'Px' is given as:

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

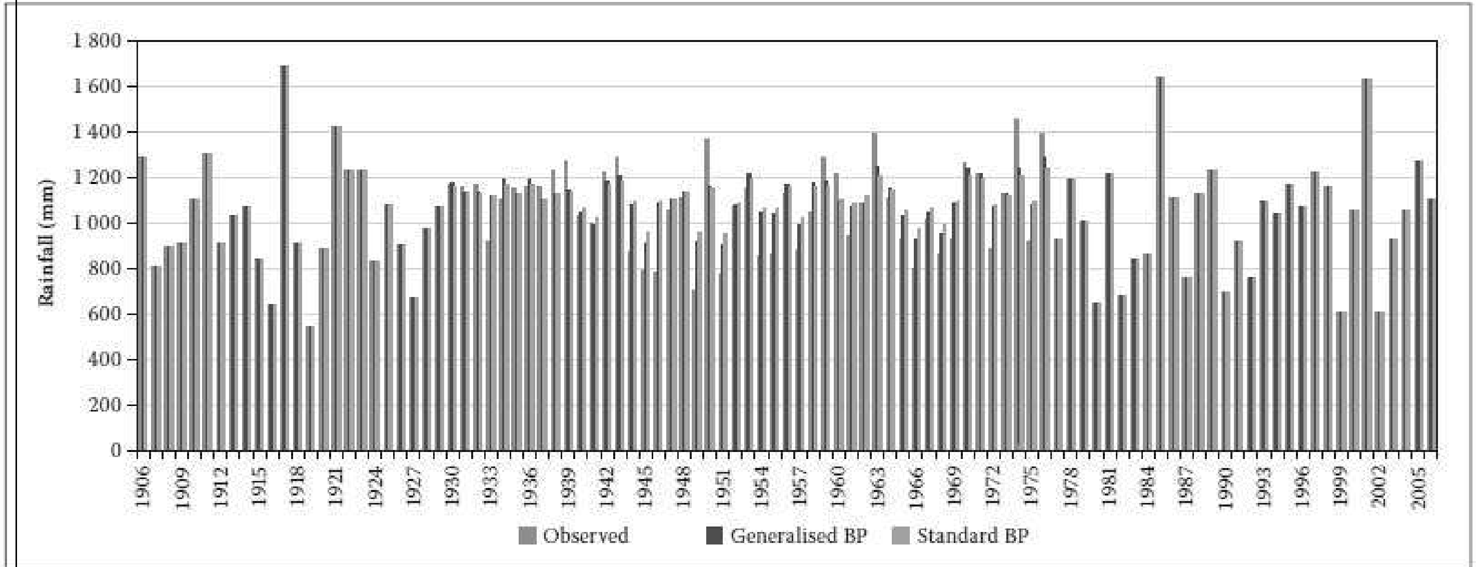


Figure 9 Annual rainfall totals at 0079490 (45% missing data from 1930)

Where 'n' is the number of nearby stations, 'Pi' is precipitation at ith station and 'Px' is missing precipitation.

In case of three stations 1, 2 and 3,

Px = (P1 + P2 + P3)/3

Naming stations as A, B and C instead of 1, 2 and 3

Px = (Pa + Pb + Pc)/3

Where Pa ,Pb and Pc are defined above.

2. Normal Ratio Method

According to the normal ratio method the missing precipitation is given as:

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

Where Px is the missing precipitation for any storm at the interpolation station 'x', Pi is the precipitation for the same period for the same storm at the "ith" station of a group of index stations, Nx the normal annual precipitation value for the 'x' station and Ni the normal annual precipitation value for 'ith' station.

For example, for the symbols defined above for three index stations in a catchment area.

$$P_x = \frac{1}{3}\left[\frac{N_x}{N_1}P_1 + \frac{N_x}{N_2}P_2 + \frac{N_x}{N_3}P_3\right]$$

If the normal annual precipitation of the index stations lies within ±10% of normal annual precipitation of interpolation station then we apply arithmetic mean method to determine the missing precipitation record otherwise the normal ratio method is used for this purpose.

Consider that record is missing from a station 'X'.

Now let

N = Normal annual precipitation. (Mean of 30 years of annual precipitation data)

P = Storm Precipitation.

Let Px be the missing precipitation for station 'X' and Nx , the normal annual precipitation of this station, Na, Nb and Nc are normal annual precipitations of nearby three stations, A, B and C respectively while Pa, Pb and Pc are the storm precipitation of that period for these stations.

Now we have to compare Nx with Na ,Nb and Nc separately. If difference of Nx - Na, Nx - Nb, Nx - Nc is within 10% of Nx then we use simple arithmetic mean method otherwise the normal ratio method is used.

<u>Rain gauge networks:</u>

Design of Rain gauge Networks

- **Rainfall data is the most important and fundamental data required for all hydrological investigations.**
- **Catch area of a rain gauge is very small compared to the aerial extent of a storm. Hence to get a representative picture of a storm over the entire drainage basin, the number of raingauges should be as large as possible (drainage area/rain gauge should be small).**
- **The rain gauge network should consist of adequate number of rain gauges evenly distributed all over the drainage basin.**
- **However the number of rain gauges is many a time restricted by economic considerations as well as topography, accessibility etc.**
- **Desired density would also depend on the purpose.**

Aim: Establish a rain gauge network with an optimum density of rain gauges from which a reasonably accurate information about storms can be obtained.

WMO recommendations on rain gauge density

Flat regions of temperate, Mediterranean and tropical zones

- **Ideal – 1 station for 600-900 sq.km.**
- **Acceptable – 1 station for 900-3000 sq.km.**

Mountainous regions of temperate, Mediterranean and tropical zones

- **Ideal – 1 station for 100-250 sq.km.**
- **Acceptable – 1 station for 250-1000 sq.km.**

Arid and polar zones

- **Ideal – 1 station for 1500-10000 sq.km. Depending on the feasibility.**

10% of rain gauge stations should be equipped with self recording rain gauges

BIS recommendations on rain gauge density

- **In plains – 1 station for every 520sq.km.**
- **In regions with average elevation 1000m – 1 station per 260-390 sq.km.**
- **In hilly areas with heavy rainfall – 1 station for every 130 sq.km.**

Adequacy of rain gauge stations

– The optimum number of rain gauge stations that should exist in order that the mean rainfall can be estimated with an assigned percentage of error is given by

$$N = \left[\frac{C_v}{\varepsilon}\right]^2$$

$N = optimal\ number\ of\ raingauge\ stations$

$\varepsilon = allowable\ degree\ of\ error\ in\ the\ estimation\ of\ mean\ rainfall$

$C_v = coefficient\ of\ variation\ of\ rainfall\ based\ on\ the\ existing\ m\ stations (in\ \%)$

If the value of ε is small, the number of rain gauge stations required will be more.

• If there are m rain gauge stations in the catchment (existing), each recording rainfall values $P_1, P_2, P_3, \ldots\ldots\ldots\ldots P_m$, in a known time, the coefficient of variation C_v is given by

$$C_v = \frac{100\,\sigma_{m-1}}{\bar{P}}$$

$$\sigma_{m-1} = \sqrt{\frac{\sum_1^m \left(P_i - \bar{P}\right)^2}{m-1}}$$ **=Standard deviation**

$P_i = precipitation\ magnitude\ at\ the\ i^{th}\ station$

$$\bar{P} = \frac{\sum_1^m P_i}{m} = mean\ precipitation$$

Index of Wetness

• **Index of Wetness =** $\dfrac{Actual\ rainfall\ in\ a\ given\ year\ at\ a\ place}{Normal\ annual\ rainfall\ at\ that\ place}$

It gives an idea of the wetness of that year and hence is a measure of the deficiency of rainfall. A 60% index of wetness means a deficiency of 40%.

- **Deficiency ~ 30-45% – Large**
- **Deficiency ~ 45-60% – Serious**
- **Deficiency ~ >60% – Disastrous**

Annual rainfall < Average Annual Rainfall – Bad (Subnormal) Year

Annual rainfall ~ Average Annual Rainfall – Normal Year

Annual rainfall > Average Annual Rainfall – Good Year

Mean depth of precipitation over a drainage area:

1. Arithmetic Mean:

When the area of the basin is less than 500 km^2 this method implies summing up of all the rainfall values from all the rain gauging stations and then dividing it by the number of stations in that basin. The method becomes very clear by the use of a tabular forra.

Table 2.3.

Rain gauging station	*Rainfall in cm*
A	5.6
B	4.9
C	5.2
D	5.5
Σ 4	Σ 21.2

$$\text{Now average depth} = \frac{\Sigma \text{ Rainfall values}}{\text{Number of stations}} = \frac{21.2}{4} = 5.3 \text{ cm.}$$

To explain, there are in all four rain-gauging stations A, B, C, D in the basin, whose rainfall values are given in the table 2.3. Sum of the rainfall values comes out to be 21.2 cm. It is divided by number of stations to give average depth of precipitation which comes out to be 5.3 cm.

This method gives accurate results if the stations are uniformly distributed over the area. There should not be much variation in the rainfall values of the stations under consideration. Drawback of this method is the

stations just outside of the basin are not considered although these stations might have some influence on the basin under consideration.

2. Theissen Polygon Method:

This method is very accurate. It is used for basins having areas between 500 – 5000 km^2. This method can be best understood with the help of Fig. 2.7.

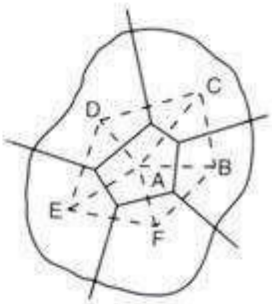


Fig. 2.7. Theissen polygon method

The firm closing line shows a basin having an area between 500 to 5000 sq km. Let there be rain-gauging stations A, B, C, D, E and F. It is assumed that each station has its own domain in the total area. While finding out the average value of rainfall it is very essential to divide the total basin area in such a way that each station enclosed in a particular area represents that area in true sense.

The domain of each rain recording gauge station can be marked as now mentioned here. Join all the stations to each of the adjacent stations by dotted line so as to form a system of triangles. Rain-gauging stations form vertices of the triangles. Then draw the perpendicular bisector of each of the sides of all the triangles. In Fig. 2.7 triangles are shown by dotted lines and perpendicular bisectors by firm lines. As a result the whole basin area is divided into number of polygons.

Remarkable thing is one polygon enclose only one rain-gauging station. Each polygon is the domain of the rain-gauging station which is enclosed in it. The justification for it can now be given. Each firm line is perpendicular bisector of the line joining two stations. So any point on this line will be equidistant form both the stations. If we go slightly this or that side of the bisector our position will distinctly fall in the domain of that station to which our position is now nearer.

Naturally perpendicular bisector will mark the boundary of the domain. As all the sides of the polygons for all the stations are perpendicular bisectors the new polygons system drawn by firm lines in Fig. 2.7 represents the domain of various stations. Thus the domain of each station can be plotted. Then the area of each domain can be found by use of a graph paper or a planimeter.

The values can now be tabulated as shown below:

Table 2.4.

Station	Rainfall in cm	Area of Polygon in sq km	Weighted depth of rainfall
1	2	3	4 = (2) × (3)
A	5.6	a	5.6 × a
B	4.9	b	4.9 × b
C	5.2	c	5.2 × c
D	5.4	d	5.4 × d
E	5.5	e	5.5 × e
F	5.2	f	5.2 × f
		Σ	Σ

To explain the procedure, column:

(i) Shows the various rain-gauging stations, column

(ii) The amount of rainfall at each station, column,

(iii) Gives area of each polygonal domain of the stations and column,

(iv) Gives weighted depth of rainfall which is obtained by multiplying values in columns 2 and 3.

