KARPAGAM ACADEMY OF HIGHER EDUCATION
(Deemed to be University)
(Established Under Section 3 of UGC Act, 1956)
Eachanari Post, Coimbatore-641021.Tamilnadu, India.

FACULTY OF ENGINEERING
DEPARTMENT OF CIVIL ENGINEERING
SEMESTER-V

17BECE505A WATER RESOURCES ENGINEERING 3 0 0 3 100

OBJECTIVES:

- To build on the student's background in hydrology and hydraulics an understanding of water resources systems.
- To develop the skills in modeling of flood flows and flood routing
- To develop skills in the ground water flow, type of aquifer and yield from the well.
- To provide the knowledge of design of reservoir, operation and sedimentation.

UNIT I **9**

INTRODUCTION: Irrigation – Need and mode of irrigation – Merits and demerits of irrigation –environmental impacts of irrigation- Classification of irrigation projects - Crop and crop seasons – consumptive use of water – Duty, Delta and Base period – Factors affecting duty – Irrigation efficiencies.

PRECIPITATION: Types of precipitation – Forms of precipitation – Measurement of Rainfall –Losses from precipitation-- Hydrograph - Factors affecting Hydrograph – Base flow separation – Unit hydrograph – S curve hydrograph

UNIT II **9**

RIVER ENGINEERING: Rivers –Types and Behavior

WATER LOGGING: Causes of water logging - Effects of water logging – Remedial measures for water logging

DRAINAGE: Necessity – Advantages – Methods.

RIVER STRUCTURES: Diversion Head works- Brief Description of component parts and their functions- - Seepage theories.

UNIT III **9**

CANAL ENGINEERING: Alignment of canals – Classification of canals - Distribution network - Canal Losses - Cross sectional details - Sedimentation in canals - Silt theories - Balancing depth of cutting

CANAL LINING: Types, Construction and Maintenance

CANAL AND RIVER STRUCTURES: Canal regulators and Types - Canal Falls and Types

CROSS DRAINAGE WORKS: Types- Selection -River Training works – types.

UNIT IV **9**

RIGID STORAGE STRUCTURES: Gravity dams Description– Arch and Buttress dam – Spillways – Factors affecting location and type of dams – Forces on a dam – Galleries and types.

Non Rigid Storage Structures: Earth dams - Causes of failure - Typical cross sections to suit site conditions and available materials - Phreatic line – Tanks – Classification – Components - types of Bunds

UNIT V **9**

RESERVOIR PLANNING: Reservoirs- Types- Zones of storage – Capacity - Yield- Area - Elevation and capacity- Elevation curves - Mass curve analysis - Capacity for specific demand and yield for given capacity- Fixing reservoir capacity- Reservoir sedimentation and control- Selection of site for reservoir

Other Irrigation Structures: Surplus Weir- Tower Head Sluice- Wing wall type- (Theoretical Approach only)- Culverts- Small ROAD bridges across drains- Canal outlets and flumes- Types (Theoretical Aspect only).

TOTAL: 45HRS

TEXT BOOKS:

Sl.No	Title of Book	Author of Book	Publisher	Year of Publishing
1	Irrigation Engineering and Hydraulic structures	Garg, S.K	KhannaPublishers,New Delhi	2012

REFERENCES:

Sl.No	Title of Book	Author of Book	Publisher	Year of Publishing
1	Irrigation and Water Power Engineering	Punmia B.C., Pande B.B.Lal	Lakshmi Publications, Chennai.	2012
2	Irrigation Engineering and Hydraulic Structures	SahasraBudhe S.R	S.K. Kataria &Sons, Chennai	2014
3	Irrigation Engineering	RK Sharma, TK Sharma	S.Chand& Company Ltd., New Delhi	2009

WEBSITES:

- http://www.icivilengineer.com
- http://www.engineeringcivil.com/
- http://www.aboutcivil.com/
- http://www.engineersdaily.com
- http://www.asce.org/
- http://www.cif.org/

- http://icevirtuallibrary.com/
- http://www.ice.org.uk/
- http://www.engineering-software.com/ce/

COURSE OUTCOMES

On completion of the course, the students will be able to:

- Incorporate the analytical abilities in the planning and design of water resource systems.

Apply the knowledge on reservoir planning and investigation

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COIMBATORE-641 021

17BECE505A-WATER RESOURCES ENGINEERING

Lecture Plan

Staff Name : **Ms.P.PREETHI, M.E,**

Semester : **5 (2019-20 ODD)**

Course Type : **Core**

Number of credits : **3**

LTPC : **3 0 0 3**

S.No	Lecture Duration (Hour)	Topics to be covered	Support Materials
UNIT I INTRODUCTION AND PRECIPITATION			
1.	1	Introduction about Irrigation, Need and mode of irrigation	T_1/1,3
2.	1	Merits and demerits of irrigation, environmental impacts of irrigation	T_1/2,3
3.	1	Classification of irrigation projects	T_1/5
4.	1	Crops and crop seasons, Consumptive use of water	T_1/22,27,34
5.	1	Duty, Delta, Base period and its relationship, factors affecting duty, Irrigation efficiencies.	T_1/22-27, 31-34
6.	1	Precipitation - definition, types and forms	T_1/235,251
7.	1	Measurement of Rain fall, Different losses from precipitation	T_1/252,312, 325
8.	1	Hydrograph, Factors affecting Hydrograph, Base flow separation	T_1/306,312
9.	1	Unit hydrograph ,S-curve hydrograph	T_1/306,433
UNIT II RIVER ENGINEERING - WATER LOGGING – DRAINAGE – RIVER STRUCTURE			
10.	1	Introduction about River engineering, water logging, Drainage and River structure	T_1/491
11.	1	Rivers- Types and Behaviour of Rivers	T_1/494
12.	1	Water logging - Definition, Causes and Effects	T_1/212
13.	1	Remedial measures for water logging	T_1/213
14.	1	Drainage - Definition, necessity, advantages and	T_1/218
15.	1	Methods of Drainage	T_1/218
16.	1	Diversion Head works –Typical layout, Description of component Parts	T1/521,523
17.	1	Diversion Head works – Functions of different Components	T1/523-532
18.	1	Seepage theories	T1/553
UNIT III CANAL ENGINEERING – CANAL LINING – CANAL AND RIVER STRUCTURES - CROSS DRAINAGE WORKS			
19.	1	Introduction about Canal Engineering, Lining, Canal and River structure and Cross Drainage works	T1/65

20.	1	Canal – Classification, Alignment, Distribution network	T1/65, 66, 72
21.	1	Canal Losses, Cross sectional details	T1/86,146
22.	1	Sedimentation in canals, Silt theories, Balancing depth of cutting.	T1/553,150
23.	1	Canal lining – Types, construction and maintenance	T1/ 192 -208
24.	1	Canal Regulators- Definition and types	T1/ 684
25.	1	Canal Falls – Definition and types	T1/ 639
26.	1	Cross drainage works – types and selection	T1/ 720-724
27.	1	River training works -types	T1/ 500,523
UNIT IV RIGID STORAGE STRUCTURES – NON RIGID STORAGE STRUCTURES			
28.	1	Introduction about rigid storage structures and Non rigid structures	T1/ 984
29.	1	Gravity dams – Arch and Butress dams	T1/ 984, 1237
30.	1	Spillways- Definition and types	T1/ 1099
31.	1	Factors affecting location and type of Dams	T1/ 890
32.	1	Forces on a dam, Galleries and its types	T1/ 984, 1029
33.	1	Earthen dams- Causes of failure and typical cross section	T1/ 1045,1209
34.	1	Phreatic line	T1/ 1062
35.	1	Tanks – definition, its components & classification	T1/ 1207
36.	1	Bunds – definition, types and design aspects	T1/ 1052
UNIT V RESERVOIR PLANNING – OTHER IRRIGATION STRUCTURES			
37.	1	Reservoirs - Types, Storage zones	T1/ 902, 909
38.	1	Reservoir - Capacity, Yield, Area, Elevation and capacity	T1/ 910
39.	1	Elevation Curves, Mass curve analysis, Capacity for specific demand	T1/ 904, 910
40.	1	Yield for given capacity, Fixing reservoir capacity, Reservoir sedimentation and control	T1/ 910, 921, 980,956
41.	1	Selection of site for reservoir	T1/ 979
42.	1	Tank surplus weir, Sluice with tower head	T_1/1209
43.	1	Culverts, Small road bridges across drains	T_1/775,788
44.	1	Canal outlets and Flumes -Types	T_1/700,1155
45.	1	End Semester Question paper discussion	

TEXT BOOKS:

Sl.No	Title of Book	Author of Book	Publisher	Year of Publishing
1.	Irrigation Engineering and Hydraulic Structures	Garg.S.K	Khanna Publishers, New Delhi	2010

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Sl.No	Title of Book	Author of Book	Publisher	Year of Publishing
1.	Irrigation and Water Power Engineering	Punmia.B.C.., PandeB.B.Lal	Lakshmi Publications, Chennai	2012
2.	Irrigation Engineering and Hydraulic Structures	SahasraBudhe S.R	S.K.Kataria & Sons, Chennai	2014
3.	Irrigation Engineering	RK Sharma, TK Sharma	S.Chand & Company Ltd., New Delhi	2009

WEBSITES:

- nptel.ac.in/downloads/105105110
- www.faadooengineers.com/.../9469-Water-resource-engineering-full-notes-pdfs-eboo.
- www.aboutcivil.org/irrigation-engineering-water-resources-lectures.html
- https://www.vidyarthiplus.com/vp/thread-14066.html
- https://www.vidyarthiplus.com/vp/thread-21750.html
- www.purdue.edu/dp/gk12/downloads/Water-Resources.pdf
- https://sites.google.com/a/venusict.org/...and-water-resources-engineering/material

LIST OF JOURNALS:

- **ADVANCES IN WATER RESOURCES** Editors: P. D'Odorico, G.C. Sander
- **JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING** (J IRRIG DRAIN E-ASCE), Publisher: American Society of Civil Engineers; American Society of Civil Engineers. Irrigation and Drainage Division; American Society of Civil Engineers. Water Resources Engineering Division, American Society of Civil Engineers
- **WATER RESOURCES MANAGEMENT,** Kluwer Academic Publishers, Netherlands
- **INTERNATIONAL JOURNAL OF WATER RESOURCES DEVELOPMENT (INT J WATER RESOUR D)** Publisher: Taylor & Francis (Routledge)

19/6/19

COURSE CO ORDINATOR

B.L. 20.6.19

HOD (CIVIL)

21.6.19

DEAN/FOE

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COIMBATORE-641 021

17BECE505A-WATER RESOURCES ENGINEERING

UNIT-1 INTRODUCTION AND PRECIPITATION

IRRIGATION ENGINEERING

1. DEFINITIONS

Gross commanded area (GCA):
Gross command area (or GCA) is the total area which can be economically irrigated from irrigation system without considering the limitation on the quantity of available water. It includes the area which are suitable for cultivation and areas not fit for cultivation like ponds, roads, villages, towns, rivers, hilly areas, forests and etc.

- Gross Command Area = Cultivable Command Area + Uncultivable Area

Culturable commanded area:
Culturable Command Area is that part of Gross Command Area, which is fit for cultivating crops. So, cultivable area excludes forest and barren land from the Gross Command Area.

Intensity of irrigation:
It is defined as the percentage CCA proposed to be irrigated annually or seasonly.
The various factors considered in fixing the intensity of irrigation are climate, soil, topography, cropping pattern, drainage, groundwater condition, amount and nature of available water, socio-economic needs of the area, water application method, dispersal of benefits. Rainfall and its distribution has a marked relation to intensity of irrigation. In high rainfall areas intensity is high because water needs are less and in semi-arid areas intensity is low due to frequent irrigation needs.

Crop ratio:
Crop ratio or Kharif-Rabi ratio is defined as the ratio between the areas anticipated to be irrigated in these two crops.
Crop ratio adopted in Punjab and Haryana is 1: 1.5, Uttar Pradesh I: 1.2, Maharashtra, Madhya Pradesh, Orissa, West Bengal, Andhra Pradesh 1: 1.

Overlap allowance:
Crop of one season may extend into the other season. In such a period of overlapping, both the crops require irrigation simultaneously. Thus there is extra demand during this period. To cater for this, usually 5 percent of canal discharge is provided as overlap allowance which implies that the canal discharge is increased by 5 per cent for this period of overlap.

Crop period:
It is the time that a crop takes from the instant of its sowing to that of its harvesting.

Base Period:
It is the time in days between first watering of a crop at the time of sowing to its last watering before harvesting.

Delta:
Delta is the total depth of water in cm required by a crop to come to maturity. It depends on the amount of each watering and the interval between successive waterings during the base period

Duty:
It may be defined as the area irrigated by unit discharge which means the number of hectares under a particular crop brought to maturity by a constant supply of 1 cubic of water per second flowing continuously for the base period.
Duty based on discharge passed through the outlet and thus including all losses in the canal system is called the outlet discharge factor.
In practice duty is expressed in hectares per cubic meter per second and is represented by D. If 1 cubic meter/see water flowing continuously for a base period B, matures 175 hectares.

Cumec day:
A unit of volume used in irrigation practice and means the volume of water resulting from a discharge of 1 cumec for one day (24 hours). It amounts to 8.64 hectare meters.

1.2 IRRIGATION

Irrigation is defined as the artificial application of water to agricultural land for growing crops.

1.3 NEED FOR IRRIGATION

1. Deficient rainfall.

   When rainfall is less than 100 cm, irrigation water is essentially required.

Rainfall (cm)	Irrigation requirement
100	Rainfall needs to be supplemented by irrigation
100-50	Rainfall is insufficient. Irrigation is essential
50-25	Irrigation is essentially required
Less than 25	No crop can be grown without irrigation.

2. Non-uniformity of rainfall.

   Where rainfall is sufficient but is not uniform, concentrated as it usually is in monsoon months, there is acute requirement of irrigation in other periods.
3. Augmentation of crop yields.

   New high yielding varieties of crops have higher water requirement for giving higher yields. Sugarcane and rice have higher requirement of water.
4. Exacting water requirement.

   The high yielding varieties of crops have more exacting requirement of water.

5. Cash crops cultivation

Cash crops require higher and assured supply of water with frequent watering for maturity.

6. Assured water supply.

For successful farming, availability of water in needed quantum and at right times is very essential.

7. Orchards and gardens.

Fruit trees grown in orchards and gardens have higher requirement of water.

1.4 IRRIGATION SYSTEMS

The various systems of irrigation have been developed depending on the nature of source of water and location of command area such as gravity irrigation, lift irrigation (which includes water lifted from canals, wells, tube wells etc.), tank irrigation, etc.

1. 4.1 Gravity Irrigation

Gravity or flow irrigation is the type of irrigation in which water is available at a higher level so as to enable supply to the land by gravity flow. In flow irrigation water is supplied to the fields through the canals off taking from head works.

Gravity flow irrigation is cheaper compared to lift irrigation. The gravity irrigation is further classified as under:

Perennial Irrigation:

In this system assured supply of water throughout the crop period to meet irrigation requirement of the crops is made available to the command area through storage of water done at the dam or diversion of supply made by means of head works at the off take point of the canal.

Perennial irrigation may be either direct or indirect, as follows:

Direct irrigation.

In direct irrigation system water is directly diverted from the river into the canal by construction of diversion weir or barrage across the river without attempting to store water. This method is practiced where the river has adequate perennial supply to feed the canal system at all times of crops periods.

Indirect irrigation.

It is also termed as storage *irrigation.* Here water is stored in a reservoir during monsoon period by construction of a dam across the river for supply into the off taking canals. Evidently indirect irrigation is adopted where the river is non-perennial or flow in the river is inadequate during lean period. Storage irrigation has greater irrigation potential than direct irrigation but is costly due to the cost of construction of dam.

Non-Perennial irrigation

Also called restricted irrigation. Canal supply is generally made available in non-monsoon period from the storage in small dams as· in Kandi areas which is inadequate to feed all the year round, and/or canal water is not required during monsoon due to adequate rainfall in the command area.

1.4.2 Inundation Irrigation

Inundation irrigation is done by a canal taking off from a river in flood without any diversion work. -It depends on the periodical rise in water level of the river and the supply is drawn through open cuts in the river bank or creeks which are called *heads.* Owing to changes in the river course, the heads have often to be changed. A regulator is, however, provided at the canal about 5 Ian downstream from the off take, where the discharge passing below in the canal is controlled and the surplus supply is escaped back into the river.

Inundation canals usually flow only during the summer months and bring in large quantity of silt beneficial to crops.

Selection of Off take Point:

The various factors which govern the selection of off take point are

(i) Site which is least likely to silt,

(ii) Site on a creek of suitable size is preferred, since it is more constant in discharge than main river and also subject to milder attacks by floods,

(iii) Site at the tail end of a creek is preferred as the flow there has less silt and is less liable to changes,

(iv) Site on concave curve towards the downstream is preferred for minimum silt entry. A part of concave reach remains always within the range of outside curvature for low as well as high river discharges, otherwise a site in a straight reach free from erosion upstream is suitable

(v) Site with stable and high river banks is suitable,

(vi) A back water reach also offers a good site,

(vii) Wider river section at the off take point which embodies two benefits, low velocity in the river and as such low silt charge in the water drawn in the canal, and low variation in water level, and

(viii) If other conditions are favorable, a site close to the command area is preferred.

1.4.3 SUB-SURFACE IRRIGATION

In sub-surface irrigation water is applied beneath the ground by creating and maintaining an artificial water table at some depth, usually 30 to 75cm, below the ground surface. Moist moves upwards towards the land surface through capillary action from requirements of the plant roots. Water is applied through underground distribution system consisting of a purely designed main field ditches, laterals, laid 15 to 30 m apart.

Water may be obtained from rivers, streams, lakes etc. Water is introduced into soil profile through open ditches, mole drains or z drains. Open ditches are preferred because they are relatively inexpensive and suitable for all 1'Cs of soils. Tiles and mole drains are suitable only for organic soils. Sub-surface irrigation requires little field preparation and labour. It entails minimum evaporation loss and surface waste. irrigation water is essentially required to be of good quality to prevent excessive soil salinity. flow rate in supply ditches is required to be low to prevent water logging of the field. The use sub-irrigation is limited because it requires certain soil condition that is the soil is permeable in t zone, underlain by an impervious horizon or high water table.

Requirements:

The essential requirements for a successful sub-surface irrigation are *(i)* Availability of adequate supply of good quality water throughout growth period of the crop, *(ii)* Fields must be level and smooth. Ground slope is moderate. Land is approximately parallel to water table, Availability of a layer of permeable soil such as sandy loam or loam immediately below the soil to permit free and rapid movement of water laterally and vertically, *(iv)* Availability 3 relatively impervious layer at 2 to 3 m in the substratum to prevent deep percolation of water a permanently high natural water table on which an artificial water table can be built, *(v)* A well distribution system of main ditches, field laterals, etc., which raises the water table to a *corm* depth below the ground surface over the entire area, *(vi)* Availability *of* adequate outlet drainage of the area so irrigated particularly in humid areas, *(vii)* Subsoil water table is within 3 m below the ground surface, *(viii)* Topographical conditions are uniform, and *(ix)* Soil is able of lifting moisture from the water table to the root zone. Also the soil permits lateral and upward movement of water. The efficiency of water use depends on soil characteristics, topography and operation and maintenance management. In good system, the efficiency is 70-75 percent.

1.4.4 Classification of Sub-surface Irrigation

The sub-surface irrigation may be classified into *(i)* natural sub-irrigation, and *(ii)* artificial irrigation.

1. Natural sub-irrigation. This method is applicable to low lying lands where the water table is and within the capillary reach of root zone of crops. The water table is charged by seepage from irrigation canals. It is better controlled lest it may develop into waterlogging conditions. The method, applicable where above conditions exist, offers most economical means of raising crops.

2. Artificial sub-irrigation. It is a very expensive method. Its use is indicated only under favorable water supply and subsoil conditions for high yielding crops. The water is provided to crops by capillarity through a network of buried perforated pipes which carry water under pressure to percolate into soil.

Advantages of Sub-surface Irrigation. (i) Minimum water requirement for raising crops. (ii) Suitable for most crops, (iii) Minimum evaporation and deep percolation losses, *(iv)* High crop yield, *(v)* Most economical method of irrigation, *(vi)* Involves no wastage of land, (vii) No interference in free movement of farm machinery, *(viii)* Cultivation operations can be carried out without concern for the irrigation period, and *(ix)* Little field preparation and labour.

Disadvantages. (i) Requires a special combination of natural conditions so that only limited areas are suitable for irrigation by this method, (ii) There is danger of development of waterlogging. (iii) Possibility of choking of the pipes laid underground, and *(iv)* High cost.

1.4.5 SURFACE IRRIGATION

It is by far the most common type of irrigation. In surface irrigation method, since water is applied to the field in varied quantities and at different times, the flow remains unsteady. The method involves diverting a stream of water from the head of a field into furrows or borders, an allowing it to flow downward. Water infiltrates into the soil while traversing the furrow. By subsequent ponding and lateral movement, the soil is restored to its full water holding capacity to depth that depends on the quantity of water introduced, the duration and rate of stream flow, the gradient and the soil structure and texture. Generally under open ditch conveyance and surface irrigation methods, less than one half of the water released reaches plants. Highly efficient irrigation can be achieved by an appropriate combination of size of the irrigation stream, unifom application of water, minimum soil erosion, minimum labour requirement, maximum land use.. size and shape of field and use of machinery. The surface irrigation is essentially supplement with efficient water disposal system:

Advantages: (i) Allows use of machinery for land preparation, cultivation and harvesting and (ii) Helps to store the required amount of water in the capillary, zone of the soil for supply t the root zone of plants.

Disadvantages: (i) Greater loss of water by surface runoff and deep percolation, larger requirement of water per unit area, (ii) Water is lost in infiltration and deep percolation, (iii) Lo efficiency due to imperfect control over the water flow, *(iv)* Inferior quality crops with a 10 yield, *(v)* Wasteful use of water compared to better irrigation methods, and *(vi)* Costly and time consuming preparation of land.

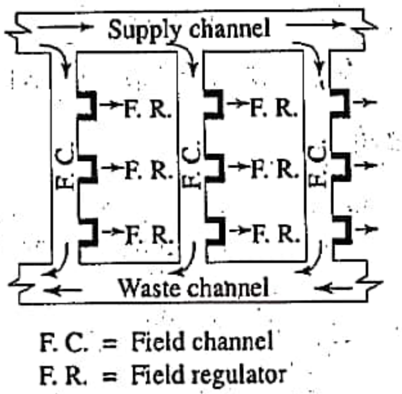
1.4.6 Classification of Surface Irrigation

Surface irrigation may be classified as t100ding method, furrow method and contour farming method, with further divisions as illustrated in Fig.

1.4.6.1 Flooding Method: In flooding irrigation, water is allowed to cover the surface of land '. a continuous sheet, the water standing just long enough in the field for the soil to absorb the water applied to refill the root zone. A properly designed size of irrigation stream aims at proper balance against the intake rate of soil, the total depth of water to be stored in the root zone and the area to be covered so as to give reasonably uniform coverage of water over the entire field. The flooding may be (i) wild, and (ii) controlled.

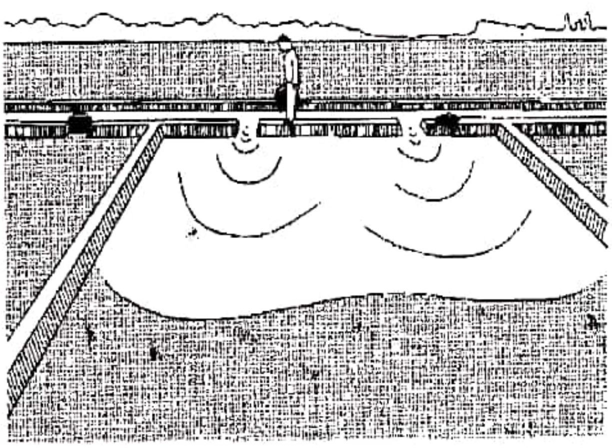
(a) **Wild Flooding:** It is also called *uncontrolled flooding.* It is the primitive and mo. inefficient method of irrigation. In this method water is spread over the smooth or flat field without much control over the flow or prior preparation. The water is spread into the field from the ditch excavated either on the contour or up and down the slope. This method is applicable inundation irrigation system or for pastures or forage crops where water is available in abundant at the highest elevation and is inexpensive or the crop values do not justify adoption of best method. The water distribution is quite uneven. The method is suitable for all medium to soils. It has low cost and does not interfere with tillage. The disadvantages of the method *(i)* wasteful use of water, *(ii)* non-uniform distribution of water, *(iii)* excessive soil erosion on per slopes, *(iv)* require drainage arrangement to reduce ponding.

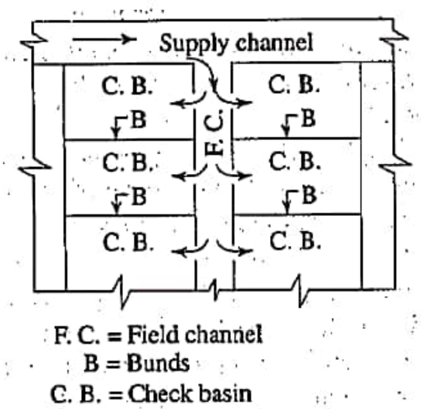
(b) **Controlled Flooding:** *(i) Free flooding.* Also called *ordinary flooding.* It is the commonly adopted method where irrigation water is in abundance and cheap. The land is divided into boundaries of suitable size depending on porosity of soil. Water is spread over the field from . recourse. The irrigation operation begins at the higher area and proceeds towards the lower . The flow is stopped when the lower end of the field has received the desired depth of water. The field watercourse is properly spaced, the spacing depends on the topography, soil texture, and size of stream. The spreading may vary from less than 15 m to more than 60 m. The method is most suitable for soils of medium texture and with moderate slopes.



(ii) **Border flooding:** In this method, the field is divided into narrow strips by low parallel on the sides. The border strip formed by leveling and grading the ridges ,size of the strip depends on the type of soil, slope of the land and size of irrigation stream. The width of the strip varies from 5 to 15 m and length lies from 60-100 m for sandy loam. Thus no land is lost to production. Water is let into each strip in a thin sheet through set of outlets or siphon pipes and underground concrete pipes through risers placed along the per end of the border. Water flows down the slope along the length of the strip at non erosive

The method is applicable to most soil textures but is best adapted to soils having moderately w to moderately high infiltration rates. It is suitable for high value crops and all close growing _.ops and is used for some row crops like cotton. In general, it is suitable for hay, pastures and ~m crops on lands having slopes up to 3 per cent.