Now, mean depth of rainfall = (∑ column No. 4)/(∑ column No. 3)

∑ Column number 3 = Total area of basin = a + b + c + d + e + f

Mean depth of rainfall = (5.6a + 4.9b + 5.2c + 5.4d x 5.5e + 5.2f)/(a + 6 + c + d + e+ f)

3. Iso-Hyetal Method:

As contours are lines joining points of equal height, iso-hyetes are the Knes joining the points of equal depth of precipitation. The properties of iso-hyetes are similar to that of contours.

For example:

i. Two different iso-hyetes do not cross each other;

ii. Iso-hyet of higher value shows the places which receive more rainfall;

iii. Each iso-hyet must close on itself or must go out of the area under consideration.

Iso-hyetal method is used for basins having area more than 5000 km^2

For a given basin iso-hyetes are drawn by joining the points of equal depth of precipitation as shown in Fig. 2.8. The points of equal depth of precipitation can be computed by the method of estimation from the rainfall values of rain- gauging stations.

In Fig. 2.8 dotted lines show iso-hyetes and the outer most firm line is basin boundary. The interval of iso-hyetes is 1 cm. The highest spot rainfall value in area is 9.4 cm. Now the areas between two successive iso-hytes can be found by using a graph paper or a planimeter.

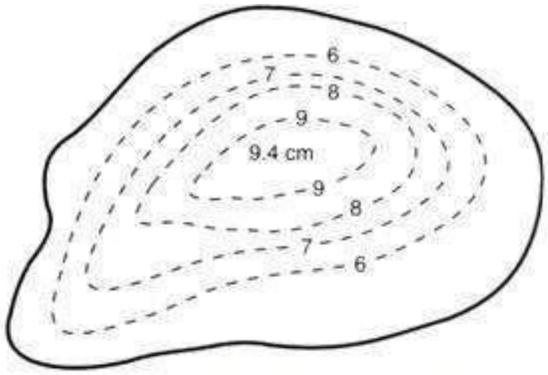


Fig. 2.8. Iso-hyetal diagram for a basin

The rest of the procedure of finding out average or mean depth of rainfall is done by tabulating the values as shown in Table 2.5.

Table 2.5.

Iso-hyetal interval	*Mean*	*Area between two successive iso-hyetes*	*Mean × area*
(1)	*(2)*	*(3)*	*(4) = (2) × (3)*
9.4 – 9	9.2	a	$9.2 \times a$
9 – 8	8.5	b	$8.5 \times b$
8 – 7	7.5	c	$7.5 \times c$
7 – 6	6.5	d	$6.5 \times d$
6 – boundary	5.5	e	$5.5 \times e$
		Σ	Σ

To explain, column (1) shows the iso-hyetal interval of successive iso-hyetes, column (2) gives the average of the two extreme values of interval, column (3) gives the area enclosed between two successive iso-hyetes and column (4) shows mean of interval multiplied by the area of interval.

Now, Mean depth of rainfall = ∑ column No. 4/∑ column No. 3

∑ Column number 3 = Total area of basin = a + b + c + d + e

Mean depth of rainfall = (9.2a+ 8.5b +7.5c + 6.5d x 5.5e)/a + b+ c + d + e

<u>Mass rainfall curves:</u>

• It is a plot of accumulated precipitation against time, plotted in chronological order.

- **Records of float type, weighing bucket type etc raingauges are of this form.**

- **It gives information on duration and magnitude of a storm.Intensity at various time intervals in a storm = slope of the curve.**

- **It can be prepared for non-recording raingauges also if the approximate start and end of a storm are known.**

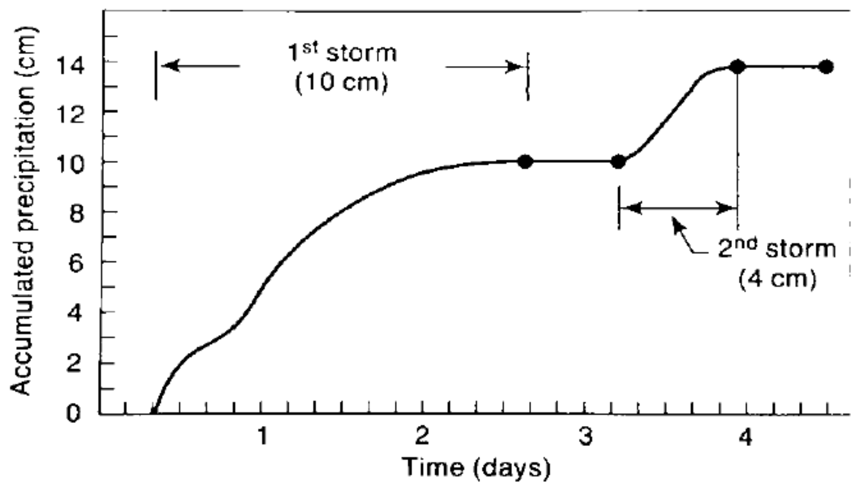
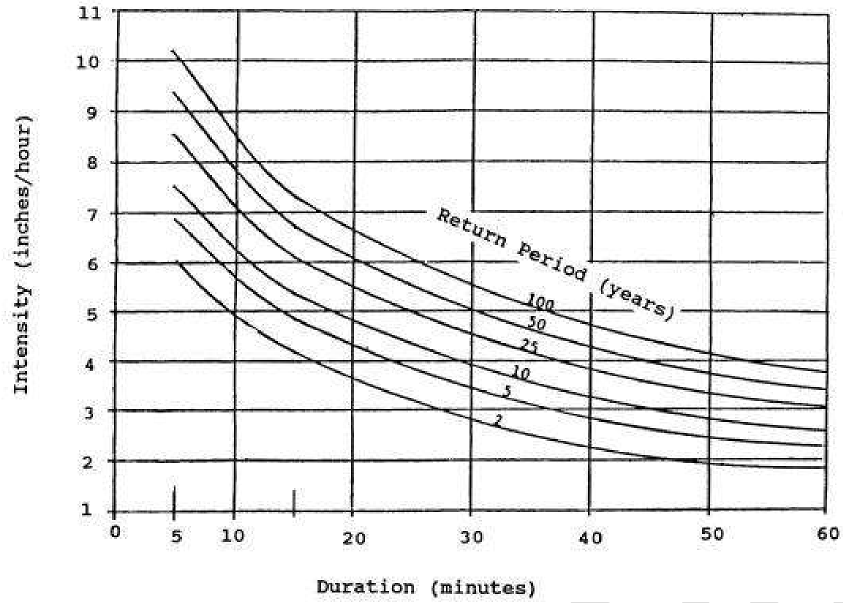


Fig.3 ***Mass Curve of Rainfall***

<u>Intensity-duration curves:</u>

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



Depth-area duration curves:

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

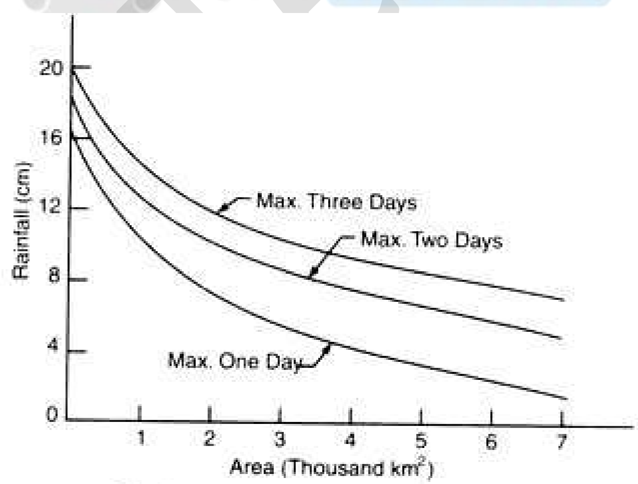


Fig. 2.12. Depth-area-duration curves

Infiltration and infiltration indices:

Infiltration is the process by which water on the ground surface enters the soil. *Infiltration rate* in soil science is a measure of the rate at which soil is able to absorb rainfall or irrigation. It is measured in inches per hour or millimeters per hour. The rate decreases as the soil becomes saturated. If the precipitation rate exceeds the infiltration rate, runoff will usually occur unless there is some physical barrier. It is related to the saturated hydraulic conductivity of the near-surface soil. The rate of infiltration can be measured using an infiltrometer.

Various infiltration indices give rates of infiltration in different ways to help assessment of the water lost by way of infiltration.

The important among them are the following:

(i) Infiltration Capacity:

It is the maximum rate at which water can enter through the soil surface at a particular point of time under the given set of conditions. By now it is clear that actual rate of infiltration will be less than infiltration capacity unless the net rainfall rate that reaches the ground after fulfilling retention (i.e., interception + depression storage) is equal or more than infiltration capacity. The infiltration capacity goes on reducing as the soil profile becomes saturated. Like infiltration the infiltration capacity also depends on soil type, moisture content, organic matter present in the soil, vegetal cover and season.

Horton gave the following mathematical expression to find out the value of infiltration capacity at any time:

$f_p = f_c + (f_o - f_c)\, e^{-Kt}$

Where f_p is infiltration capacity.

f_o is infiltration rate at the beginning of storm.

f_c is constant infiltration rate which is achieved after the soil profile becomes saturated.

e is base of natural logarithms (Napierian base).

t is time from beginning of rainfall and K is a constant. It may be remembered that this equation can be applied only when rate of net rainfall reaching the surface is more than infiltration capacity throughout the storm rainfall.

(ii) ϕ Index:

The ϕ index is that portion of average rate of rainfall during any storm which gets lost by the processes of interception, depression storage and infiltration taken together. It can, therefore, be defined as that rate of average rainfall during any storm beyond which the volume of remaining rainfall equals the volume of direct surface runoff. The index can be calculated from a hyetograph (time versus intensity of rainfall graph) of the storm in such a way that the rainfall volume in excess of this rate will equal the volume of the storm runoff Fig. 3.2.

If the rainfall intensity throughout the storm remains equal to or more than ϕ index then the ϕ index represents basin recharge because ϕ index represents sum total of infiltration, interception and depression storage.

(iii) W Index:

This index gives the average rate of infiltration for that time period of the storm rainfall during which rainfall intensity is greater than W. Thus it can be said to be refinement over ϕ index which apart from infiltration also includes interception and depression storage.

The W index can be obtained from the following equation:

W = P-Q-S/t

Where

W is average rate of infiltration

P is total storm rainfall corresponding to t

Q is total storm run-off.

t is time during which rainfall intensity is more than W and

S is effective surface retention.

W = ϕ average rate of retention

Where retention includes interception and depression storage.

For all practical purposes ϕ index can be taken to represent average rate of infiltration. Since ϕ and indices assume average rate of infiltration which in fact is less than initial infiltration rate and more than ultimate infiltration rate their utility is limited to major flood producing storms.

Such storms generally occur on wet soil and storms are of such intensity and duration that the infiltration rate could be very nearly taken to be constant for whole storm or majority period of storm. Obviously for short isolated storms ϕ and W indices are not useful.

<u>Evaporation stream gauging:</u>

Evaporation and its Measurement

Evaporation is a cooling process in which the latent heat of evaporation of about 585 cal/gm is provided by the water body. in this process liquid changes into gaseoues phase at free surface, below the boiling point through the transfer of heat energy.

Dalton's Law

The rate of evaporation is proportional to the difference between the stauration vapour pressure at the water temperature, e_s and the actual vapour pressure in the air e_a thus

$E = K(e_s - e_a)$

Where, E = Rate if evaporation (mm/day)

e_s = Saturation vapour pressure of air (mm)

e_a = Actual vapour pressure of air (mm)

e_s-e_a Saturation difficiency

Measurement of Evaporation

i. **ISI standered pan**
Lake avaporation = C_p × panevaporation
Where, C_p pan coeffcient
= 0.8 for ISI pan
= 0.7 for class A-Pan

ii. **Empirical Evaporation Equatons (Meyer's Formula)**

$$E = k_m(e_s - e_a)\left[1 + \frac{V_9}{16}\right]$$

Where, k_m = Coeffcients which accounts for size of water body.
= 0.36 (for large deep water)
$\simeq$ 0.50 (for small and shallow waters)
e_s = Saturation vapour pressure of air in mm of Hg.
e_a = Actual vapour pressure of overlying air in mm at Hg at specified height of 8 m.
V_9 = monthly mean wind velocity in km/hr at about 9 m above the ground level.

1/7th power Law

$$\frac{V_1}{V_2} = \left(\frac{H_1}{H_2}\right)^{1/7}$$

Where, V_1 is the wind velocity at height H_1 and V_2 is the wind velocity at height H_2.

Water Budget Method

This is simplest method bit it is least reliable it is used for rough calculation, it is based on mass conversation principle.

$P + V_{is} + V_{ig} + V_{og} + E + \Delta S + T_L$

Where, P=Daily precipitation on the water surface.

V_{is} = Daily surface inflow into take.

V_{os} = Daily surface outflow from lake.

V_{ig} = Daily underground inflow into the lake.

V_{og} = Daily underground outflow from the lake.

E = Daily Evaporation

ΔS = change in storage of lake

= +ve if increase in storage

= -ve if decrease in storage

T_L = Daily transpiration loss from the plants on the lake.

Energy Budget Method

The energy budget method is an application of the law of conservation of energy. The energy available for evaporation is determined by considering the incoming energy. Outgoing energy and energy stored in the water body over a known time interval.

$$E = \frac{H_n - H_g - H_s - H_i}{\delta \cdot L(1+\beta)}$$

Where, H_n = Net heat energy received by the water surface

$H_n = H_c(1-r)-H_b$

$H_c(1-r)$ = incoming solar radiation into a surface of reflection coefficient, r

H_b = Back radiation from water body

H_g = Heat flux into the ground

H_S = Heat stored in water body

H_i = Net heat conducted out the system by water flow (advected energy)

β = Bowen's ratio

δ = Density of water

L = Latent heat of evaporation.

Evapo-Transpiration:

While transpiration takes place, the land are in which plants stand also lose moisture by the evaporation of water from soil and water bodies. In hydrology and irrigation practice, it is found that evaporation and transpiration processes can be considered advantageously under one head as evapo-transpiration.

The real evapo-transpiration occurring in a specific situation is called actual evapo-transpiration (AET).

- **Penman's Method**

Penman's equation is based on sound theoretical reasoning and is obtained by a combination of the energy balance and mass transfer approach.

$$PET = \frac{AH_n + E_a\gamma}{A+\gamma}$$

Where, PET = daily evaporation in mm/day.

A = slope of the saturation vapour pressure v/s temperature curve at the mean air temperature in mm of Hg per °C.

H_n = Net radiation in mm of evaporable water per day

E_a = Parameter including wind velocity and saturation deficit.

γ = Psychometric constant

= 0.49 mm of Hg/°C

It is based on mass transfer and energy balance.

Transpiration Loss (T)

$T = (w_1+w_2)-w_2$

Where, w_1 = Initial weight of the instrument

W = Total weight of water added for full growth of plant.

w_2 = Final weight of instruction including plant and water

T = Transpiration loss.

Run off and its estimation:

Surface runoff (also known as overland flow) is the flow of water that occurs when excess storm water, melt water, or other sources flows over the Earth's surface. This might occur because soil is saturated to full capacity, because rain arrives more quickly than soil can absorb it, or because impervious areas (roofs and pavement) send their runoff to surrounding soil that cannot absorb all of it. Surface runoff is a major component of the water cycle. It is the primary agent in soil erosion by water.

Theoretical Estimates of Flow:

A great deal of research has been undertaken to develop hydrological models that can predict runoff peak flows and volumes. The majority, however, are not suited to general use. Sometimes they are too complex but most frequently they are limited by the geographical localities and hydrological conditions within which the data were collected. Many models are regression models and their value is difficult to assess outside their own particular circumstances.

Presented here are five models that can be used to predict peak flows and three models that are suitable to estimate runoff volumes. They are suitable for use with a wide range of catchment sizes and conditions. These methods of estimation have certain drawbacks: they can be relatively inaccurate because they make simplifying assumptions. They demand the availability of some primary data such as catchment physical

characteristics and rainfall. However, they have been used for some time in a variety of environments with success and are based on measurements from a great number of catchments, with a wide range of physical characteristics.

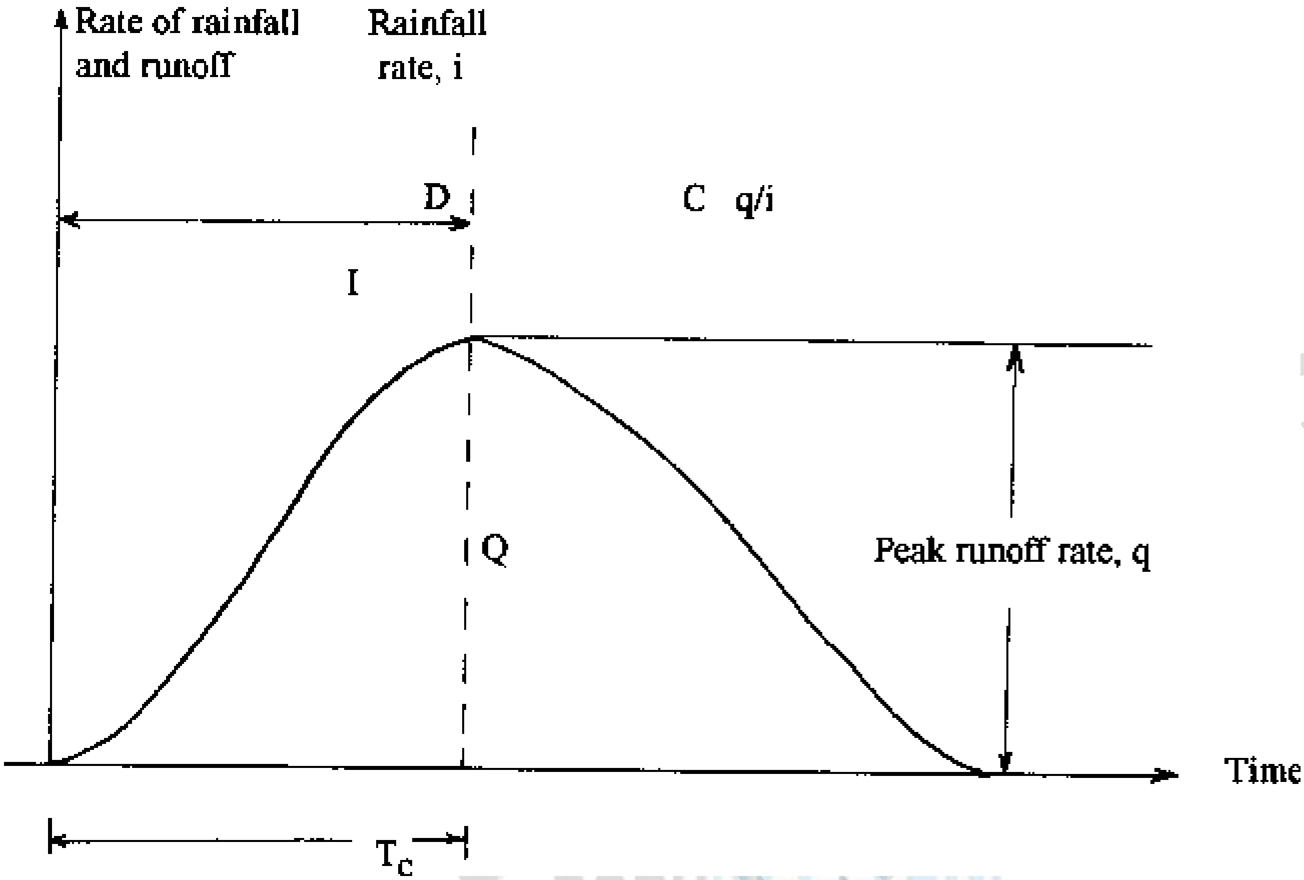
Peak Flows

Peak flows determine the design specifications of structures such as bunds, channels, bridges and dams. Peak flows also determine the capacity of the control sections of flow-through measurement systems and the collection pipes and transfer conduits of volumetric collection vessels. Some estimate of peak flows must be made before the design of these systems can be completed.

Design peak flows are linked to particular return periods, such as the maximum flow in 5, 10, 25, etc. years and design specifications are a balance between economic cost and the prevention of failure of the structure. Where no serious damage will result, for example on field bunds, a low return period (say 5 or 10 years) can be used. The 10 year return period is commonly used for agricultural purposes. Where serious damage or the loss of life is involved, then designs for large return periods, perhaps 50 or 100 years, are necessary. The return period most appropriate to the objectives of the project should be decided upon.

a. Rational Method

The Rational Method which estimates peak flows, is a simplified representation of the complicated process whereby rainfall amount and intensity, catchment conditions and size as well as human activity, determine runoff amount, but it is suitable where the consequences of the failure of structures are limited. The method is usually restricted to small watersheds of less than 800 ha and is based on the rainfall/runoff assumptions of the hydrograph below.



Hydrographic Basis of the Rational Method:

The equation to calculate peak flows is:

$q = 0.0028\ C i_r A$ where (2.1)

q = peak flow in $m^3\ s^{-1}$

C = the runoff coefficient

i_r = maximum rainfall intensity in mm h-1 for the desired return period and the "time of concentration" of the catchment, T_c.

A = area of the watershed in hectares (1 ha = 10,000 m²)

The rainfall intensity is assumed to be uniform for the period and over the whole catchment for a time at least as great as the time of concentration of runoff, (T_c).

Values of Coefficient C

<u>Hydrograph analysis:</u>

- **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**

<u>Unit hydrograph and its derivation from isolated and complex storms:</u>

1. A number of isolated storm hydrographs caused by short spells of rainfall excess, each of approximately the same duration (0.9 to 1.1D h) are selected from a study of continuously gauged runoff of the stream

2. For each of these surface runoff hydrographs, the base flow is separated

3. The area under DRH is evaluated and the volume of direct runoff obtained is divided by the catchment area to obtain the depth of ER

4. The ordinates of the various DRHs are divided by the respective ER values to obtain the ordinates of the unit hydrograph

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

1. The storms should be isolated storms occurring individually

2. The rainfall should be fairly uniform during the duration and should cover the entire catchment area

3. The duration of rainfall should be 1/5 to 1/3 of the basin lag

4. The rainfall excess of the selected storm should be high (A range of ER values of 1.0 to 4.0 cm is preferred)

• A number of unit hydrographs of a given duration are derived as mentioned above and then plotted

• Because of spatial and temporal variations in rainfall and due to deviations of the storms from the assumptions in the unit hydrograph theory, the various unit hydrographs developed will not be exactly identical

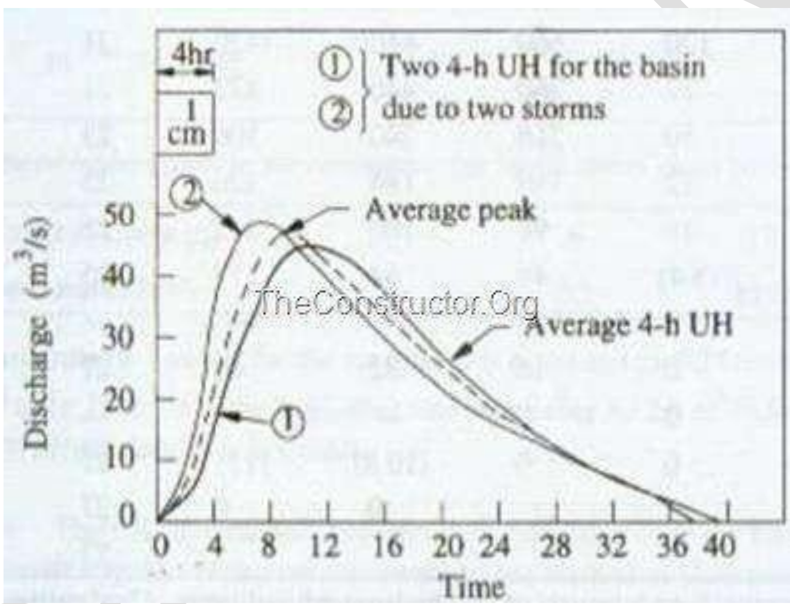
• In general, the mean of these curves is adopted as the unit hydrograph of the given duration for the catchment

• The average of the peak flows and the time to peaks are computed first

• Then a mean curve of best fit (by eye judgment) is drawn through the averaged peak to close on an averaged base length

• The volume of the DRH is determined and any departure from unity is corrected by adjusting the peak value

• Note – It is customary to draw the averaged ERH of unit depth in the plot of the unit hydrograph to indicate the type and duration of rainfall creating the unit hydrograph.