Advantages: (i) Utilizes large water streams safely, *(ii)* Requires less labour and time; low maintenance cost, *(iii)* Provides uniform wetting and efficient use of water.

Disadvantages: (i) Requires proper leveling, *(ii)* High initial cost, and *(iii)* A large supply of water is needed.

(vi) **Check flooding**. It is a widely practiced method of irrigation in India. In consists of applying water to relatively level check basins enclosed by small bunds. The checks are square, rectangular or irregular plots. If the ground has some initial slope, levees may follow the contours. The size of check basin may range from 3 x 2 m to 30 x 30 m or even larger. In orchards, checks are used to irrigate each tree or a group of few trees in a check basin. The levees are 2 to 3 m wide at the base and 25 to 30 cm high in order to avoid obstruction to the movement of farm machinery as also to permit growth of crops over them.

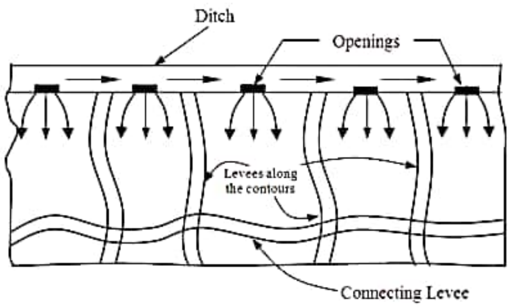


Fig: Check flooding (Plan view)

In highly permeable soils, large size stream is required to quickly impound the check basin with the required quantity of water without allowing deep percolation losses on the side of the irrigation ditch. In highly impermeable soil with low infiltration rate, the water is impounded in the basin and is slowly allowed to infiltrate in the soil. The method is specially suited to fine textured soils which require holding of water in order to secure the desired penetration. This method is suitable for growing grain and forage crops. The use is generally restricted to relatively smooth lands because of the expenditure involved in leveling the plots.

Advantages: (i) High irrigation efficiency can be
achieved with properly designed check system, and Fig. 4.3 Check basIn irrigation system
(ii) Unskilled labour can be employed as there is no danger of erosion.

Disadvantages: (i) High labour requirement, *(ii)* Levees impose restrictions in the use modern farm machinery, and *(iii)* Use is generally restricted to relatively smooth lands because the expenditure involved in leveXing the plots.

1.4.6.2 Contour lateral method: This method is best suited to steeper terrain. The field is c by relatively dense network of contour laterals; their spacing depends on the *(i)* grade of land between two adjacent ditches or laterals, *(ii)* uniformity of slope, and *(iii)* type of soil. It may vary from 15 to 50 m. The contour ditches may have practically little grade if they are not too lonf The water flows through the openings in the laterals. On the other side of contour lateral, a sm~ bund is provided to divert the water from the main to the lateral. The stream size per unit area 'the same as in border irrigation.

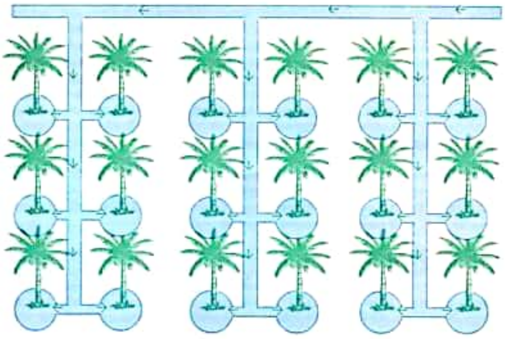
Contour lateral flooding is adopted on close growing crops on sloping or rolling lands n subject to any degree of levelling necessary for other methods of irrigation. Water flows slope between closely spaced ditches running along the contour of the land.

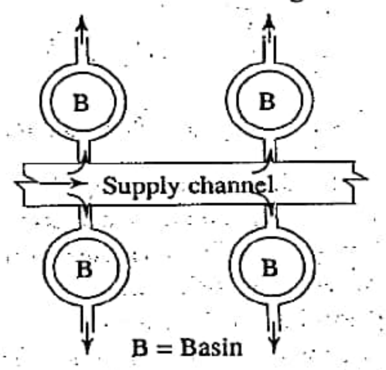
Disadvantages: (i) High labour cost of irrigation, and *(ii)* Not suitable if other methods of irrigation can be adopted.

1.4.6.3 Zig zag method: It is a special method of flooding suitable for relatively level fields.

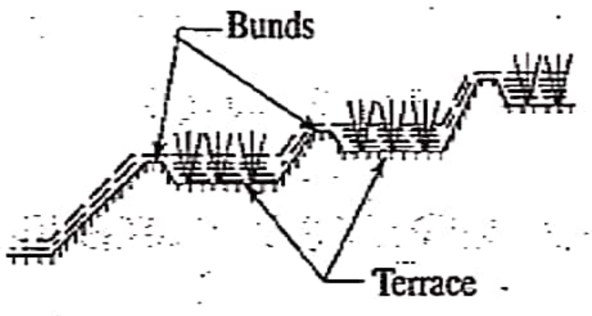
But the method is unsuitable for mechanical farming operation. In this method, land is divide into square or rectangular plots; each plot is further subdivided with the help of low bunds levees. Water enters at the upper end of the plot and follows circuitous route to reach the low end of the plot when the supply is cut off.

1.4.6.4 Basin flooding: It is essentially a check method of flooding adapted for irrigation orchards. In orchards basins are made around one or more trees depending on the soil conidian topography. For efficient irrigation, each basin has to be level, grade less than 0.1 per c with no cross slope. It is adapted especially to flat lands. Water is filled quickly in the basin and' allowed to percolate into the soil. It is desirable for close-growing crops and orchards on medium to coarse textured soils as also rice grown on fine-textured, slowly permeable soils. Water conveyed to the basin or preferably through small ditches feeding individual basins. The merit and demerits of the method are broadly the same as indicated for border irrigation method.

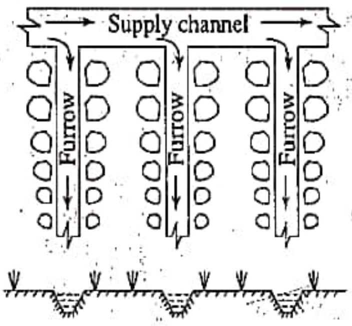


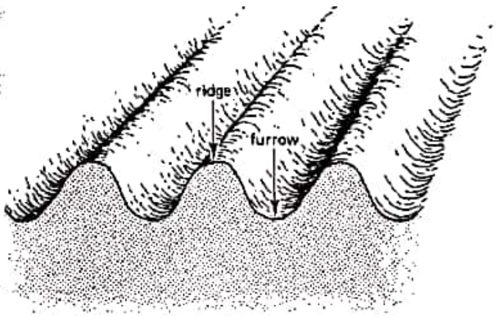


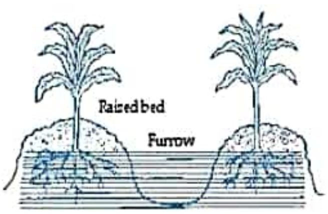
1.4.6.5 Contour Farming: It is adapted to hilly areas with steep slopes and quickly falling . The land is divided into longitudinal curved plots, the bunds of the plots.. The irrigation water stored higher up in some depressions flows between the bunds. The formation of crops is along the contour lines instead of the usual down the slope. Contour reduces runoff and soil loss.



1.4.6.6 Furrow Method: It is the common method of irrigating row crops. A furrow consists of ow ditch between the rows of crops. Water is applied in small streams between rows of grown on ridges or in furrows . The characteristic feature of furrow irrigation is unlike flooding method, only half to one-fifth of the irrigated land surface is wetted, thereby down evaporation losses. Water flowing in the furrow seeps into the soil and spreads y to irrigate areas between the furrows. For distribution of water to the furrows, the main is placed on the higher side of the field.







The size and shape of the furrows depend on the soil, crop spacing, equipment used for the action of furrow, and inter cultivation. Long furrows are advantageous in inter cultivation. However, too long furrow results in deep percolation losses and soil erosion near the upper end of the -d, and too little water near the tail. It may range from 70 m on light soils to 200 m on heavy s. The usual size of furrow for row crops is about 25 cm wide and 8 to 10 cm deep. Furrows may vary from 0.1 to 0.5 per cent for different soils and stream sizes.

Furrow irrigation is adaptable to all row crops orchards etc. but not suitable for very soils having high infiltration capacity, as water is wasted on the upper end of the furrow due deep percolation.

Advantages: (i) Low evaporation losses as only one-half to one-fifth of irrigated land su is wetted, *(ii)* It is possible to cultivate earlier, especially in heavy soils, *(iii)* Furrows serve drainage ways for surface runoff in areas of heavy rainfall, *(iv)* Especially suitable for crops maize that are injured by contact with water, *(v)* No wastage of land in field ditches, *(vi)* F efficient in use of water, *(vii)* Relatively cheap to construct and maintain, and *(viii)* Efficient use of water.

Disadvantages: (i) Not recommended for very light soils having high infiltration capacity *(ii)* Ditches may interfere with tillage, *(iii)* Usually expensive from the consideration of time labour cost, *(iv)* Serious erosion hazard, and *(v)* Adequate drainage need to be provided.

Furrow irrigation may be contour furrow, shallow furrow and deep furrow.

(a) **Contour furrow:** It is an adaptation of furrow irrigation. If the slope of land is too s for effective irrigation, the furrows are laid across the slope on a proper grade and are termed contour furrows. The furrows are useful in the land of uneven topography.

(b) **Shallow furrow:** Also termed as corrugation method. In this method, the stream of w is guided through small channels or corrugations running down the slope from the head ditch evenly spaced across the field. The corrugations are made by means of a corrugators after the crops are sown. The corrugations are primarily for guiding stream of water, rather . conveying water. Some overtopping of the furrow may occur. The size and spacing of corrugate depend on water intake rate of the soil. The corrugations are more closely spaced in more impervious soils to permit wetting between the corrugation without excessive deep percolation 10 These are V-shaped or U-shaped channels about 10 cm deep, spaced 40 to 75 cm apart. irrigation is suitable for fine to moderately coarse textured soils that take water slowly tend to seal over and bake when flooded. It is suitable for close growing crops.

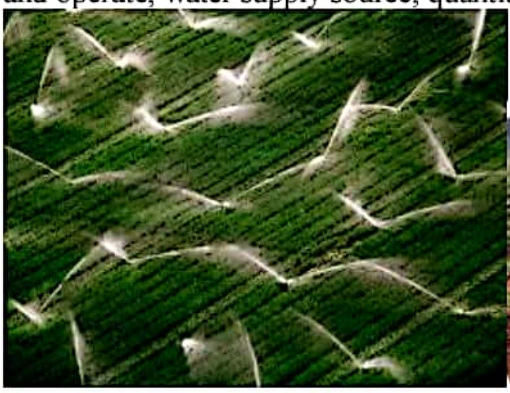
Advantages: (i) Low evaporation losses as water does not cover the entire field surf *(ii)* Useful for fine textured soils that take water slowly, *(iii)* Suitable for sloping and ro lands, and *(iv)* Provides uniform wetting.
Disadvantages: (i) Relatively expensive in labour cost, and *(ii)* Not suitable where the flow capacity is available and where irrigation can be done almost round the clock.
(c) **Deep furrows:** Deep furrows 15 to 30 cm deep, spaced 1 to 2 m apart and of length 1 than 30 m are more suitable for orchards and sugarcane. The longitudinal slope may vary from to 0.5 per cent. This method is adapted to soils of low permeability.

1.4.7 SPRINKLER IRRIGATION

Sprinkler irrigation is an improvement over conventional surface irrigation. It simulates rainfall to spread water in the form of rain uniformly over the land surface just when ne and as much needed at a uniform pattern and at a rate less than the infiltration rate of the soil so to avoid surface runoff from irrigation. It is generally indicated for undulating lands, poor w availability, sandy or shallow soils and where uniform application of water is required. No I levelling is required for sprinklers thereby saving considerable cost. The soil is not disturbs expose the less fertile subsoil. Even on sand dunes crops can be grown under sprinkler irrigation It enables economical use of water through control over the application rate and uniform application of water. The fertilizer is applied through the sprinkler system to ensure even distribution avoids waste, saves cost and gives immediate plant response. The sprinkler irrigation is suit for all types of soils, more particularly coarse, sandy and gravelly soils and for almost all like wheat, jowar, cotton, potatoes, tobacoo, groundnut, vegetables, ragi, etc. However, it is ~ recommended for crops having high water requirement such as rice, jute and plantation crops .This system is suitable for any size of farm.
Presently it is being tried on a large scale in Tamil Nadu, karnataka, Haryana and Punjab and lift irrigation areas where land is sandy and undulating.

Sprinkler Irrigation System

sprinkler irrigation system, water is pumped under pressure, carried through high pressure line and let out through sprinkler nozzles placed at regular intervals on lateral lines to form tie rain.
The system is designed considering agro-climatic conditions, general land condition, maximum difference in elevation, cropping pattern as different crops require different amounts of and different irrigation schedules, cover-crop requirements and their effect on peak water requirement and rates, availability of labour, matching pump and power unit, pipe sizes to install and operate, water supply source, quantity and quality as essentially clean



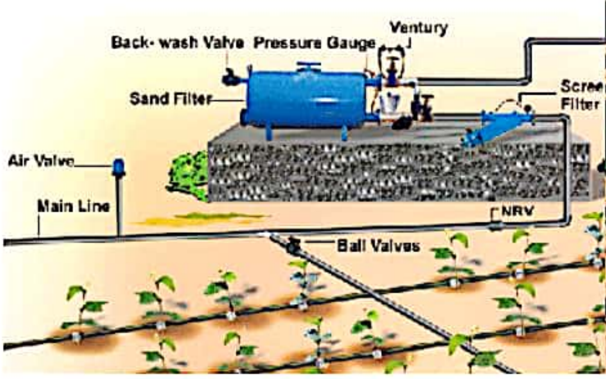
Advantages of Sprinkler Irrigation

(i) *Saves water, irrigates more land.* Compared to surface irrigation only 30 to 50 percent the water is required depending on the type of soil. Thus with same quantity of water 2 to 3 . area can be irrigated, (Ii) *Low water loss:* Water loss is estimated as 18 per cent against 54 per in a surface irrigation system with lined channels and 71 per cent in a system without any Ii (iii) *Effective water management:* Since the water application is controlled, over or under imitation is avoided. Just the right quantity of water at the right time can be applied according to needs of the crops, slope and soil texture, (iv) *Saving in land:* Saving in land which other occupied by the canal section, banks and watercourses in surface irrigation, *(v) Saving inferiors:* Application of soluble fertilizers is efficient and automatic. Nearly half of fertilizers ~are lost due to excessive leaching below the root zone and drainage in surface irrigation are s

(vi) Land levelling not necessary: Even undulated lands can be irrigated effectively without levelling. Time and money to be spent in land levelling are saved. Moreover, when the I levelled, top fertile soil gets disturbed and it takes years to develop new soil suitable for irrigation, *(vii) Soil conserved:* Due to controlled rate of water application, water is not allowed to but is absorbed by the soil fully. Hence there is no soil erosion, *(viii) Soil condition is main* The soil is kept open and its structure unbroken whilst soluble fertilizers and soil amend me easily applied with irrigation water, *(ix) Soil is stabilized:* Light. and frequent waterings aR served to have stabilized sand dunes, *(x) Better seed germination:* More seeds germinate, earlier and growth is vigorous. Fine droplets absorb more oxygen and supply to root zone for gro crops, *(xi) Frost control:* Crops are protected against frost damage, *(xii) Instant irrigation*, *(xiii) Use of limited source:* Even a limited source of water can m of sprinkler irrigation to irrigate more area, *(xiv) Uniform application:* Uniform application of water is possible on all kinds of soils, *(xv) Controls climate:* Light sprinkling reduces textures to safe level, *(xvi) Sport grounds:* Best for watering lawns and sport grounds, *(xvi, aeration of root zone:* Top soil becomes porous and there is free aeration of the root zone helps better growth of plants, *(xviii) Poor soils irrigated:* Poor soils such as sandy soil an _cotton soil can be irrigated with equal ease and efficiency, *(xix) Drainage problems*Surface runoff of irrigation water is eliminated with the controlled water application, *proved soil fertility organism:* The better aeration also enables micro-organism to work fullest extent to improve soil fertility, *(xxi) Weeds and pests controlled:* Harmful ditch not appear, cannot establish themselves because sprinkled water washes plants regular. *High crop yield and quality:* Crops yield is appreciably higher and quality is very 0 proved. Three or even four crops per year can be grown, *(xxiii) Reduced labour require* means low running cost comparable to lift irrigation. Being automated manpower needed *(xxiv) People's participation:* Peoples' participation in the development is achieved as farmer who adopts sprinkler irrigation helps the Nation in the efficient and economic of water and fertilizers

1.4.8 DRIP IRRIGATION

Also called *Trickle irrigation.* It is the latest developed method of irrigation. It was first introduced in Israel. In India, it is being increasingly practised in Gurjarat, Maharashtra, Keral and Kamataka. In this system water is applied in the form of drops directly to the plants through drip nozzles from which it drops into the soil slowly and frequently to keep the soil moisture within the desired range for healthy plant growth so that the plants do not experience any moisture stress throughout their life cycle. It is particularly suited to soils with very low and very high infiltration rates under the conditions of water scarcity and in areas where drainage of excess water is difficult. It is more economical for orchard crops than for other crops and vegetable since in the orchards plants as well as the rows are widely spaced. It is most successful for big income crops because of the relatively high first cost of the installation. Coconut is the major crop, followed by grapes, vegetables, citrus and sugarcane. Drip irrigation limits the water supplied for consumptive use of the plant by maintaining a minimum soil moisture in the root zone thereby maximizing the water saving. A dripper discharges water (and nutrients) directly into th area of the root system. It permits fine control of application of moisture and nutrients at frequencies prescribed for the individual plants. Drip irrigation involves the lateral spread of water on surface to be irrigated by conducting the water under pressure to a relatively closely spaced grid outlets, and discharge the water (together with fertilizer solution) through these outlets virtually zero pressure. Irrigation is done through drippers fitted on small diameter lateral lines The dripper located at suitable spacing delivers the water to the soil surface near the base of plan:



The basis of this potential water saving method is that frequent but just sufficient amount irrigation guards the plant free of water stress by maintaining soil moisture level at the fieid capacity. Water is filtered to remove the suspended impurities so as not to block the find nozzles. The effective working of the dripper lines lies in efficient functioning of the filter. fertilizer mixed water is led into the filter tank from which dirt free solution gets into the m supply lines

with laterals spread on the field in rows. The laterals hold the drippers through while the fertilizer-cum-irrigation water trickles.
At the beginning of each plot there is a secondary line which distributes the water into trickle lines. To the secondary line is connected a discharge regulator whose capacity is in accordance with the size and number of nozzles being used. The automatic valve at the head is adjust to deliver desired quantity of water and irrigation terminates automatically after this amount discharged. Pipes are made of cheaper materials like polyethylene, polyvinyl chloride .

1.5 MERITS OF IRRIGATION

I. Direct Benefits.

(i) Increase in food output through higher yield to attain self sufficiency in food,
(ii) Cultivation of cash crops,
(iii) With the introduction of irrigation land value appreciates manifold which makes wealthy the land holders, the State and the country,
(iv) Growing of fruit trees and development of gardens,
(v) Protection from famine-irrigation makes agriculture and economy drought proof,
(vi) Prevention of damage through floods,
(vii) Domestic water supply to towns and villages. Important cities like Delhi, JaipuR , Bikaner and Chandigarh depend on canal water for public water supply,
(viii) Hydel power generation at dam site and canal falls,
(ix) The rise in subsoil water level in dry areas assists in meeting demands of domestic water supply by pumping the ground water,
(x) Means of communication where navigation is possible in the canal. Network of canals with inspection bank boundary roads along them improve the communication in remote command areas,
(xi) Revenue from recreation facilities such as boating, fishing and swimming,
(xii) Fish and wild life preservation and development of fish culture.
(xiii) Afforestation plantation is raised along the banks of canals and field boundaries,
(xiv) Irrigation substantially lowers production risks and farmers are greatly encouraged to raise productivity through input intensification,
(xv) Makes agriculture competitive and profitable,
(xvi) Industrial and thermal plant requirements are met with from canal water,
(xvii) The reduced risk of crop failures and increased food production,
(xviii) Improve the nutrition of the people and cattle considerably which leads to increased resistance to diseases and hence improved health.

II. Indirect Benefits.

(i) Increase in gross domestic product of the country,
(ii) Increase in revenue from sales tax on food grains,
(iii) Increase in employment. Retards migration to cities for livelihood,
(iv) Improvement in groundwater storage,
(v) Increased revenue to government from other departments such as custom, excise, posts and telegraph, railways, taxes on vehicles etc.,
(vi) Increase in value of land property,
(vii) General development of country,

(viii) Farm labourers are benefited who get higher wages,
(ix) Creation of more jobs and incomes, and
(x) Rise to whole array of agro-based industries.

1.6 DEMERITS OF IRRIGATION

(i) Climate becomes damp and cold, causing malarial diseases,

(ii) Over irrigation coupled with poor drainage in an areas where water-table is high leads to water logging of the area and causes efflorescence. Crop yield is drastically reduced as a result,

(iii) Low land revenue in certain cases where irrigation is extended as a protective measure, and

(iv) Excessive seepage from unlined canals leads to water logging of lands adjacent to canals.

1.7 ENVIRONMENTAL EFFECTS OF IRRIGATION '

Environmental impacts of irrigation are the changes in quantity and qualityof soil and water as a result of irrigation and the ensuing effects on natural and social conditions at the tail-end area of the river basin and downstream of an irrigation scheme. The impacts stem from the changed hydrological conditions owing to the installation and operation of the scheme. An irrigation scheme often draws water from the river and distributes it over the irrigated area. As a hydrological result it is found that:

- the downstream river discharge is reduced
- the evaporation in the scheme is increased
- the groundwater recharge in the scheme is increased
- the level of the water table rises
- the drainage flow is increased

These may be called direct effects.

The effects thereof on soil and water quality are indirect and complex, water logging and soil salination are part of these, whereas the subsequent impacts on natural, ecological and socio-economic conditions are very intricate. Irrigation can also be done extracting groundwater by (tube)wells. As a hydrological result it is found that the level of the water descends. The effects may be water mining, land/soil subsidence, and, along the coast, saltwater intrusion. Irrigation projects can have large benefits. The irrigated area occupies world wide about 16% of the total agricultural area, yet the crop yield is roughly 40% of the total yield. However, the negative side effects are often overlooked The reduced downstream river discharge may cause:

- reduced downstream flooding
- disappearance of ecologically and economically important wetlands or flood forests
- reduced availability of industrial, municipal, household, and drinking water
- reduced shipping routes.

In India, barrages control all of the tributaries to the Ganges and divert roughly 60 percent of river flow to irrigation.

Increased groundwater recharge, waterlogging, soil salinity

An environmental impact of upstream irrigation developments causing an increased flow of groundwater to this lower lying area leading to the adverse conditions. The increased groundwater recharge stems from the unavoidable deep percolation losses occurring in the irrigation scheme. The lower the irrigation efficiency, the higher the losses. Although fairly high irrigation efficiencies of 70% or more (i.e. losses of 30% or less) can be obtained with sophisticated techniques like sprinkler irrigation and drip irrigation, or by precision land levelling for surface irrigation, in practice the losses are commonly in the order of 40 to 60%. This may cause:

- rising water tables,
- increased storage of groundwater that may be used for irrigation, municipal, household and drinking water by pumping from wells,
- waterlogging and drainage problems in villages, agricultural lands, and along roads with mostly negative consequences. The increased level of the water table can lead to reduced agricultural production.

Reduced downstream drainage and groundwater quality

- The downstream drainage water quality may deteriorate owing to leaching of salts, nutrients, herbicides and pesticides with high salinity and alkalinity. There is threat of soils converting into saline or alkali soils. This may negatively affect the health of the population at the tail-end of the river basin and downstream of the irrigation scheme, as well as the ecological balance.
- The downstream quality of the groundwater may deteriorate in a similar way as the downstream drainage water and have similar consequences.

Reduced downstream river water quality

Owing to drainage of surface and groundwater in the project area, which waters may be salinized and polluted by agricultural chemicals like biocides and fertilizers, the quality of the river water below the project area can deteriorate, which makes it less fit for industrial, municipal and household use. It may lead to reduced public health. Polluted river water entering the sea may adversely affect the ecology along the sea shore

Affected downstream water users

Flood-recession cropping may be seriously affected by the upstream interception of river water for irrigation purposes.

Lost land use opportunities

Irrigation projects may reduce the fishing opportunities of the original population and the grazing opportunities for cattle. The live stock pressure on the remaining lands may increase considerably, because the ousted traditional pastoralist tribes will have to find their subsistence and existence elsewhere, overgrazing may increase, followed by serious soil erosion and the loss of natural resources.

Flooding as a consequence of land subsidence

When more groundwater is pumped from wells than replenished, storage of water in the aquifer is being mined. Irrigation from groundwater is no longer sustainable then. The result can be abandoning of irrigated agriculture.

Impacts on Environment

Changes in landuse of area and changes within ecosystems for purposes of agricultural production, along with application of irrigation, have direct impacts on biosphere. Transition of non-fertile land with specific ecosystems developed (wetland, forest and meadow ecosystems with great biological diversity), which was common practice not so long ago is now forbidden and not practised any more. Secondary or indirect impacts on biosphere as a consequence of irrigation may appear with significant reduction of ground water levels which impairs biological conditions within ecosystem. According to the Law on environmental protection (OG 82/94) the main aims of environmental protection are permanent preservation of biological diversity of natural communities and preservation of ecological stability, followed by preservation of quality of living and non-living environment and rational use of natural resources, preservation and regeneration of cultural and aesthetic values of landscape and improvement of environmental.

1.8 CLASSIFICATION OF IRRIGATION PROJECTS

The irrigation projects are classified as

1. Classification Based on Source of Water

(i) Direct Irrigation Project: In this project, water is directly diverted from the river into the canal by the construction of a diversion weir or barrage across the river with some pondage to take care of diurnal variations as also to raise water level to feed the off taking channel.
(ii) Indirect Irrigation Project. In this project, water is stored in a reservoir with the construction of a dam across the river or stream to provide dependable supply into the off taking canals.

2. Classification Based on Purpose Served

(i) Single Purpose Irrigation Project: A single purpose irrigation project, as the name implies, is meant for a particular purpose *i.e.*, irrigation. The pre-independence irrigation projects were mostly single purpose, but the necessity to derive the maximum benefits from the surface water resources inevitably led to the concept of multipurpose projects.
Multipurpose Irrigation Project. It is a project which is constructed for two or more purposes such as irrigation, flood control, power generation, navigation, domestic and industrial water supply etc. etc.