• It is assumed that the rainfall excess occurs uniformly over the catchment during the duration D hours of a unit hydrograph

• An ideal duration for a unit hydrograph is one in which small fluctuations in rainfall intensity does not have any significant effect on the runoff

• The duration of the unit hydrograph should not exceed 1/5 to 1/3 of the basin lag

• In general, for catchments larger than 250sq.km. 6 hour duration is satisfactory.

Unit Hydrograph from a Complex Storm

• When suitable simple isolated storms are not available, data from complex storms of long duration will have to be used to derive the unit hydrograph

• **The problem is to decompose a measured composite flood hydrograph into its component DRHs and base flow**

• **A common unit hydrograph of appropriate duration is assumed to exist**

• **This is the inverse problem of derivation of the flood hydrograph**

• **Consider a rainfall excess made up of three consecutive durations of D hours and ER values of** R_1, R_2 and R_3.

• **After base flow separation of the resulting composite flood hydrograph, a composite DRH is obtained. Let the ordinates of the composite DRH be drawn at a time interval of D hours.**

• **At various time intervals 1D, 2D, 3D, from the start of the ERH let the ordinates of unit hydrograph be** $u_1, u_2, u_3, \ldots$ **and the ordinates of the composite DRH be** $Q_1, Q_2, Q_3 \ldots$

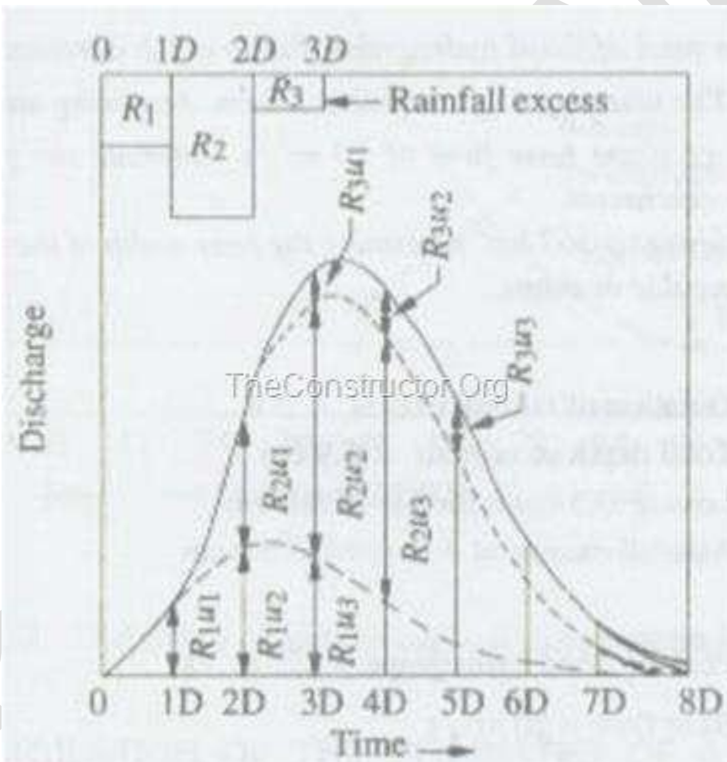


Figure: Unit hydrograph from a complex storm

Then

$Q_1 = R_1u_1$

$Q_2 = R_1u_2+R_2u_1$

$Q_3 = R_1u_3+R_2u_2+R_3u_1$

$Q_4 = R_1u_4+R_2u_3+R_3u_2$

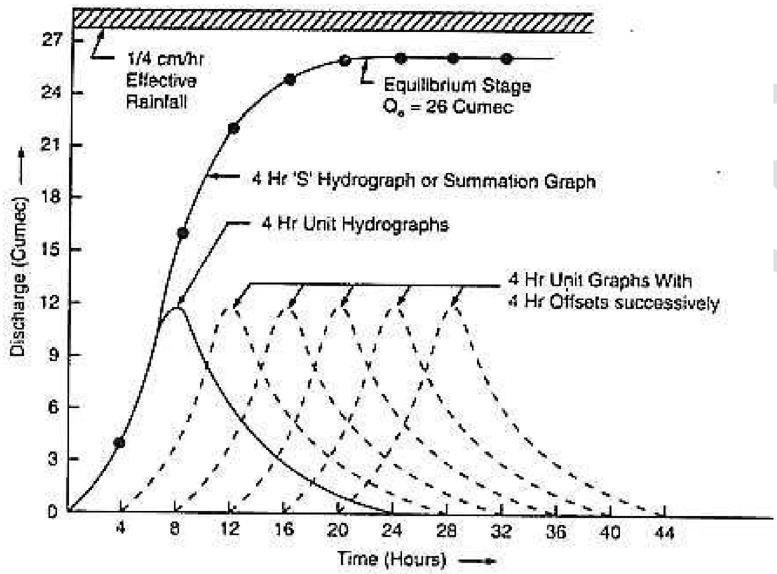
$Q_5 = R_1u_5+R_2u_4+R_3u_3+$.................. and so on

• **The values of** $u_1, u_2, u_3, \ldots$ **can be determined from the above**

• Disadvantage of this method – Errors propagate and increase as computation proceeds

S-curve hydrograph:

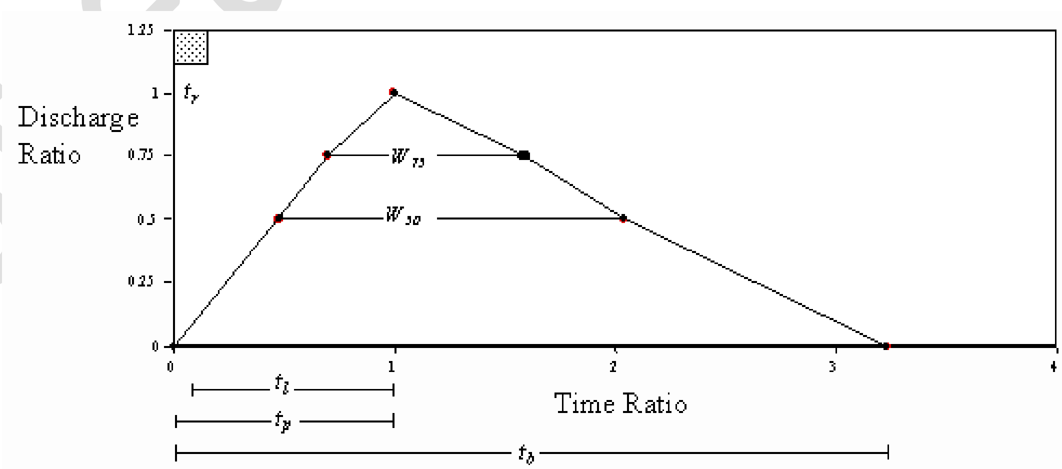
A 'S' hydrograph is nothing but a hydrograph generated by a continuous effective rainfall occurring at an uniform rate for an indefinite period. It is called 'S' hydrograph because the shape of the hydrograph comes out like alphabet 'S' though slightly deformed.



Synthetic Unit hydrograph:

A synthetic unit hydrograph retains all the features of the unit hydrograph, but does not require rainfall-runoff data. A synthetic unit hydrograph is derived from theory and experience, and its purpose is to simulate basin diffusion by estimating the basin lag based on a certain formula or procedure.

The first synthetic unit hydrograph was developed by Snyder in 1938.[1] In order to provide sufficient flexibility for simulating a wide range of diffusion amounts, Snyder devised two parameters: (1) a time parameter C_t, and (2) a peak parameter C_p. A larger C_t meant a greater basin lag and, consequently, greater diffusion. A larger C_p meant a greater peak flow and, consequently, less diffusion.



Unit - IV

Canals and Structures: Types of canals, alignment, design of unlined and lined canals, Kennedy's and Lacey's silt theories, typical canal sections, canal losses, lining-objectives, materials used, economics. Introductions to Hydraulic Structures viz.Dams,Spillways,Weirs ,Barrages,Canal Regulation Structures.

Types of canals:

There are different types of canals some of them listed below

Alumina & non-alumina canals

Permanent & inundation canals

Productive & protective canals

Lined & unlined canals

Classification based on discharge:

Main canal

Branch canal

Major distributaries canal

Minor distributaries canal

Water course or field channel

Classification of canals based on their alignment:

Contour canal

Watershed canal

Side slope canal

Detour canal

Canal Alignment:

Canal Alignment should be done in such a way that

1. **It should serve the entire area proposed to be irrigated.**
2. **Cost of construction including cross drainage works should be minimized.**
3. **A shorter length of canal ensures less loss of head due to friction and smaller loss of discharge due to seepage and evaporation, so that additional area may be brought under cultivation.**
4. **A canal may be aligned as a contour canal, a side slope canal or a ridge canal according to the type of terrain and culturable area.**
5. **A contour canal irrigates areas only on one side of the canal.**

6. **Where canal crosses valleys, different types of cross drainage works are required.**
7. **A side slope canal is aligned at 90 degree to the contours of the region.**
8. **A watershed or ridge canal irrigates areas on both sides.**
9. **Cross drainage works are eliminated in case of ridge and side slope.**
10. **Main canal is generally carried on a contour alignment.**
11. **Branch and distributaries take off from a canal from or near the points where the canal crosses the watershed.**
12. **There should be Consideration of economy in alignment of contour canals.**
13. **All possible alignments should be studied and the best suited alignment should be selected.**
14. **Number of rinks and acute curves should be minimized.**
15. **They should be aligned as far as possible in partial cutting partial filling.**
16. **Deep cutting should be avoided by comparing the overall cost of alternative alignments.**
17. **A canal section is economical if there is equal amount of cut and fill.**

<u>Design of unlined and lined canals:</u>

Lined:

For triangular section, the following expressions may be derived

$A = D2\ (+\cot\ )$

$P = 2\ D\ (+\cot\ )$

$R = D / 2$

The above expressions for cross sectional area (A), wetted perimeter (P) and hydraulic radius (R) for a triangular section may be verified by the reader.

For the Trapezoidal channel section, the corresponding expressions are:

$A = B\ D + D2\ (+\cot\ )$

$P = B + 2\ D\ (+\cot\ )$

$R = A / P$

Unlined:

Unlined alluvial canals in clear water

The particle A would get dislodged when the shear stress, τ, is just able to overcome the frictional resistance. This critical value of shear stress is designated as C τ may be related to the weight of the particle, W, as τ bC = W tan ϕ (8)

For the particle B, a smaller shear stress is likely to get it dislodged, since it is an inclined plane. In fact, the resultant of its weight component down the plane, W Sin , and the shear stress (designated as ′ C τ) would together cause the particle to move. Hence, in this case,

$(\tau\ cs)^2+(W\sin^2\theta)= [W\cos\theta]\tan\phi$ (9)

In the above expression it must be noted, that the normal reaction on the plane for the particle B is W Cos θ. Eliminating the weight of the particles, W, from equations (8) and (9), one obtains,

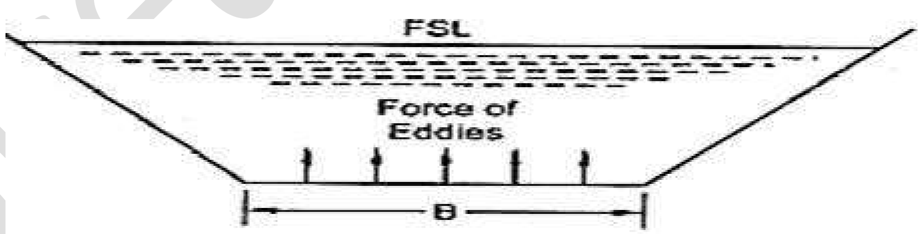
<u>Kennedy's and Lacey's silt theories:</u>

Introduction to Kennedy's Silt Theory

Any canal has to draw the fair share of silt when it is off taking from another canal. The silt either may be deposited or kept in suspension. If the silt is deposited in the canal the water carrying capacity is reduced. If the velocity is more there may be a chance of scouring. The velocity should be just sufficient to keep the silt in suspension without scouring. Based on this Mr. R.G. Kennedy made the investigations on earthen channels and developed the silt theory to overcome this problem.

Kennedy's theory

1. The flowing water has to be counter act some amount of friction against the bed of the channel. By the result of that eddies are formed. These eddies are responsible to keep the silt in suspension without scouring.



(a) According to Kennedy

2. Kennedy define the critical velocity which is the mean velocity which will just keep the channel without silting and scouring.

3. Kennedy gave the equation for the determination of critical velocity

Where V_o = Critical velocity

D = Depth of channel

C & n = Constants

He found the values of C & n are <u>0.55</u> and <u>0.64</u>

Therefore $V_o = 0.55.D^{0.64}$

4. Initially Kennedy assumed that the type of silt as Sandy silt. He realized that different types and grades of silt are available and finally he introduced the factor "m" which is the critical velocity ratio and is defined as the ratio of mean velocity to critical velocity.

Therefore $m = V/V_o$

So $V = m.V_o$

$V = m.0.55.D^{0.64}$

5. He also used the kutter's equation for the determination of mean velocity.

$$V = \frac{\frac{1}{N}+(23+\frac{0.00155}{s})}{1+(23+\frac{0.00155}{s})\frac{N}{\sqrt{R}}}\ .\sqrt{RS}$$

For the Design of Channel Kennedy's theory can be used in two different cases:

Case 1:

When discharge (Q), rugosity coefficient (N), Critical velocity ration (m) and bed slope of the channel (s) are given,

1. Assume a trail value of Depth of channel (D) in meters. Then find the mean velocity by using Kennedy's formula. $V = m.0.55.D^{0.64}$

2. By using continuity equation Q= AV find the area of cross section.

3. Assume the shape of channel section with side slopes and find out the value of base width of channel (B).

4. Then find the perimeter of the channel (P). Which helps to find out the hydraulic mean depth of channel (R). R = A/P

5. Finally by using kutter's formula find the mean velocity (V)

Both the values of V (Kennedy) and V (Kutter's) must be same. Otherwise repeat the above procedure by assuming another value of D.

Case 2:

When discharge (Q), rugosity coefficient (N), Critical velocity ration (m) and B/D ratio are given.

1. Assume B/D = X

2. By using the Kennedy's equation find "V" in terms of D.

3. Find the area of cross section of the channel in terms of D^2.

4. By using continuity equation Q=AV, find the value of D. and then Find the base width (B).

5. Find hydraulic mean depth (R)

6. Finally find the value of "V" by Kennedy's formula. $V = m.0.55.D^{0.64}$

7. Substitute the value of V (Kennedy) in the kutter's equation will gives the longitudinal slope of the channel (S). This case will be done by trial and error method.

Concept of Lacey's silt theory:

Taking lead from the Kennedy theory Mr. Gerald Lacey undertook detailed study to evolve more scientific method of designing irrigation channels on alluvial soils. He presented revised version of his study in 1939 which is popularly known as Lacey's theory. In this theory, Lacey described in detail concept of regime conditions and rugosity coefficient. The definitions of these terms are already given.

It may be seen that for a channel to achieve regime condition following three conditions have to be fulfilled:

i. Channel should flow uniformly in "incoherent unlimited alluvium" of same character as that transported by the water;

ii. Silt grade and silt charge should be constant; and

iii. Discharge should be constant.

These conditions are very rarely achieved and are very difficult to maintain in practice. Hence according to Lacey's conception regime conditions may be subdivided as initial and final. The definitions of these two terms are already given earlier.

In rivers achievement of initial or final regime is practically impossible. Only in bank full stage or high floods the river may be considered to achieve temporary or quasi-regime. The recognition of this fact can be utilised to deal with the issues concerning scour and floods.

Lacey also a state that the silt is kept in suspension solely by force of eddies. But Lacey adds that eddies are not generated on the bed only but at all points on the wetted perimeter. The force of eddies may be taken normal to the sides,

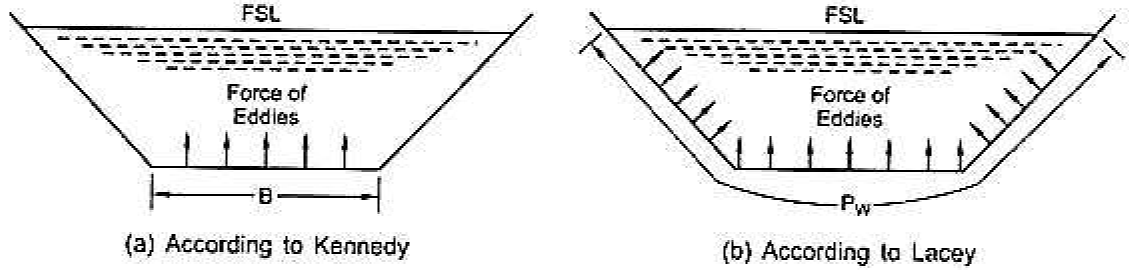


Fig. 9.2. Lacey's theory

Obviously the vertical components of forces due to eddies are responsible for keeping the silt in suspension. Unlike Kennedy, Lacey takes hydraulic mean radius (R) as a variable rather than depth (D). So far as wide channels are concerned there is hardly any difference between R and D. When the channel section is semi-circular there is no base width and sides actually and hence assumption of ii as a variable seems to be more logical. From this point of view velocity is no more dependent on D but, rather depends on R. Consequently amount of silt transported IS not dependent on the base width of a channel only.

On the basis of arguments Lacey plotted a graph between regime velocity (V) and hydraulic mean radius (R) and gave the relationship.

$V = K.R^{1/2}$…(1)

Where K is a constant.

It can be seen here that power of R is a fixed number and needs no alteration to suit different conditions.

Lacey recognised the importance of silt grade in the problem and introduced a concept of function 'f' known as silt factor.

He adjusted the values of such that it also came under square root sign. Thus it gave scalar conception. Equation (1) is thus modified as

$V = K. \sqrt{f.R}$… (2)

Kennedy's general equation is

$V = c.m.D^n$ …… (3)

Comparing equations (2) and (3)

$f = m^2$

It can also be recognized from equation (2) that in regime channels if the mean velocity is same then hydraulic mean radius varies inversely with the silt factor. Lacey takes silt as a standard silt when silt factor is unity for that silt. He further states that standard silt is sandy silt in a regime channel with hydraulic mean radius equal to one metre.

Lacey's Regime Equations:

After study and plotting of large data to justify his theory Lacey gave three fundamental ^ equations from which other equations have been derived for design of irrigation channels.

The three fundamental equations are:

$V = 0.639 \sqrt{fR}$

Where V is regime velocity in m/sec.

$Af^2 = 141.2\ V^5$…… (2)

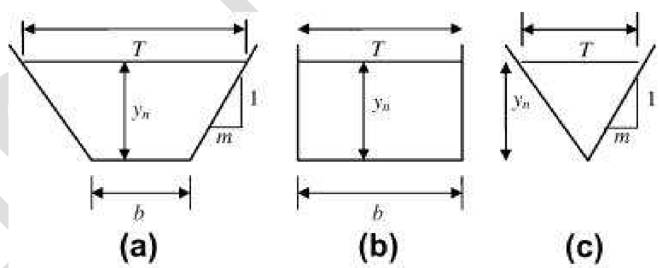
$V = 10.8\ R^{2/3}\ S^{1/3}$ …..(3)

Where S is the slope of water surface.

Equation (3) is called regime flow equation and is of great practical importance. It may be seen that the equation does not contain the term of rugosity coefficient. While adopting similar equations like Manning's or Kutter's equation it is necessary to know the value of coefficient of rugosity (AO, the selection of which most of the time remains a matter of experience and many not be reliable especially in case of rivers in floods. Considering that at high flood river flows in quasi-regime the regime flow equation (3) given above can be adopted though it may have some exceptions.

<u>Typical canal sections:</u>

a) **Trapezoidal section**
b) **Rectangular section**
c) **Triangular section**



<u>Canal losses:</u>

Loss Due to Evaporation:

As canal water is exposed to the atmosphere at the surface, loss due to evaporation is obvious. It is of course true that in most of the cases evaporation loss is not significant. It may range from 0.25 to 1% of the total canal discharge.

The rate of loss of water in the process of evaporation depends mainly on the following factors:

i. Temperature of the region,

ii. Prevailing wind velocity of the region,

iii. Humidity,

iv. Area of water surface exposed to the atmosphere.

Generally it is considered that the rate of evaporation loss depends mainly on temperature. It is not hundred per cent correct. The rate of loss also equally depends on the velocity of wind which carries vapour from the water surface to the atmosphere. Loss due to evaporation is more for shallow water depths. Many times it is observed that due to above mentioned factors the rate of loss due to evaporation does not differ much for day and night periods.

Thus it can be inferred that the loss due to evaporation is directly dependent on the climatic conditions of the region and hence cannot be checked. It also depends directly on the exposed area of the water surface and inversely on the depth of water in the channel.

Loss Due to Seepage:

The water lost in seepage may find its way finally into the river valley on enters an aquifer where it can be utilized again. But many times the seepage water is not recoverable.

The loss due to seepage is the one which is most significant so far as irrigation water loss from a canal is concerned.

The seepage loss depends mainly on the following factors:

i. Underground water table conditions,

ii. Porosity of the soil,

iii. Physical properties of the canal water for example its temperature and quantity of suspended load carried by the water (turbidity of water),

iv. Condition of the canal system.

Measurement of Loss due to Seepage:

The seepage loss which occurs in an existing canal system or which may occur in the proposed canal system can be estimated by several methods. Some useful methods of calculating seepage loss are mentioned below.

(a) Permeameters and Seepage Meters:

Permeameters measure permeability of a canal bed or lining. It is no doubt very much different from the seepage rate. In order to determine the seepage rate it is necessary also to know the hydraulic slope causing flow through the canal bed. It is also essential to know the effective permeability of the sides of the

canal. The depth of water in permeameter should be approximately equal to the normal depth of water in the canal.

Seepage-meter consists of a metal cylinder. At the top it is dome shaped. A valve is fixed on the dome to remove the entrapped air. A plastic bag is attached to the cylinder by a tube. For calculating seepage rate the plastic bag is filled with water and the cylinder is then pressed slowly into the soil. The remaining space above the cylinder is also filled with water. The whole meter remains below the water surface of the canal.

Seepage occurred in the cylinder causes a corresponding reduction in the water content of the plastic bag. The rate of reduction of water content gives the seepage rate. The plastic bag helps in maintaining the same hydrostatic pressure on the soil of the cylinder as that surrounding the meter. The area under test is very small.