3. Classification Based on Administrative Convenience

Major project ,Multipurpose river valley projects, barrages, weirs etc.
Low earthen dams and canal irrigation schemes Extension of irrigation, tube well and well irrigation, lift irrigation

4. Classification Based on Financial Return

(i) Productive Irrigation Projects: Productive irgation projects are those the benefit-cost ratio in respect of which is not less than 1.5: .
(ii) Unproductive Irrigation Projects: Unproductive irrigation projects are those the benefit~cost ratio in respect of which is less than 1.5.
(iii) Protective Irrigation Projects: Protective irrigation projects are unproductive but taken up as for protection against famine and are financed from famine relief fund.
C.C.A. (ha) Over 10,000
Medium project Minor project
10,000-2,000 Less than 2,00

1.9 CONSUMPTIVE USE OF WATER

Considerable part of water applied for irrigation is lost by evaporation and transpiration. The processes being difficult to separate are taken as one and called evapo-transpiration or consumptive use. Consumptive use is thus the sum of two terms

Water deposited by dew, rainfall or irrigation and subsequently evaporated without entering the plant system is part of consumptive use. Consumptive use is expressed in water depth or depth area units per unit area for periods such as days, months or seasons. Consumptive use of water by a crop is the depth of water consumed by the plant in transpiration and evaporation during the crop growth.

Optimum consumptive use: It is the consumptive use which produces a maximum crop yield.

Potential evapo-transpiration: It is the amount of water transpired by a green crop of about the same colour as green grass, which completely covers the ground, and which has an adequate water supply.

Seasonal consumptive use: Depths of water consumed by evapotranspiration during crop growth till maturity including water used by accompanying weed growth.

Consumptive Irrigation Requirement (CIR)

It is the amount of irrigation water required to meet the consumptive use of crop during the growth period. It is the same as consumptive use exclusive of effective precipitation, stored soil moisture or groundwater.

CIR = C_u-Re

where, C_u = consumptive use, and R_e = rainfall effective *i.e.* the rainfall falling during the growth period of a crop and is available to meet evapotranspiration needs of the crop exclusive of the rainfall lost through deep percolation below the root zone or the water lost as surface runoff.

Net Irrigation Requirement (NIR)

It is the amount of irrigation water required to meet the evapotranspiration need of the crop as also other needs such as leaching.

NIR = $C_u - R_e + L_e$

where, L_e = water lost as percolation in satisfying other needs like leaching

Determination of Consumptive Use

Consumptive use can be measured or estimated by following methods:

1. Direct Measurement

Climatic conditions: The rate of evapotranspiration principally depends on *(a)* climate, *(b)* supply of soil moisture, *(c)* plant cover, *(d)* soil type and structure, and *(e)* land management. When the soil moisture is maintained at the optimum, land management and soil type or structure have little effect on the rate of evapotranspiration. When the root zone of the soil is well supplied with water, the amount used by vegetation depends more on the amount of solar energy received by the surface and the resultant temperature than on the kind of vegetation grown in the area. The water loss under optimum conditions of soil moisture, the potential evapotranspiration, thus appears to be determined principally by climatic conditions.

Field plot method: It is a more reliable method and is based on natural conditions. Irrigation water is applied to experimental field plots such that there is no runoff or deep percolation. In irrigated land, water input, *i.e.,* water applied for irrigation, rainfall water and outflow are measured and the fraction of water applied that does not runoff, adjusted for changes in soil moisture, is taken as evapotranspiration, usually in terms of cm of depth. Deep percolation, being not susceptible to precise measurement, introduces an error in the result and in order to limit it irrigation water is applied in small quantities.

Tanks and lysimeters: It is a reliable method provided the tanks and lysimeters are properly designed and the soil within the tank simulates approximately field conditions and plant density

1.10 DUTY, DELTA AND BASE PERIOD

Base Period: It is the time in days between first watering of a crop at the time of sowing to its watering before harvesting.
Delta: It is an expression used in irrigation practice to mean the depth of water that would be supplied over a given area from a given discharge for a certain length of time.
Delta is the total depth of water in cm required by a crop to come to maturity. It depends on the amount of each watering and the interval between successive waterings during the base period
Duty: Duty or duty of water is the relation between the area irrigated, or to be irrigated, and the quantity of water used, or required to irrigate it for the purpose of maturing its crop.

It may be defined as the area irrigated by unit discharge which means the number of hectares under a particular crop brought to maturity by a constant supply of 1 cubic of water per second flowing continuously for the base period.
Cumec day: A unit of volume used in irrigation practice and means the volume of water resulting from a discharge of 1 cumec for one day (24 hours). It amounts to 8.64 hectare meters.

1.11 RELATION BETWEEN DUTY AND DELTA:

Let D = duty of water (hectares/cumec),
B = base period (days), and Δ = delta of water (m).
(i) Volume of one cubic metre flowing for one day = $1 \times 24 \times 60 \times 60 = 86{,}400$ m^3 = 8.64 ha m.
(ii) Volume of one cubic metre flowing for B days = 8.64 B (ha m).
(iii) By the definition of duty *(D)*, one cubic metre = 10^4 D m^2 of area supplied for B days matures D hectares of land.
Total depth of water applied on the land = Volume/area = $86400B/10^4$ D. = 8.64 B/D metre
(iv) Now, delta is total depth of water, ie 8.64 B/D m

or D = 8.64 B/Δ m

D = 864 B/Δ cm Hence, delta (Δ) = 864 B/D m
where, Δ = delta (cm), B = base period (days), and D = duty (hectares/cumec).

Gross duty: It is the duty of water measured at the source of diversion of irrigation supplies.
Nominal duty: It is the duty sanctioned as per schedule of an irrigation department
Economic water duty: It is the duty of water which results in the maximum yield, *(i)* per unit area when land is the limiting factor, and *(ii)* per unit of irrigation water when water is the limiting factor.
Designed duty: It is the duty of water assumed in an irrigation project for designing capacities of the channels.

1.12 FACTORS AFFECTING DUTY

Various factors affecting duty of water are

(i) Kind of Crop Grown: Different crops require different amounts of water and hence have different duties. Duty of water for a crop requiring more water is less and vice versa. Obviously duty of water for rice is less than that for wheat,

(ii) Nature of Soil: Evidently porous soil under a crop has less duty due to high absorption loss. Duty of water is more in heavy (clay) soils than light (sandy) soils,

(iii) Cultivation Methods: Properly ploughed and tilled field before irrigation retains higher amount of water in its saturated zone, thereby reducing the number of waterings and increasing the duty. Better tillage envisages less evaporation losses from soil surface, besides soil is properly aerated and results in better yield. More efficient the cultivation method, higher is the duty,

(iv) Method of Water Application: The more efficient the mode of application of water, higher is the duty. Flooding irrigation system has lesser duty than furrow irrigation. Basin irrigation too has less duty. Sub-irrigation system has higher duty. Sprinkler and drip irrigation have the highest duty, *(v) Irrigation System:* Perennial irrigation system has higher duty than inundation canal system, because in the former case not only the soil is continuously moist requiring lesser amount of water for initial saturation of soil but also there is lesser wasteful use of water than in the latter system of irrigation. Gravity flow irrigation has lesser duty due to transmission losses in the canal water. Tube well irrigation and tank irrigation have higher duty of water due to low transmission losses and more efficient use of water,

(vi) Water Quality: Better the quality of water, higher is the duty of water and vice versa. Liberal quantity of water is required to be applied to leach off salts in case the water is of inferior quality,

(vii) Climate and Season: Since water duty includes losses of water which, in turn, vary with climate and season, more precisely temperature, humidity, wind velocity, etc., the duty, therefore, varies from season to season and from time to time, during the same season. The values of duties for various crops generally referred to are the average values considered over whole crop period,

(viii) Rainfall: Useful rainfall in the crop period meets the part requirement of water and hence duty of water is higher. Duty exclusive of rainfall is low,

(ix) Base Period: Different crops have different base periods. Smaller the base period lesser is the amount of water required and higher is the duty and vice versa,

(x) Method of Assessment: Volumetric system of assessment implies more efficient and economical use of water and hence higher duty of water because the cultivator has the tendency to cultivate more area with the same amount of water. In the area under conventional method of assessment, the duty is low, because the farmer has a tendency to use more water in the same area.

(xi) Canal Section: Earthen section of the canal entails more transmission losses and hence low duty of water. Lined section results in low transmission losses and hence higher duty of water. Canal Network: Canal with small network, *i.e.,* having concentrated command area means higher duty of water and vice versa, and

(xii) Topography of Land: A level field means uniform application of water, but if it is not level, low portions receive more depth of water than higher level portions which implies wasteful use of water and hence less duty. Properly leveled field means more economical use of water and high duty.

1.13 METHODS OF IMPROVING DUTY

Various methods of improving duty are

(i) Land should be properly ploughed, and tilled,

(ii) Correct quantity and timing of water application mean higher duty. Drip irrigation is the most modern and efficient water application method,

(iii) Canals be lined to cut down transmission losses in the canal system. Higher velocity in lined section also results in reduced evaporation losses,

(iv) The canal should be nearest to the command area so that idle length of the canal is minimum and hence reduced transmission losses,

(v) Good quality of water should be used for irrigation. Pollution of the canal should be avoided. Canal alignment through the soils which may dissolve harmful salts in the canal water should be avoided,

(vi) Rotation of crops be practiced, and *(vii)* Volumetric assessment of water is enforced so that efficient and economical use of the canal water is made by the cultivators.

1.14 IRRIGATION SYSTEM EFFICIENCY

Irrigation system efficiency, implies minimum loss from the time water is taken from the canal outlet till it becomes available in the root zone for plant utilization. The objective of the efficiency concept is to show where improvements can be made so as to have more efficient irrigation. Method of measurement and evaluation of performance in terms of efficiency are pre-requisites for proper use of irrigation water. Generally speaking water use in an irrigation project under development has lower efficiency. However, as water becomes more and more scarce and as the need for it becomes more pressing, its utilization improves. Various concepts of irrigation efficiencies are as under:

1. *Irrigation Efficiency:* It is defined as the ratio of water output to the water input, *i.e.,* the ratio or percentage of the irrigation water consumed by the crops of an irrigated farm, field or project to the water delivered from the source of supply and is usually expressed as percentage. In view of water losses occurring at various stages before the plants ultimately utilize it, several partial efficiencies have been defined. For maximum overall efficiency the various partial efficiencies should individually be maximum:
In most irrigation projects, the irrigation efficiency ranges between 12 to 34 per cent.

2. *Water Conveyance Efficiency:* It is a measure of efficiency of water conveyance system from canal network to watercourses and field channels. It is the ratio of water delivered in fields at the outlet head to that diverted into the canal system from the river or reservoir. Water losses occur in conveyance from the point of diversion till it reaches the farmer's fields which can be evaluated by water conveyance efficiency, as under:

$E_e = (W/W) \times 100$

where, E_c = water conveyance efficiency, per cent, W_f = water delivered to the farm by conveyance system (at field supply channel), and *W,* = water introduced into the conveyance system from the point of diversion.
Water conveyance efficiency is generally low; about 21 % losses occur in earthen watercourses only.

3. *Water Application Efficiency:* It is a measure of efficiency of water application in the field. It is the ratio of volume of water that is stored in the root zone of crops and ultimately consumed by transpiration or evaporation or both to the volume of water actually delivered at the field. Alternatively, it may be defined as the percentage of water applied that can be accounted for as

increase in soil moisture in soil as occupied by principal rooting system of the crop. It is also termed as *farm efficiency* as it takes into account water lost in application at the farm.

$Eo = (W/W_f) \times 100$

where, E_a = water application efficiency, percent, W_s = irrigation water stored in the root zone of farm soil, and W_f = irrigation water delivered to the farm (at field supply channel).

In general, water application efficiency decreases as the amount of water during each irrigation increases. Water losses due to inefficient application of water in the field vary from 28 to 50 percent.

Common sources of loss of irrigation water during application are represented as R_f = surface runoff from the farm, and D_f = deep percolation below the farm root zone soil. Neglecting evaporation losses during application:

$W_f = W_s + D_f + R_f$

$$E_a = \left[\frac{Wj-(Dj+R_j)}{W_j}\right] \times 100$$

4. *Water Use Efficiency:* Having conveyed water to the point of use and having applied it, the next efficiency concept of concern is the efficiency of water use. It is expressed in kg/ha cm. The proportion of water delivered and beneficially used on the project can be calculated using the following formula:

$E'' = (W JW) \times 100$

where, E'' = water use efficiency, percent, W'' = water beneficially used, and W_d = water delivered.

Water use efficiency is also defined as *(i)* crop water use efficiency and *(ii)* field water efficiency.

(a) Crop Water Use Efficiency: It is the ratio of yield of crop (Y) to the amount of water depleted by crop in evapo-transpiration *(En i.e., YIET.*

(b) Field Water Use Efficiency: It is the ratio of yield of crop (Y) to the total amount of water used in the field *i.e., Y/WR.*

5. Water Storage Efficiency: Also termed as water storage factor. It is defined as the ratio of the water stored in the root depth by irrigation to the water needed in the root depth to bring it to the field capacity *i.e.,* $E_s = (W$ jWJ x 100

where, E_s = water storage efficiency, percent, W_s = water stored in the root zone during the irrigation, and W_w = water needed in the root zone prior to irrigation, *i.e.,* field capacityavailable moisture.