The character of the bed material may not be same everywhere. This method only gives an indication of the order of the seepage rate. For collecting reliable information it is very essential to obtain several readings on the bed and sides of the canal.

(b) Ponding Method:

This method involves isolation of a section of a canal by means of temporary cross bunds. The enclosed area is filled with water and the decrease in the volume over a certain period of time is noted. It may then be used to calculate the rate of loss. Proper allowance is made for rainfall and evaporation. The canal cannot be used during the period of tests.

(c) Inflow and outflow method:

It is a very simple method. It consists in measuring the quantity of water entering a certain reach and the quantity of water going out of that reach. The difference gives the amount of water lost. The discharge can be measured by flumes, weirs, current-metres or venturimeter. It is necessary to maintain constant water level. Allowance should be made for evaporation loss also.

Occurrence of Seepage Loss:

The seepage loss may occur in two characteristic ways, namely:

(i) Absorption, and

(ii) Percolation,

(i) Absorption:

When the underground water table is at a considerable depth, the water entering the soil is unable to join the saturated zone and wets the subsoil locally immediately below the canal bed

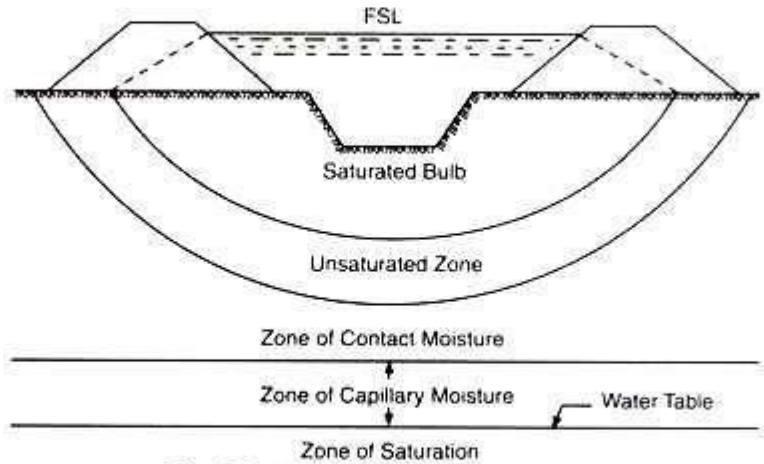


Fig. 8.7. Loss of water due to absorption

The soil layer which is in immediate contact with the channel section is completely saturated due to the absorbed water. It forms a bulb of saturated soil below the channel.

The soil layer below the saturated bulb is not fully saturated. Thus the extent of saturation goes on decreasing from the ground level below in the soil with depth. There now exists a zone of instauration between the underground saturated zone and the saturated bulb. Thus there is no chance of continued and constant flow from the canal to the groundwater reservoir.

It is observed that loss of due to absorption is more when the canal is in cutting reach. The loss due to absorption may be calculated from an empirical formula given below. It was given primarily for the state of Punjab.

P = C√D WL/10, 00,000

Where P is the loss due to absorption in m^3/sec

C is a constant and generally taken as 1.932

D is the depth of water in a canal in m

W is the width of water, surface in m

L is the length of reach in m.

From the above formula it is clear that C√D or 1.932√D gives the loss due to absorption m^3/sec per million m^3 of exposed water surface area. Another formula which is also used in Punjab is

$K = 1.905\ Q^{0.0625}$

Where K is absorption loss per million m^2 of wetted perimeter, and

Q is discharge in any reach of a canal in m^3/sec.

This formula holds good for average soil.

In case channel is lined the loss is given by

$K = 0.467\ Q^{0.056}$

(ii) Percolation:

When the underground water-table is nearer to the natural surface, the water which has entered the subsoil may join the saturated zone or underground reservoir to maintain a continuous direct flow.

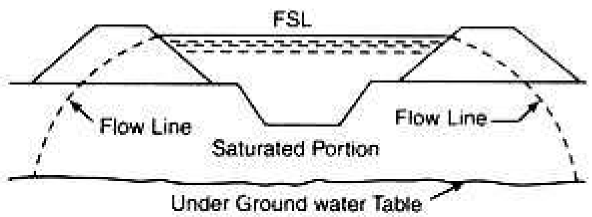


Fig. 8.8. Loss of water due to percolation

Lining-objectives:

The following are the main objects of canal lining,

1. **To Control Seepage:**
   The seepage loss is the maximum loss in unlined canals. Due to seepage the duty of canal water is much reduced which involves enhancement of storage capacity of a reservoir by constructing high dam. So, to control seepage loss through the bed and sides of the canal, the lining of the canal is necessary.

2. **To Prevent Water-logging**
   Along the course of the canal, there may be low lying areas on one side or both sides of the canal. Due to the seepage of water through the sides of the canal, these areas may get converted into marshy lands. This water logging makes the land alkaline which is unsuitable for agriculture. This water logging area may become the breeding place of mosquitoes which are responsible for many infectious diseases.

3. **To Increase the Capacity Of Canal:**
   In unlined canal, the velocity of flow should be fixed such that the silting and scouring is avoided. In practice, the velocity should always be kept below 1 m/s. Due to this low velocity, the discharge capacity of the canal becomes low. In unlined canal, if the capacity of the canal is to be increased the cross sectional area has to be increased which involves more land width. So, the lining of the canal should be such that the velocity and the discharge of the canal are more with minimum cross-Sectional area.

4. **To Increase the Command Area:**

If the lining is provided in the canals the various losses can be controlled and ultimately the command area of the project may be enhanced.

5. **To Protect the Canal From The Damage By Flood:**
   The unlined canals may be severely damaged by scouring and erosion caused due to high velocity of flood water at the time of heavy rainfall. So, to protect the canals from the damage, the lining should be provided.

6. **To Control the Growth of Weeds:**
   The growth of various types of weeds along the sides of the canals is a common problem. Again, some types of weeds are found to grow along the bed of the canals. These weeds reduce the velocity of flow and the capacity of the canals. So, the unlined canals require excessive maintenance works for clearing the weeds. If lining is provided in the canal, the growth of weeds can be stopped and velocity and the capacity of the canal may be increased.

Materials used:

Concrete:

Concrete canal lining is often used due to its high structural strength and longevity. Concrete used for canal lining is typically non-reinforced, as a way to reduce cost. A common method for constructing concrete lining is the use of slip forms, which are drawn down the length of the canal as the concrete is poured. Hand laying of concrete or prefabricated sections are also used when only a short distance needs to be covered. Certain additives, such as kankar lime and surkhi, are sometimes included in the concrete mixture to improve water retention.

Prior to constructing concrete linings, it is common practice to ensure the sub-grade layer of soil is adequately consolidated. If expansive clay is located on the site of a canal, a layer of this clay is removed and replaced with sand or gravel before the concrete lining is constructed. This removal minimizes the risk of ground swelling, which can cause cracking in the concrete. In order to prevent cracking during the curing process, water is sprinkled on the concrete or a damp cover is placed over the lining. Another preventative measure against cracking, includes adding transverse and longitudinal grooves or expansion joints which help absorb cracking that may occur.

Compacted soil

Compacted clay is a simple form of soil canal lining, which serves as a relatively cheap alternative to other methods. Certain clays, such as bentonite, have high water absorption but then become impervious, which makes them an ideal soil lining. It has been shown through studies done in the U.S., that a layer of bentonite 2 to 5 cm thick, underneath a layer of earth 15 to 30 cm thick, makes for an adequate lining system. Typically, porous soils are removed before compacted clay is applied to the bed and sides of a canal.

Another simple method of canal lining with soils entails applying a layer of compacted silt on top of the subgrade of the canal. The use of soils as canal linings is efficient for controlling seepage, but not effective against weed growth.

Plastic membrane

Plastic linings are often referred to as geomembranes or flexible membrane linings. Plastic linings are often covered with soil, rocks, brick, concrete or other material. This is done in order to anchor the lining down and to protect it from deterioration and disintegration. Plastic membranes are very thin, varying in thickness from 8 up to 100 thousandths of an inch. Low-density polyethylene (LDPE) film, similar to the material used in trash bags, is a common type of plastic membrane used. Plastic linings are also used as a method of retrofitting damaged concrete linings.

<u>Economics:</u>

Justification for Lining the Existing Canals

(i) Annual Benefits. Irrigation water is sold to the cultivators at a certain rate. Let this rate be rupees R1 per cumecs. If m cumecs of water is saved by lining the canal, annually, then the money saves by lining = mR 1 rupees.

Lining will also reduce maintenance cost. The average cost of annual upkeep of unlined channel can be worked out from previous records. Let it be Rs. R2• If p is the percentage fraction of the saving achieved in maintenance cost by lining the canal, then the amount saved = pR2 rupees. (The value of p is generally taken as 0.4)

ii) Annual Costs. If the capital: expenditure required on lining is-C rupees, and the lining has a life of say y years, then the annual depreciation charges will be rupees. If r percent is the rate of annual simple interest, then a locked up capital of C rupees would earn, annually C the asset decreases from C to zero in Y years, the average annual interest cost may be taken as rupees.

For project justification, benefit cost ratio. Must be greater than unity. In addition to the benefits grouped above i.e. (water saving' and reduction in maintenance cost) there may be benefits, like prevention of water-logging, reduced cost of drainage for adjoining lands, reduced risk of breaching, reduced incidence of malaria and other diseases in damp areas. Actual evaluation of these benefits is very difficult and may be approximated, based on experience, and may be taken into account for evaluating the annual benefit cost ratio.

<u>Introductions to Hydraulic Structures:</u>

A hydraulic structure is a structure submerged or partially submerged in any body of water, which disrupts the natural flow of water. They can be used to divert, disrupt or completely stop the flow. An example of a hydraulic structure would be a dam, which slows the normal flow rate of the river in order to power turbines. A hydraulic structure can be built in rivers, a sea, or any body of water where there is a need for a change in the natural flow of water.

Hydraulic structures may also be used to measure the flow of water. When used to measure the flow of water, hydraulic structures are defined as a class of specially shaped, static devices over or through which water is directed in such a way that under free-flow conditions at a specified location (point of measurement) a known level to flow relationship exists. Hydraulic structures of this type can generally be divided into two categories: flumes and weirs.

Dams:

Dam is any artificial barrier and its appurtenant works constructed for the purpose of holding water or any other fluid. There are three common classification schemes for dams. According to the function performed, dams are classified into:

- **i) Storage dams for impounding water for developmental uses.**
- **ii) Diversion dams for diverting stream flow into canals or other conveyance system and**
- **iii) Detention dams to hold the water temporary to retard flood flows**

From hydraulic design considerations, dams are classified as:

i)overflow dams to carry discharge over their crests, and

ii) Non-overflow dams, which are not designed to be overtopped. The most common classification is one based on the materials of which dams are made. This classification makes further sub-classification by recognizing the basic type of design, such as concrete gravity or concrete arch dams.