6. Water Distribution Efficiency: It is the expression for distribution efficiency to evaluate the extent to which the water is uniformly distributed .

A water distribution efficiency of 80% means that 10% of water was applied in excess and consequently 10% was deficient in comparison to the average depth of application.

7. Consumptive Use Efficiency: It is defined as the ratio of consumptive water use by the crop of irrigated farm or project and the irrigation water stored in the root zone of the soil on the farm or the project area. After irrigation water is stored in the soil, it may not be available for use by the crop because water may evaporate from the ground surface or continuously move downward beyond the root zone as it may happen in a wide furrow spacing. The loss of water by deep penetration and by surface evaporation following an irrigation is evaluated.

Consumptive use efficiency is useful in explaining the difference in crop response from different methods of irrigation.

POSSIBLE QUESTIONS

1. Define irrigation. Explain the necessities of irrigation.
2. What are the merits and demerits of irrigation?
3. Define consumptive use of water. Also explain the different methods of determining the consumptive use.
4. Derive the relation between duty, delta &base period.
5. Explain about the classification of irrigation projects.
6. Define crop season & explain its types
7. The gross command area of an irrigation project is 1 lakh hectares. The culturable Command area is 75% of G.C.A. The intensities of irrigation for kharif and rabi are 50% and 55% respectively. If the duties for kharif and rabi are 1200 hectare/cumec and 1400 hectare/cumec respectively, determine the discharge at the head of the canal considering 20% provisions for transmission loss, overlap allowance ,evaporation loss etc
8. Explain in detail about (i) Irrigation Effiency (ii)Frequency of irrigation
9. Explain briefly about the drip irrigation? What are the advantage and disadvantage of this method?
10. Differentiate between drip and sprinkler irrigation.
11. Explain the term duty and explain in detail about the various factors affecting duty and various methods of improving duty.
12. Explain in detail about environmental impacts of irrigation
13. What are the different factors affecting the water requirement.
14. A channel is to be designed for irrigating 5000ha in kharif crop and 4000ha in rabi crop.The water requirement for kharif and rabi are 60 cm and 25 cm respectively. The kor period for kharif is 3 weeks and for rabi is 4 weeks. Determine the discharge of the channel for which it is to be designed
15. Define any eight of the following terms.
    (i) Gross Command Area (ii) Culturable Command Area (iii) Intensity of irrigation
    (iv) Crop ratio (v) Crop Seasons (vi) Crop rotation (vii) Crop period
    (viii) Time factor (ix) Capacity factor (x) Number of watering.
16. What are the different methods of distribution of water? Explain in detail about it.

2. PRECIPITATION

2. TERMS RELATED TO HYDROLOGY

Catchment Area The catchment area of a river means the area from where the surface run off flows to that river through the tributaries, streams, springs etc. The area is bounded by watershed line.

Run-off When it rains, some portion of rain water infiltrates into the soil, some is intercepted by vegetation, some evaporates and the remaining portion flows over the ground surface to join the rivers, streams, lakes etc. This portion of water which flows over the ground surface is known as surface run off or run-off.

The surface run off is also designated by rainfall excess or effective rainfall

2.1 DEFINITION

The science of studying the different forms of water available above the earth surface or below the earth surface is known as hydrology. It includes the following points

1. The measurement of precipitation, (i.e. rainfall).
2. The study of water losses due to transpiration, evaporation; absorption and infiltration.
3. Estimation of run-off and peak flow.
4. The procedure of river gauging.
5. Preparation of hydrograph to predict maximum food discharge.
6. The procedure of river training works.
7. The procedure of flood forecasting and flood control works.
8. Availability of underground water.

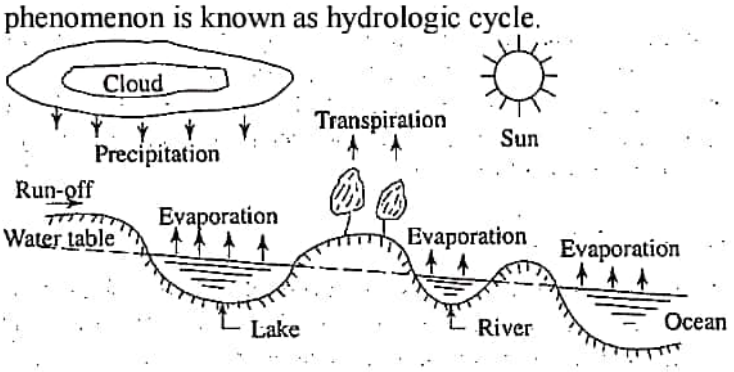
IMPORTANCE OF HYDROLOGY

Hydrology is very essential for the applications:

(a) Determination of the capacity of a reservoir from the rainfall records and the yearly discharge observation of a river.
(b) Determination of peak flow of a river.
(c) Determination of suitable site for hydro-electric power generation.
(d) Sources of water supply in a town Or city.
(e) Methods to be adopted for the flood control.

2.2 HYDROLOGIC CYCLE

The water of the universe always changes from one state to other under the effect of the sun. The water from the surface sources like lakes, rivers, ocean, etc. converts to vapour by evaporation due to solar heat. The vapour goes on accumulating continuously in the atmosphere. This vapour is again condensed due to the sudden fall of temperature and pressure. Thus clouds are formed. These clouds again causes the precipitation (i.e. rainfall). Some of the vapour is converted to ice at the peak of the mountains. The ice again melts is summer and flows as rivers to Meet the sea or ocean. These processes of evaporation, precipitation and melting of ice go on continuously like an endless chain and thus a balance is maintained in the atmosphere. This phenomenon is known as hydrologic cycle.



2.3 PRECIPITATION

Definition : From the principle of hydrologic cycle we have seen that water goes on evaporation continuously from the water surfaces on earth,(e g. river, lake, sea, ocean, etc.) by the effect of sun. The water vapour goes collecting in the atmosphere up to a certain limit. When this limit exceeds and the temperature and pressure fall to a certain value, the water vapour will get condensed and thereby cloud is formed. Ultimately droplets are formed and returned to earth in the form of rain, snowfall, hail, etc. This is known as precipitation. (Simply, the definition of precipitation is any form of water - liquid or solid - falling from the sky. It includes rain, sleet, snow, hail and drizzle plus a few less common occurrences such as ice pellets, diamond dust and freezing rain.)

2.4 Forms of Precipitation

Liquid precipitation

- **Rain**

Rain is drops of liquid water falling from the sky. In order for the raindrops to become heavy enough to fall, droplets of water in the cloud collide together with other droplets and other particles in the air - like soot and dust - to become larger. Once the drops become too heavy to stay in the cloud, we get rain.

There are three main types of rainfall - frontal rain, orographic rain and convective rain.

Size: Raindrops can be up to 6 mm in diameter, but anything less than 0.5 mm in diameter is classed as drizzle.

- **Drizzle**

Drizzle consists of very small droplets of water falling from low level stratus clouds.

In the UK we're very familiar with drizzle. As we have a mild temperate climate we don't tend to get the extreme temperatures that can cause heavy rain, but our prevailing winds from the Atlantic pick up lots of moisture, and therefore clouds, as they travel over the sea.

Size: Drizzle droplets are less than 0.5 mm in diameter - larger than the droplets in clouds, but smaller than raindrops.

- **Freezing rain**

Freezing rain is rain droplets which fall in supercooled liquid form, but freeze on impact with the ground or another object to form clear ice - also known as glaze. Supercooling occurs in clouds where droplets remain in a liquid from in temperatures below the normal freezing point. In order for the supercooled droplets to freeze on impact, the ground temperature is normally close to or below 0 °C.

Size: Freezing rain can fall as rain droplets or drizzle.

Solid precipitation

- **Hail**

Hail is solid precipitation in the form of balls or pieces of ice known as hailstones. Hail only forms in cumulonimbus clouds - more commonly known as thunder clouds.

In thunderclouds, drops of water are continuously taken up and down though the cloud. When they go to the top of the cloud, it is very cold and they freeze. As the updraughts in thunderclouds are very big, they can keep these hailstones for a long time, so they get larger and larger by becoming coated with more and more ice. Then, when they get really big, the updraughts in the cloud cannot hold them up anymore and they fall to earth, and by this time they are big balls of ice, and so don't have time to melt before they reach the ground. Hail can only be formed in this way, unlike snow which can be formed in fronts, and orographically too, just like rain.

Size: Hailstones can vary in size from 5 mm to 150 mm in diameter, however most hailstones are smaller than 25 mm.

- **Ice pellets**

Ice pellets are snowflakes which have started to melt, and then re-frozen as they fall through colder air. The result is a grainy snow pellet encased in ice. Ice pellets are generally smaller than hailstones and bounce when they hit the ground.

- **Snow**

Snow is tiny ice crystals stuck together to become snowflakes. If enough ice crystals stick together, they'll become heavy enough to fall to the ground.

- **Sleet**

Sleet has no internationally agreed definition but is reported in meteorological observations as "rain and snow mixed". Sleet, which is sometimes known as ice pellets, is basically snow which has begun the melting process before it reaches the ground.

- **Snow grains**

Snow grains are very small white and opaque grains of ice, less than 1 mm in diameter.
Size: Less than 1 mm in diameter.

- **Diamond dust**

Diamond dust, sometimes just called ice crystals, consists of extremely small ice crystals, usually formed at low levels at temperatures below -30 °C. The name diamond dust comes from the sparkling effect created when light reflects on the ice crystals in the air.

Depending upon the size of the falling droplets from the cloud, precipitation may occur in the form of Drizzle, rain or hail

Drizzle –	40- 500	microns in diameter with 1m/ sec falling speed.
Rain Drops-	500-4000	microns in diameter with 10m/ sec falling speed.
Hail stones-	10,000-50,000	microns in diameter with 20-50m/ sec falling speed.

(Forms of Precipitation:

1. Drizzle: When the size of water droplet is under 0.5 mm and its intensity is < 0.01 mm/h.
2. Rain: The size of the drops is more than 0.5mm. The upper size of water drop is generally 6.25 mm, as drops greater than this tend to break up as they fall through the air.
3. Glaze: When the drizzle or rain freezes as it comes in contact with cold object, it is known as glaze.
4. Sleet: It is frozen raindrops cooled to the ice stage while falling through air at sub-freezing temperature (about 4 or 5 degrees centigrade).
5. Snow: precipitation in the form of ice crystals resulting from sublimation (i.e. water vapor changed directly to ice).
6. Snow flakes: Number of ice crystals fused together form snowflakes.

Hail: Lumps or bulbs of ice over 5mm diameter formed by alternative freezing or melting as they are carried up & down in highly turbulent air currents.

Forms of Precipitation

Rain – Precipitation in the form of water drops of size larger than 0.5mm. The maximum raindrop size is about 6mm. Drops of larger size break up into smaller drops as it falls down. It is the major form of precipitation in India.

Snow – Consists of ice crystals in flaky form (average density ~ 0.1g/cc). It is also an important form of precipitation. Occurs in the Himalayan region in India.

Drizzle – A fine sprinkle of tiny water droplets of size < 0.5mm and intensity < 1mm/h. The tiny drops forming a drizzle appear to float in air.
Glaze (Freezing Rain) – Formed when rain or drizzle comes in contact with cold ground at around 0 deg C. The water drops freeze to form an ice coating.
Sleet – Frozen rain drops formed when rain falls through air at subfreezing temperature.
Hail – Showery precipitation in the form of pellets or lumps of size >8mm. These occur in violent thunderstorms.

Characteristics of Precipitation in India

The Indian subcontinent has two major seasons and two transition periods as follows:

- **South-West Monsoon** (June to September) – the major rainy season in most parts of India (except the SE part of the peninsula and J&K) accounting for about 75% of the annual rainfall. Monsoon winds advance across the country in two branches viz. the Arabian sea branch and the Bay of Bengal branch. A low pressure region called monsoon trough is formed between the two branches extending from the Bay of Bengal to Rajasthan. The precipitation pattern over the country is determined by its position.
- **Post Monsoon (North-East Monsoon)** (October-November) – As the SW monsoon retreats, low pressure regions form in the Bay of Bengal and a north-easterly flow of air that picks up moisture in the Bay of Bengal is formed. This strikes the east coast of the peninsula causing rain. Also several tropical cyclones form in the Bay of Bengal and the Arabian Sea during this period.

Winter (December to February) Western disturbances cause moderate to heavy rainfall and snowfall in the Himalayas and J&K.
Summer (Pre-monsoon – March to May) – Convective cells cause some rain.

Rainfall intensity is classified according to the rate of precipitation:

- Light rain — when the precipitation rate is < 2.5 mm (0.098 in) per hour
- Moderate rain — when the precipitation rate is between 2.5 mm (0.098 in) - 7.6 mm (0.30 in) or 10 mm (0.39 in) per hour
- Heavy rain — when the precipitation rate is > 7.6 mm (0.30 in) per hour, or between 10 mm (0.39 in) and 50 mm (2.0 in) per hour
- Violent rain — when the precipitation rate is > 50 mm (2.0 in) per hour)

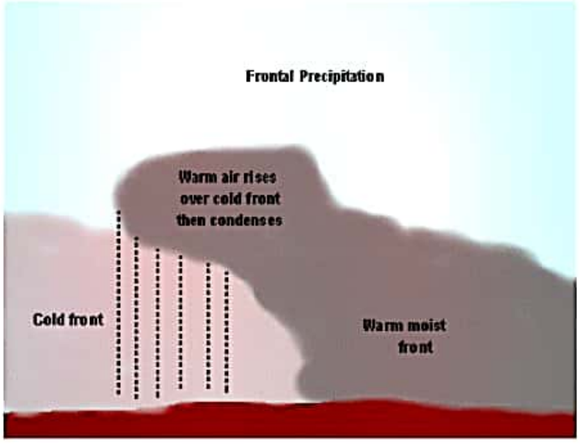
2.4.2 Types of Precipitation or Rainfall

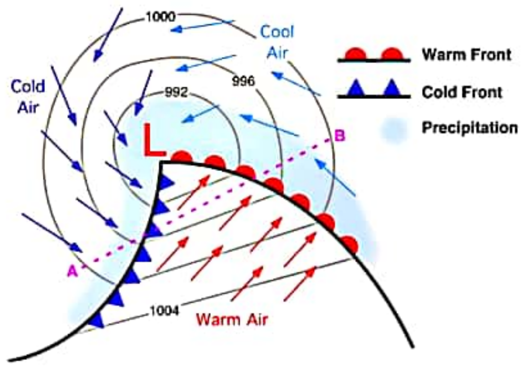
Depending upon the various atmospheric conditions the precipitation may be of the following types.

1. ***Cyclonic Precipitation*** This type of precipitation is caused by the difference of pressure within the air mass on the surface of the earth. If low pressure is generated at some place the warm moist air from the surrounding area rushes to the zone of low pressure with violent force. The warm moist air rises up with whirling motion and get condensed at higher altitude and ultimately heavy rainfall occurs. This may be of two types.
   (a) Frontal Precipitation When the moving warm moist air mass is obstructed by the zone of cold air mass, the warm moist air rises up (as it is lighter than cold air mass) to higher altitude where it gets condensed and heavy rainfall occurs .

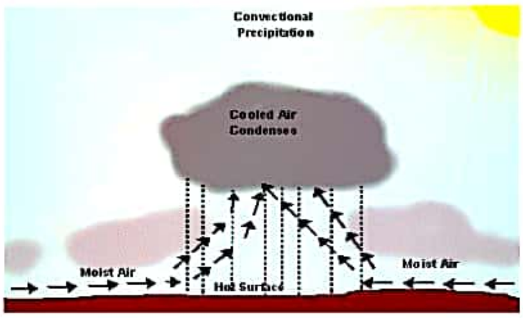
This is known as frontal precipitation.

(b) Non Frontal Precipitation When the warm moist air mass rushes to the zone of low pressure from the surrounding area, a pocket is formed and the warm moist air rises up like a chimney towards higher altitude. At higher altitude this air mass gets condensed and heavy, rainfall occurs. This is known as non frontal precipitation.

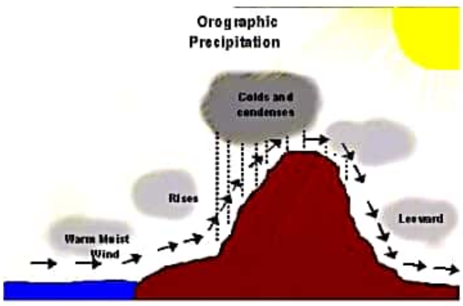




2. ***Convective Precipitation*** In tropical countries when on a particular hot day the ground surface gets heated unequally, the warm air is lifted to high altitude and the cooler air takes its place with high velocity. Thus, the warm moist air mass is condensed at the high altitude causing heavy rainfall, This is known as convective precipitation.



3. ***Orographic Precipitation*** The moving warm moist air when obstructed ,by some mountain rises up to a high altitude. It then gets condensed and precipitation occurs. This is known as orographic precipitation



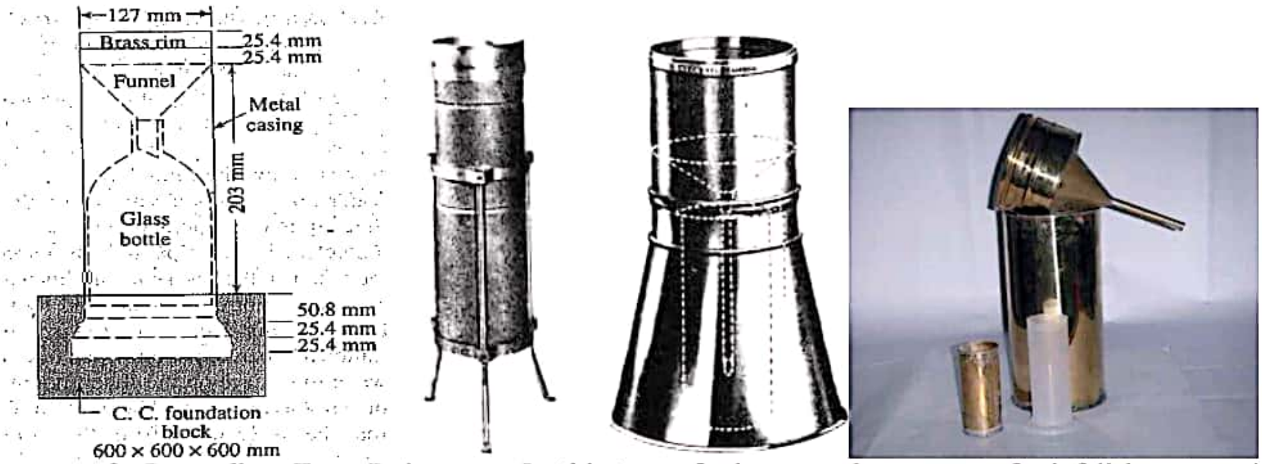
2.4.3 Rain Gauge

The instrument which is used to measure the amount of rainfall is known as rain gauge.
The principle of rain gauge is that the amount of rainfall in a small area will represent the amount of rainfall in a large area provided the meteorological characteristics of both small and large area are similar.

The rain gauges are of the following types.

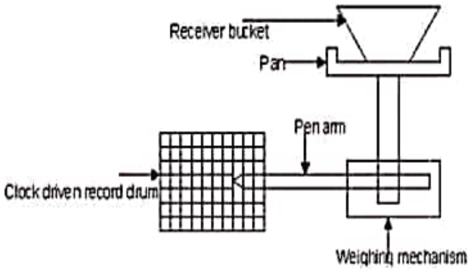
1. Non-Recording Type Raingauge Simon's raingauge is a non-recording type of raingatige which is most commonly used. It consists of metal casing of diameter 127 mm which is set on a concrete foundation A glass bottle of capacity about 100 mm of rainfall is placed within the casing. A funnel with brass rim is placed on the top of the bottle. The arrangement is shown in Fig The rainfall is recorded at every 24 hours. Generally, the measurement is taken at 8.30 a.m. everyday. In case of heavy rainfall the measurement should be taken 2 or 3 times daily so that the bottle does not overflows. To measure the amount of rainfall the glass bottle is taken off and the collected water is measured in a measuring glass, and recorded in the raingauge record book. When the glass bottle is taken off it is immediately replaced with a new bottle of same capacity.

Simon's raingauge



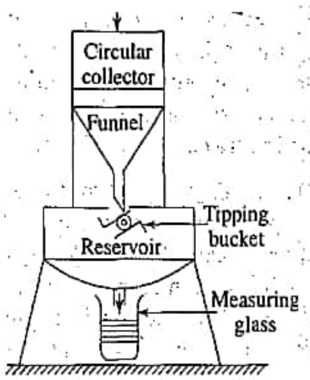
2. Recording Type Raingauge In this type of raingauge, the amount of rainfall is automatically recorded on a graph paper by some mechanical device. Here, no person is required for measuring the amount of rainfall from the container in which the rain water is collected. The recording type raingauge may be of three types.

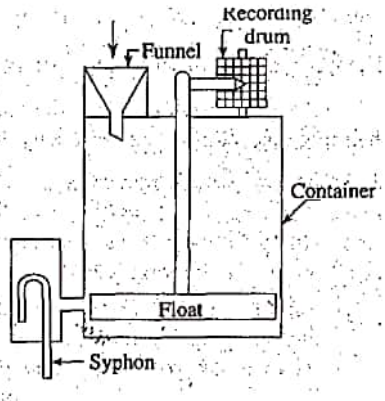
- ***Weighing Bucket Raingauge*** This type of raingauge consists of a receiving bucket which is placed on pan. The pan is again fitted with some weighing mechanism. A pencil arm is pivoted with the weighing mechanism in such a way that the movement of the bucket can be traced by a pencil on the moving recording drum. So, when the water is collected in the bucket the increasing weight of water is transmitted through the pencil which traces a curve on the recording drum. The raingauge produces a graph of cumulative rainfall- versus time and hence it is some times called Integrating raingauge. Thegraph is known as the mass curve of rainfall



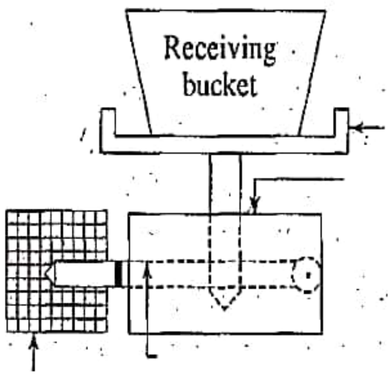
(b) Tipping Bucket Raingauge It consists of a circular collector of diameter 30 cm in which the rain water is initially collected. The rain water then passes through a funnel fitted to the circular collector and gets collected in two-compartment tipping buckets pivoted below the funnel.

When 0.25 mm rain water is collected in one bucket then it tips and discharges the water in a reservoir kept below the buckets. At the same time the other bucket' comes below the funnel and he rainwater goes on collecting in it. When the requisite amount of rainwater is collected, it also tips and discharges the water in the reservoir. In this way, a circular motion is generated by the buckets. This circular motion is transmitted to a pen or pencil which traces a wave like curve on the sheet mounted on a revolving drum. The total rainfall may be ascertained from the graph. There- is an opening with stopcock at the bottom of the reservoir for discharging the collected rainwater; Sometimes a measuring glass is provided to verify the results shown by the graph.





FLOAT TYPE RAIN GAUGE



(c) Float Type Rain gauge In this type of rain gauge; a funnel is provided at one end of a rectangular container and a rotating recording drum is provided at the other end. The rain water, enters the container through the funnel. A float is provided within the container which rises up as the rain water gets collected there. The float consists of a rod which contains a pen arm for recording the amount of rainfall on the graph paper wrapped on the recording drum. It consists of a syphon which starts functioning when the float rises to some definite height and the container goes on emptying gradually.

Radar Measurements

In an integrated system for measurement of rainfall, raingauges are used for measuring the total amount as well as intensity of a rainstorm and a microwave radar (wavelength ~ 3 to 10cm) is used for determining the areal extent, location, and movement of rainstorms. Also the amount of rainfall over large areas can be determined using radars with a good degree of accuracy.

- The hydrological range of radar is about 200km.
- Heavy rains – 10 cm radar
- Light rains and snow – 5cm radar
- Doppler type radars are used for measuring the velocity and distribution of raindrops.

Selection of Site for Raingauge Stations The following points should be considered while selecting a site for rain gauge station.

(a) The site should be on level ground and on open space. It should never be on sloping ground.
(b) The site should be such That the distance between the gauge station and the objects pike tree, building etc) should be at least twice the height of the objects.
(c) In hilly area where absolutely level ground is not available, the site should be so selected that the station may be well shielded from high wind.
(d) The site should be easily accessible to the observer.
(e) The site should be well protected from cattle's by wire fencing.

Network of Raingauges The network of raingauge stations should be properly designed to cover the whole area of the basin. A guide line has been set up by the World Meteorological Organisation (WMO) for the network of raingauge stations.

(a) For plain region—one station for every 600-900 sq. km.
(b) For mountainous region—one station for every 100-250 sq. km.
(c) For arid region—one station for every 1500-10000 sq. km.

AVERAGE DEPTH OF PRECIPITATION

One raingauge station cannot represent a large basin. So, a basin is always cornposed of many rainguage stations which are evenly distributed throughout the whole basin. Again, the amount of rainfall may not be equal in all raingauge stations. Since the average rainfall of the basin is required for estimating the run-off from the basin, it is apply any suitable method to determine the average depth of precipitation. The following three methods are generally adopted to calculate the average depth of precipitation:

2.5 WATER LOSSES

Matter or energy cannot be lost, it only changes from one state to other. Similarly, water also cannot be lost, but it changes from one state to other, as we have seen in hydrological cycle. Here, the point 'Water losses' indicate the Portion of , water which cannot be observed or obtained as surface run-off directly during the period of precipitation that means,

Water losses = Precipitation - Surface run-off.

Now, we are to study the causes of these losses. Under different observation it is found that the following are the main causes of water losses. .

2.5.1 Interception

Due to solar heat leaves, branches, trunks of trees and veg:- etative covers may get dried up and gain capacity of absorbing water. So, when precipitation starts some portion of water is directly' absorbed by these absorbing agents. This phenomenon is known as interception. The interception continues till the leaves, branches, etc. get completely saturated. After saturation the water comes down as droplets from leaves and branches and flows down through the stem of the trees.. In forest area the amount of interception is more than that of in open area. In open area the water is mainly absorbed by grass, crops, vegetables etc. The rate of interception is high at the starting of precipitation and reduces to a negligible amount if precipitation continues for longer period.

The following are the factors affecting the process of interception.

(a) Type of Vegetative Cover The tall trees in dense forest intercept quite a substantial amount of water. But in low-lying vegetative cover the interception is very low.