Types of dams include:
i) Earth fill dams
ii) Rock fill dams
iii) Concrete dams
- **a) Concrete gravity dams**
- **b) Concrete arch dams**
- **c) Concrete buttress dams**

iv)Stone masonry
- **a) stone-masonry gravity dams**
- **b) stone-masonry arch dams**

v)Timber dams
vi) Steel coffer dams

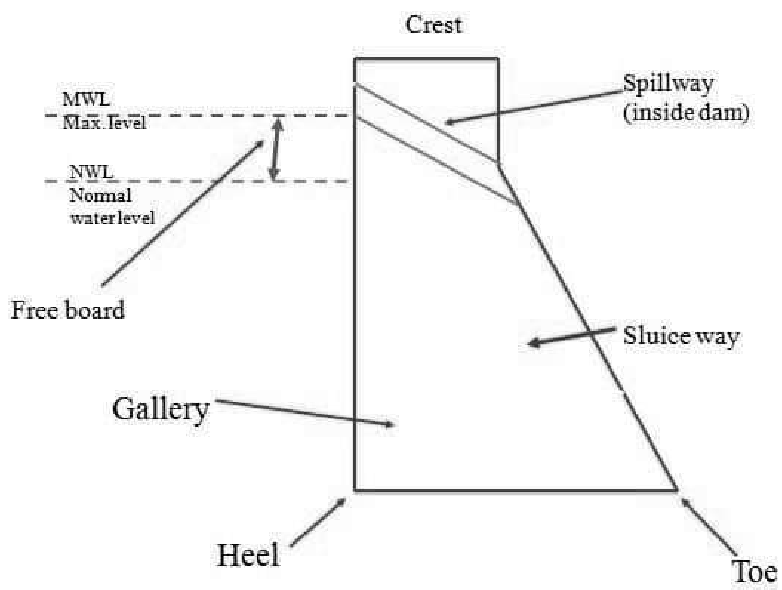
Spillways:

A spillway is a structure used to provide the controlled release of flows from a dam or levee into a downstream area, typically the riverbed of the dammed river itself. In the UK they may be known as overflow channels. Spillways ensure that the water does not overflow and damage or destroy the dam.

Floodgates and fuse plugs may be designed into spillways to regulate water flow and reservoir level. Such a spillway can be used to regulate downstream flows – by releasing water in small amounts before the reservoir is full, operators can prevent sudden large releases that would happen if the dam were overtopped.

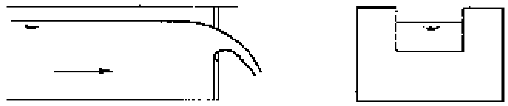
Other uses of the term "spillway" include bypasses of dams or outlets of channels used during high water, and outlet channels carved through natural dams such as moraines.

Water normally flows over a spillway only during flood periods – when the reservoir cannot hold the excess of water entering the reservoir over the amount used. In contrast, an intake tower is a structure used to release water on a regular basis for water supply, hydroelectricity generation, etc.

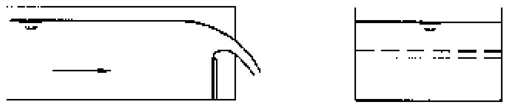


Weirs:

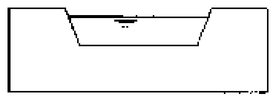
A weir is a barrier across the horizontal width of a river that alters the flow characteristics of the water and usually results in a change in the vertical height of the river level. There are many designs of weir, but commonly water flows freely over the top of the weir crest before cascading down to a lower level.



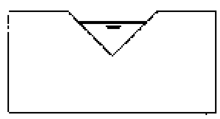
Contracted Rectangular



Suppressed Rectangular



Cipolletti Contracted



Contracted Triangular or V-Notch

Barrages:

A barrage is a type of low-head, diversion dam which consists of a number of large gates that can be opened or closed to control the amount of water passing through the structure, and thus regulate and stabilize river water elevation upstream for use in irrigation and other systems. The gates are set between flanking piers which are responsible for supporting the water load of the pool created. The term barrage is borrowed from the French word "barrer" meaning "to bar". A barrage is a weir that has adjustable gates installed over top of it, to allow different water surface heights at different times. The water level is adjusted by operating the adjustable gates.

"a barrage is built for diverting water, a dam is built for storing water in a reservoir to raise the level of water considerably and barrage is usually built where the surface is flat across meandering rivers. It raises the water level only by a few feet."

Canal Regulation Structures:

These structures may be described as follows:

1. **Drops and falls to lower the water level of the canal**
2. **Cross regulators to head up water in the parent channel to divert some of it through an off take channel, like a distributary.**
3. **Distributary head regulator to control the amount of water flowing in to off take channel.**
4. **Escapes, to allow release of excess water from the canal system.**

Unit-V

Floods: **Types of floods and their estimation by different methods, probability and frequency analysis, flood routing through reservoirs and channels, flood control measures, economics of flood control.**

Types of floods:

Coastal (Surge Flood):

A coastal flood, as the name suggests, occurs in areas that lie on the coast of a sea, ocean, or other large body of open water. It is typically the result of extreme tidal conditions caused by severe weather. Storm surge — produced when high winds from hurricanes and other storms push water onshore — is the leading cause of coastal flooding and often the greatest threat associated with a tropical storm. In this type of flood, water overwhelms low-lying land and often causes devastating loss of life and property.

Coastal flooding is categorized in three levels:

- **Minor: A slight amount of beach erosion will occur but no major damage is expected.**
- **Moderate: A fair amount of beach erosion will occur as well as damage to some homes and businesses.**
- **Major: Serious threat to life and property. Large-scale beach erosion will occur, numerous roads will be flooded, and many structures will be damaged. Citizens should review safety precautions and prepare to evacuate if necessary.**

The severity of a coastal flood is determined by several factors, including the strength, size, speed, and direction of the storm. The onshore and offshore topography also plays an important role. To determine the probability and magnitude of a storm surge, coastal flood models consider this information in addition to data from historical storms that have affected the area, as well as the density of nearby development.

Fluvial (River Flood):

Fluvial or riverine flooding, occurs when excessive rainfall over an extended period of time causes a river to exceed its capacity. It can also be caused by heavy snow melt and ice jams. The damage from a river flood can be widespread as the overflow affects smaller rivers downstream, often causing dams and dikes to break and swamp nearby areas.

There are two main types of riverine flooding:

- **Overbank flooding occurs when water rises overflows over the edges of a river or stream. This is the most common and can occur in any size channel — from small streams to huge rivers.**
- **Flash flooding is characterized by an intense, high velocity torrent of water that occurs in an existing river channel with little to no notice. Flash floods are very dangerous and destructive not only because of the force of the water, but also the hurtling debris that is often swept up in the flow.**

The severity of a river flood is determined by the amount of precipitation in an area, how long it takes for precipitation to accumulate, previous saturation of local soils, and the terrain surrounding the river system. In flatter areas, floodwater tends to rise more slowly and be shallower, and it often remains for days. In hilly or mountainous areas, floods can occur within minutes after a heavy rain. To determine the probability of river flooding, models consider past precipitation, forecasted precipitation, current river levels, and temperatures.

Pluvial (Surface Flood):

A pluvial, or surface water flood, is caused when heavy rainfall creates a flood event independent of an overflowing water body. One of the most common misconceptions about flood risk is that one must be located near a body of water to be at risk. Pluvial flooding debunks that myth, as it can happen in any urban area — even higher elevation areas that lie above coastal and river floodplains.

There are two common types of pluvial flooding:

- **Intense rain saturates an urban drainage system. The system becomes overwhelmed and water flows out into streets and nearby structures.**
- **Run-off or flowing water from rain falling on hillsides that are unable to absorb the water. Hillsides with recent forest fires are notorious sources of pluvial floods, as are suburban communities on hillsides.**

Pluvial flooding often occurs in combination with coastal and fluvial flooding, and although typically only a few centimeters deep, a pluvial flood can cause significant property damage.

Estimation by different methods:

1. Empirical Formulae:

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

A general equation may be written in the form:

$Q = CA^n$

Where Q is peak flow or rate of maximum discharge

C is a constant for the catchment

A is area of the catchment and n is an index

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

(a) Basin characteristics:(i) Area,

(ii) Shape, and

(iii) Slope

(b) Storm characteristics:

(i) Intensity,

(ii) Duration,

(iii) Distribution.

Limitations:

1. This method does not take frequency of flood into consideration.

2. This method cannot be applied universally.

3. Fixing of constant is very difficult and exact theory cannot be put forth for its selection.

However, they give fairly accurate idea about the peak flow for the catchments they represent. Some important empirical formulae are mentioned below.

(i) Dicken's formula:

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

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

Where Q is discharge in m^3/sec.

M is area of catchment in km^2.

C is a constant.

(ii) Ryve's formula:

This formula is used only in Southern India.

$Q = C.M^{2/3}$

C = 6.74 for areas within 24 km from coast.

= 8.45 for areas within 24 —161 km from coast.

= 10.1 for limited hilly areas.

In worst cases it is found that value of C goes up to 40.5.

(iii) The Inglis Formula:

This formula is used only in Maharashtra. Here three different cases are taken into consideration.

(a) For small areas only (It is also applicable for fan shaped catchment).

$Q = 123.2\sqrt{A}$

(b) For areas between 160 to 1000 km^2

$Q = 123.2\sqrt{A} - 2.62(A-259)$

(c) For large areas $Q = 123.2A/\sqrt{A} + 10.36$

In all the equations A is area in km^2.

2. Envelope Curve:

It is another method of estimation of peak flow. It is based on the assumption that highest known peak flow per unit area registered in the past in one basin in a region may occur in future in another basin in the same region or a region possessing similar hydrologic characteristics.

A graph is constructed by plotting the highest peak flows observed per unit area of the catchment against their catchment areas in the region. The points obtained on the graph are joined by an envelope curve. The curve once constructed can be used to calculate the probable maximum peak flow for any basin in that region.

This method was given formerly by Creager Justin and Hinds in USA.

The equation to the curve was of the type:

$q = C.A^n$ where q represents the peak flow per unit area

A represents the catchment area

C is a constant, and

n is some index.

By multiplying both sides of the above equation by area of the basin 'A', we get

$Q = C.A^{n+1}$

Where Q represents the peak flow.

Kanwar Sain and Karpov have developed two envelope curves to suit Indian conditions. One curve has been developed for the rivers in South India and the other for Northern and Central Indian Rivers.

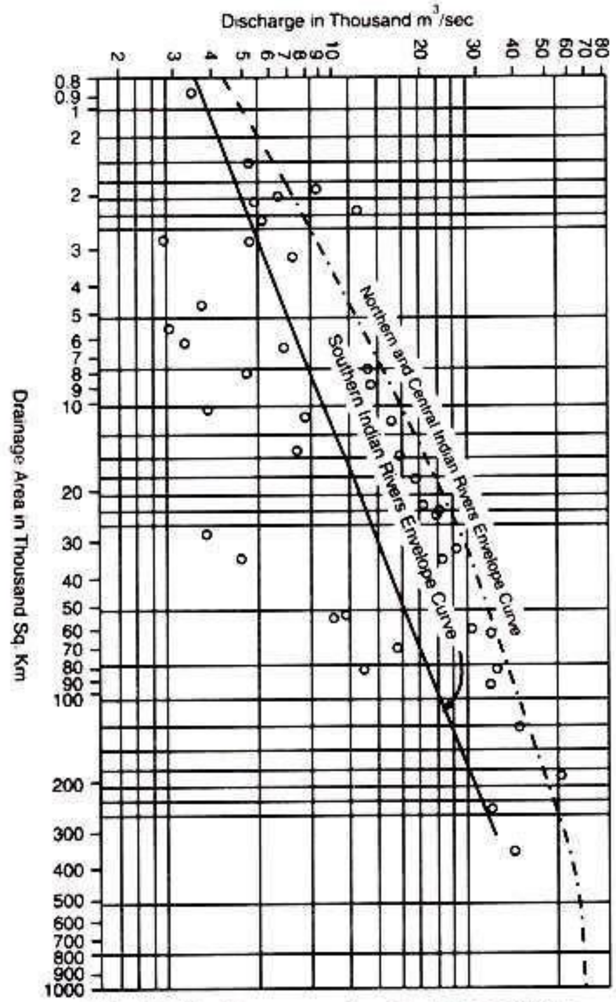


Fig. 5.4. Envelope curves for river basins of India

3. Rational Method:

This method is also based on the principle of the relationship between rainfall and runoff and hence can be considered to be similar to empirical method. It is, however, called rational method because the units of the quantities used are approximately numerically consistent. This method has become popular because of its simplicity.

The formula is expressed as follows:

Q = PIA

where Q is peak discharge in cumecs

P is runoff coefficient which depends on the characteristics of the catchment area. It is a ratio of runoff: rainfall. (P values are given later).

I is the intensity of rainfall in m/sec for the duration at least equal to “time of concentration”.

And A is area of the catchment in m^2.

Time of concentration:

It is the time taken by the rain water falling at the remotest point of the drainage basin to reach the discharge measurement point. It is given by the formula

$t_c = 0.000324\ L^{0.77}/S^{0.358}$

Where t_c is time of concentration in hours,

L is length of the drainage basin in m measured along river channel upto the farthest point on the periphery of the basin.

S is average slope of the basin from the farthest point to the discharge measuring point under consideration.

Assumptions:

The rational formula is given on the following assumptions:

(i) A peak flow is produced on any drainage basin by a rainfall intensity which continues for a period equal to the time of concentration of the flow at the point under consideration.

(ii) The peak flow resulting from any rainfall intensity attains maximum value when the rainfall intensity lasts for the time equal to or greater than the time of concentration.

(iii) The maximum peak flow resulting from long duration rainfall intensity as mentioned above is its simple fraction.

(iv)The coefficient of runoff is same for all storms of varying frequencies on a given drainage basin.

(v) The frequency of peak flow is same as that of the rainfall intensity for a given drainage basin.

While defining the peak flow When rainfall continues for such long enough time that all portions of the drainage area simultaneously contribute runoff to an outlet peak flow is reached. Obviously the rainfall must continue till water falling at the farthest point also reaches the discharge measurement point. If the rainfall occurs at uniform rate right from the beginning the time of concentration will be equal to the time of equilibrium when effective rainfall equals direct runoff.

Limitations of the Rational Method:

(i) It is clear that as the extent of the catchment area increases all assumptions cannot be fulfilled. Hence, for large catchment areas the utility of rational formula is questionable.

(ii) For very large and complex catchment areas before the water reaches outlet from the farthest point if the rainfall ceases then there is no possibility of whole catchment contributing its share of runoff to the outlet simultaneously. In such cases the lag time of peak flow is smaller than the time of concentration. In the above circumstances the rational formula does not give maximum peak flow.

Obviously the rational formula is applicable for small and simple drainage basins for which time of concentration is nearly equal to the lag time of the peak flow.

(iii) It is seen that rational formula gives better results for paved areas with drainages having fixed and stable dimensions. Therefore, it is popularly used for urban areas and small catchments only when detailed study of the problem is not justified. (The catchment area best suited is of the order of 50 to 100 ha). Since flood records are not available for small areas this method is found convenient.

(iv) The choice and selection of value of (P) the runoff coefficient is the most subjective thing and requires good judgment. Otherwise it is likely to introduce substantial inaccuracy.

Refinement of rational method:

As a refinement sometimes the drainage basin is divided into zones by contours. Each zone is so selected that the time of concentration of each zone is same. Each zone is then assigned appropriate value of (P) the runoff coefficient depending upon the imperviousness of the area. The total discharge is taken as summation of discharges from various zones. Using this value of total discharge average runoff coefficient for the drainage basin can be worked out.

4. Unit Hydrograph Method:

In the last chapter it is already mentioned that the largest ordinate of the unit hydrograph multiplied by the effective rainfall (in cm) occurring in the unit duration gives the peak flow. To this amount base flow may also be added to get total peak flow. The method is fully explained and examples solved in the last chapter to make the procedure clear. In case of ungauged basins Snyder's Synthetic unit hydrograph may be developed to estimate the peak flow.

Frequency analysis is a method which involves statistical analysis of recorded data to estimate flood magnitude of a specified frequency. It, therefore, requires knowledge of statistics to clearly appreciate the methods of frequency analysis.

<u>Probability and frequency Analysis:</u>

Frequency analysis is a method which involves study and analysis of past records (historical data) of hydrologic events to predict the future probabilities (chances) of occurrence. It is based on the assumption that the past data are indicative of the future.

Frequency analysis is done to estimate various things like annual runoff variations, frequencies of floods, droughts, rainfall etc. In other words the primary objective of the frequency analysis of hydrologic data (say flood events) is to determine the recurrence interval of the hydrologic event of a given magnitude.

For such analysis so called probability curves have been used. Given the observed data (for example maximum discharges for estimating maximum flood, average annual discharges for annual variations etc.) the task is to find a theoretical curve the ordinates of which will coincide with those observed. Good agreement of a theoretical curve with an empirical one ensures that the extrapolation can be rightly done.

When stream flood records of sufficient length and reliability are available they may yield satisfactory estimates. The accuracy of the estimates reduces with the degree of extrapolation. It is considered by some that extrapolation may be done only up to double the period for which data is available. For example, to get a 100 year flood 50 years record is necessary. However, insufficiency of recorded data makes it obligatory to use short term data to predict 1000 and 10,000 year floods also.

Flood routing through reservoirs and channels

Routing is a technique used to predict the changes in shape of a hydrograph as water moves through a river channel or a reservoir. In flood forecasting, hydrologists may want to know how a short burst of intense rain in an area upstream of a city will change as it reaches the city. Routing can be used to determine whether the pulse of rain reaches the city as a deluge or a trickle.

Routing also can be used to predict the hydrograph shape (and thus lowland flooding potential) subsequent to multiple rainfall events in different sub-catchments of the watershed. Timing and duration of the rainfall events, as well as factors such as antecedent moisture conditions, overall watershed shape, along with sub catchment-area shapes, land slopes (topography/physiography), geology/hydrogeology (i.e. forests and aquifers can serve as giant sponges that absorb rainfall and slowly release it over subsequent weeks and months), and stream-reach lengths all play a role here. The result can be an additive effect (i.e. a large flood if each sub catchment's respective hydrograph peak arrives at the watershed mouth at the same point in time, thereby effectively causing a "stacking" of the hydrograph peaks), or a more distributed-in-time effect (i.e. a lengthy but relatively modest flood, effectively attenuated in time, as the individual sub catchment peaks arrive at the mouth of the main watershed channel in orderly succession).

Other uses of routing include reservoir and channel design, floodplain studies and watershed simulations.

i) Reservoir Routing – considers modulation effects on a flood wave when it passes through a water reservoir – results in outflow hydrographs with attenuated peaks & enlarged time bases. – Variations in reservoir elevation & outflow can be predicted with time when relationships between elevation & volume are known.

ii) Channel Routing – considers changes in the shape of input hydrograph while flood waves pass through a channel downstream. – Flood hydrographs at various sections predicted when input hydrographs & channel characteristics are known.

Flood control measures:

Some methods of flood control have been practiced since ancient times. These methods include planting vegetation to retain extra water, terracing hillsides to slow flow downhill, and the construction of floodways (man-made channels to divert floodwater). Other techniques include the construction of levees, lakes, dams, reservoirs, retention ponds to hold extra water during times of flooding.

Dams

Many dams and their associated reservoirs are designed completely or partially to aid in flood protection and control. Many large dams have flood-control reservations in which the level of a reservoir must be kept below a certain elevation before the onset of the rainy/summer melt season to allow a certain amount of space in which floodwaters can fill. The term dry dam refers to a dam that serves purely for flood control without any conservation storage (e.g. Mount Morris Dam, Seven Oaks Dam).

Diversion canals

Main article: Flood control channel

Floods can be controlled by redirecting excess water to purpose-built canals or floodway, which in turn divert the water to temporary holding ponds or other bodies of water where there is a lower risk or impact to flooding. Examples of flood control channels include the Red River Floodway that protects the City of Winnipeg (Canada) and the Manggahan Floodway that protects the City of Manila (Philippines).

Floodplains and groundwater replenishment

Excess water can be used for groundwater replenishment by diversion onto land that can absorb the water. This technique can reduce the impact of later droughts by using the ground as a natural reservoir. It is being used in California, where orchards and vineyards can be flooded without damaging crops, or in other places wilderness areas have been re-engineered to act as floodplains.

River defences

In many countries, rivers are prone to floods and are often carefully managed. Defences such as levees, bunds, reservoirs, and weirs are used to prevent rivers from bursting their banks.

A weir, also known as a low head dam, is most often used to create millponds, but on the Humber River in Toronto, a weir was built near Raymore Drive to prevent a recurrence of the flood damage caused by Hurricane Hazel in October 1954.

Coastal defences

Coastal flooding has been addressed in Europe and the Americas with coastal defences, such as sea walls, beach nourishment, and barrier islands.

Tide gates are used in conjunction with dykes and culverts. They can be placed at the mouth of streams or small rivers, where an estuary begins or where tributary streams, or drainage ditches connect to sloughs. Tide gates close during incoming tides to prevent tidal waters from moving upland, and open during outgoing tides to allow waters to drain out via the culvert and into the estuary side of the dike. The opening and closing of the gates is driven by a difference in water level on either side of the gate.

Self-closing flood barrier

The self-closing flood barrier (SCFB) is a flood defence system designed to protect people and property from inland waterway floods caused by heavy rainfall, gales or rapid melting snow. The SCFB can be built to protect residential properties and whole communities, as well as industrial or other strategic areas. The

barrier system is constantly ready to deploy in a flood situation, it can be installed in any length and uses the rising flood water to deploy. Barrier systems have already been built and installed in Belgium, Italy, Ireland, the Netherlands, Thailand, United Kingdom, Vietnam, Australia, Russia and the United States. Millions of documents at the National Archives building in Washington DC are protected by two SCFBs.

Temporary perimeter barriers

When permanent defences fail, emergency measures such as sandbags, hydro sacks, Flood stop flood barriers or portable inflatable tubes are used.

In 1988, a method of using water to control was discovered. This was accomplished by containing 2 parallel tubes within a third outer tube. When filled, this structure formed a non-rolling wall of water that can control 80 percent of its height in external water depth, with dry ground behind it. Eight foot tall water filled barriers were used to surround Fort Calhoun Nuclear Generating Station during the 2011 Missouri River Flooding. Instead of trucking in sandbag material for a flood, stacking it, then trucking it out to a hazmat disposal site, flood control can be accomplished by using the onsite water. However, these are not fool proof. A 8 feet (2.4 m) high 2,000 feet (610 m) long water filled rubber flood berm that surrounded portions of the plant was punctured by a skid-steer loader and it collapsed flooding a portion of the facility.

In 1999, A group of Norwegian Engineers founded and patented Aqua fence. A transportable, removable, and reusable flood barrier which uses the water's weight against itself. In 2013, Aqua Fence was awarded the highest level USA ANSI Certification after more than one year of testing of the system by US ARMY Corps of Engineers as well as parts testing and production review by FM Global. Both commercial and municipal customers spanning across The United States of America, Europe and Asia. In the US alone, Aqua Fence removable flood panels are protecting more than $10 billion worth of real estate as well as cities and public utilities.

A similar technology is the Water-Gate Flood barrier, a rapid-response barrier which can be rolled out in a matter of minutes. It is unique in the way that itself deploys using the weight of water to hold it back. The product has been FM Approved following testing from the US Army. It is used in 30 countries around the world, and notably by the Environment Agency in the UK.

Economics of flood control:

The sense of insecurity arising out of the high risks due to recurrence of floods in flood prone but fertile plains dissuades farmers from making long-term investments in farming. It also dissuades other investors, including government agencies, from making investment in infrastructural projects. From this point of view "flood is an inhibiting factor in the process of agricultural growth of areas subject to frequent flooding". Consequently, without flood protection, flood prone areas receive low levels of investment in both the farming and non-farming sectors. These result in low levels of economic development thereby perpetuating the vulnerability of the people. In many developing countries there is a strong need for better utilization of the agro-economic potential of flood plains to provide scope for reducing people's vulnerability and providing enhanced opportunities for food and livelihood securities to the flood affected people. This, in turn, would reduce poverty and improve quality of life.