(b) Wind Velocity If the precipitation is accompanied with high wind, then the leaves, branches, etc. are not capable of holding much water.

(c) Duration of Precipitation if precipitation occurs for short duration with longer interval, then interception will be more. Again, if precipitation continues for longer period and the weather remains cloudy, then the interception will be less.

(d) Intensity of Precipitation If the intensity of precipitation is low, the interception will be more and *vice versa.*

(e) Season In summer or dry ,season the interception is more where as in winter season the interception is low.

(f) Climatic Condition In hot climate and arid region the interception is high. But in cold climate and humid region the interception is low.

2.5.2 Evaporation

It is the process of change in the state of water from liquid or solid to vapour due to the transfer of heat energy. The evaporation may be caused due to the following reasons.

(1) Evaporation from Free Water Surfaces The water from the surface of reservoirs, lakes, ponds, streams etc is constantly changing into vapour through the process of evaporation.

The water consists Of large number of molecules. These molecules are constantly moving With some Velocities in different directions. Again, the molecules are attracted to each other by some forces. It is found that the molecules near the surface are easily detached from the water surface due to temperature and can easily escape into air as vapour. Thus, the molecules from the water surface constantly leave their positions and the other molecules take their place; This process of evaporation is clearly explained in Dalton' s law of evaporation. The law is expressed by the expression,

$$\text{Evaporation} \propto (P_{sv} - P_{av})$$

$$E = K(P_{sv} - P_{av})$$

where, E . Evaporation rate in cm/day,

K -A constant, whose value depends on wind velocity, humidity, barometric pressure, temperature etc,

Psv= Saturation vapour pressure,

Pav = Actual vapour pressure.

Factors Affecting Evaporation From Free Water Surface

The following are the factors that affect the evaporation from free water surface.

- **Area of Water Surface** lithe area of water surface is large, the evaporation will be more and vice versa.
- **Depth of Water** If the depth of water is less, the evaporation will be more and vice versa.
- **Humidity** If the humidity of the atmosphere is more, the evaporation will be less and vice versa.
- **Temperature** If the temperature is more, the saturation Vapour naturally increases and the rate of evaporation also increases and vice versa..
- **Wind Velocity** If the wind velocity is more, the process of vaporisation' becomes easier, and loss of evaporation becomes more and vice versa.

(2) ***Evaporation from Soil Surfaces*** The principle of evaporation from soir surfaces is similar to that of from the free water Surface the rate of evaporation from saturated soil is identical to that of from free water surface. But when the moisture content of the soil decrease, the rate of evaporation also decreases: The evaporation from the soil surface will continue as long as the soil layer (about 20 cm) remains moist.

(3) ***Evaporation from Vegetation (i.e. transpiration)*** Transpiration is practically a process of evaporation through the leaves of living plants. This process involves continuous circulation of water-from the soil to the roots and then, passes through the stem and finally evaporates through the leaves. This is also known as evapotranspiration. This is the principal requirement for the growth of the plants.

2.5.3 INFILTRATION

When it rains in a particular area, some portion of water moves downwards through the soil pores under the force of gravity to join the water table. This phenomenon is known As infiltration. At the beginning of the rain the loss of infiltration is high and then it reduces gradually as the soil pores get saturated.

Infiltration Capacity The process of infiltration depends on the number of voids present in the soil, shape and degree of compaction. So, different soils have different number of voids, different degree of compaction and hence different capacities of absorbing water. The maximum rate.

Factors Affecting Infiltration Capacity The factors that affect the infiltration capacity are

(a) ***Texture of soil*** In coarse grained texture of soil (i.e. sand) the water infiltrates very quickly. But in fine grained texture of soil (i.e. clayey soil), the water infiltrates very slowly.

(b) ***Condition of soil surface*** If the pores of surface soil are sealed due to sedimentation of silt or due to water logging, then the water will infiltrate very negligibly.

(c) ***Content of soil moisture*** When the surface soil is dry, the rate of infiltration is high. But, if the surface soil contains moisture, the rate of infiltration is low.

(d) ***Type of vegetative surface Cover*** If the surface soil is grassless, the rate of infiltration will be more. But, if the surface soil is covered with grass, then the rate of infiltration will be low.

(e) ***Soil temperature*** If the temperature of saturated soil is very low (nearly 0°C or below) the soil mass becomes impermeable. So, the rate of infiltration will be low.

(a) ***Agriculture*** Intensive agriculture on the surface soil makes it previous and hence the rate of infiltration increases.

INFILTRATION INDICES

For the assessment of the water lost by infiltration some indices are considered which are known as infiltration indices, The following are the two indices that are generally adopted for the determination of infiltration losses.

(a) ***0-index*** It is defined as the average rate of rainfall, during any storm, above which the volume of rainfall is equal 'to the volume of direct run-off.

(b) ***W-index*** It is defined as the average rate of infiltration which is calculated by the expression,

$$\text{W-index} = \frac{R-Q}{Tr}$$

where, R = Total rainfall, Q = Total direct run-off,

T,= Duration of rainfall in hrs.

For uniform rainfall the values of 0-index and W-index will be equal.

For non-uniform rainfall the values of 0-index and W-index will not be equal.

FACTORS AFFECTING RUN-OFF

The following are the factors affecting the run-off.

Intensity of Rainfall If the intensity of rainfall is more the corresponding run-off will be more. Again if the intensity of rainfall is low, the corresponding run-off will also be low.

Soil Characteristics **of Catchment** In the catchment area consisting of rocky or clayey soil, the runoff will be more. Again, if the soil characteristic of the catchment is sandy, the runoff will be low as the loss of infiltration is more

Topography of the Catchment If the ground slope of the catchment is steep, the runoff will be more. If the ground slope is flat and consists of depressions, the run-off will be low

Shape and Size of Catchment If the catchment area is large and fan shaped, the runoff Will be more. If the catchment area is small and fern shaped, the runoff will be low

Geological Condition of Catchment If the catchment area consists of fissures, cracks, etc, the water losses will be more and the runoff will be low.

Cultivation and Vegetative Cover in Catchment Area If the catchment area consists of more cultivated area and forest areas, the runoff will be low.

Weather Condition If the temperature in the catchment area is high, the evaporation loss will be more and hence run-off will be less and vice versa.

ESTIMATION OF RUN-OFF

There are a number of empirical hydrologic methods that can be used to estimate runoff characteristics for a site or drainage sub-basin.

- *Rational Method*
- *SCS Unit Hydrograph Method*
- *USGS Regional Regression Equations*
- *Water Quality Treatment Volume Calculation*
- *Water Balance Calculations*

These methods were selected based upon a verification of their accuracy in duplicating local hydrologic estimates for a range of design storms throughout the state and the availability of equations, nomographs, and computer programs to support the methods

Rational Method

Introduction

An important formula for determining the peak runoff rate is the Rational Formula. It is characterized by:

Consideration of the entire drainage area as a single unit

Estimation of flow at the most downstream point only

The assumption that rainfall is uniformly distributed over the drainage area and is constant over time

The Rational Formula follows the assumption that:

The predicted peak discharge has the same probability of occurrence (return period) as the used rainfall intensity (I)

The runoff coefficient (C) is constant during the storm event

When using the Rational Method some precautions should be considered:

 In determining the C value (runoff coefficient based on land use) for the drainage area, hydrologic analysis should take into account any future changes in land use that might occur during the service life of the proposed facility.

 Since the Rational Method uses a composite C and a single tc value for the entire drainage area, if the distribution of land uses within the drainage basin will affect the results of hydrologic analysis (e.g., if the impervious areas are segregated from the pervious areas), then the basin should be divided into sub-drainage basins.

 The charts, graphs, and tables included in this section are given to assist the engineer in applying the Rational Method. The engineer should use sound engineering judgment in applying these design aids and should make appropriate adjustments when specific site characteristics dictate that these adjustments are appropriate.

Application

The Rational Method can be used to estimate stormwater runoff peak flows for the design of gutter flows, drainage inlets, storm drain pipe, culverts and small ditches. It is most applicable to small, highly impervious areas. The recommended maximum drainage area that should be used with the Rational Method is 10 acres.

The Rational Method should not be used for storage design or any other application where a more detailed routing procedure is required. However, due to the popularity of the Modified Rational method among Georgia practitioners for design of small detention facilities, The normal use of the Modified Rational method significantly under predicts detention volumes, but the improved method corrects this deficiency in the method and can be used for detention design for drainage areas up to 10 acres.

The Rational Method should also not be used for calculating peak flows downstream of bridges, culverts or storm sewers that may act as restrictions and impact the peak rate of discharge.

Run-off may be estimated or computed by the following mathods.

By this method the runoff is computed by the expression,

$$Q \; \frac{K\,i\,A}{36}$$

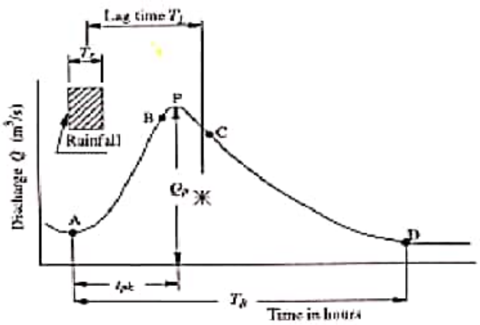
where, Q = Runoff in cumec, K = Coefficient of run-off,
= Rainfall intensity in cm/hr,, A = Catchment area in hectares

2.6 HYDROGRAPH

The hydrograph is a graphical representation of the discharge of a river (in cumec) against the time (in hr or days). The discharge is plotted as ordinate (y-axis) and the time is plotted as abscissa (x-axis).

During the dry season, there is only base flow (i.e. ground water flow) but no surface run off. This may be shown by .a line which is approximately straight (not shown in the figure).

In rainy season, at the beginning of the rainfall there is only base flow(shown by the lineAB): After some period, when the initial losses (like interception, evaporation and infiltration) are fulfilled, the surface runoff starts and hence the discharge of the river goes on increasing. Hence the limb of the curve rises which is called rising limb (shown by the line *BC)*. This.line reaches to the peak value at *'C'*. Again when the rain stops, the flow in the river decreases and the limb of the curve declines. This limb is known as recession limb) (as shown by the line *CD)*. The discharge at the point *C* indicates the maximum discharge (i.e. peak discharge or flood discharge). The total area under the curve *ABCDE* indicates the total run off. But this run off includes the base flow, and the direct runoff. So, to get the actual run off the base flow is to be deducted by separating it from total area.



Elements of flood hydrograph

2.7 HYETOGRAPH

The graphical representation of rainfall and run-off is known as hyetograph (Fig). The graph is prepared with intensity of rainfall (in cm/hr) as ordinate and time (in hrs) as abscissa. The infiltration capacity curve is drawn on this graph to show the amount of infiltration loss (shown by dotted portion). The upper portion indicates the effective rainfall (shown by hatched lines). The centroid of the effective rainfall is ascertained on the graph for the determination of total run-off at any specified period.

2.8 UNIT HYDROGRAPH

A unit hydrograph may be defined as a hydrograph which is obtained from one cm of effective rainfall (i.e. run-off) for unit duration. Here, effective rainfall means the rainfall excess (i.e. run-off) which directly flows to the river or stream. The unit duration is the period during which the effective rainfall is assumed to be uniformly distributed. The unit duration may be considered as 1 hr, 2 hr, 3 hr, 4 hr ..., etc. As for example, if a hydrograph is prepared for an effective rainfall ' of one cm lasting for 2 hrs, then it is known as 2 hr. unit hydrograph, for the duration of 3 hrs it is known as 3 hr unit hydrogra.ph and so on Fig

Concept of Unit Hydrograph

The unit hydrograph theory is based on the conception that if two identical storms occur on a drainage basin with identical conditions, then the unit hydrographs of runoff from the two storms may be expected as same. This conception of unit hydrograph was first given by L.K. Sherman in 1932.

Assumptions in Unit Hydrograph Theory The unit hydrograph theory is based on the following assumptions.

(i) The effective rainfall is evenly distributed during the specified period of time
(ii) The effective rainfall is evenly distributed over the whole drainage basin.
(iii) For a drainage basin, the base period of direct runoff corresponding to effective rain falls of different intensities is constant, provided unit duration is same. ,
(iv) The ordinates of all the hydrographs of a common base period are directly proportional to the total amount of direct run-off. This is also known as principle of linearity.
(v) The hydrograph of direct run off prepared from a given pattern of effective rainfall remains invariable' irrespective a time of occurrence. This is known as principle of time invariance.

Limitations of Unit Hydrograph Theory The following are the limitations of unit hydrograph.

(i) This theory is not applicable to large areas because uniformly distributed effective rainfall cannot be expected in large area.

This theory is not applicable in places where precipitation is composed of snowfall.

The principle of time invariance is valid only for specified time and condition of drainage basin.

- Practically no two storms have the same nature in space and time period. So, it is not possible to construct unit hydrograph for each pattern.
- The principle of linearity is not practically valid for smaller and larger storms.

Advantages of Unit Hydro graph Theory Inspite of some limitation of the unit hydrograph theory, the following are the advantages it has

- Flood hydrograph can be prepared quickly for a given basin.
- It can be utilised for the calculation of ordinates of hydrographs.
- From the unit hydrograph the expected volume of run-off from a basin can be computed.

Construction of Unit Hydrograph The rainfall records for a specified period are collected from the raingauge stations of the catchment area The discharge from the catchment area is also observed for the same period. A hyetograph is ,prepared from the rainfall records. A discharge hydrograph is also prepared from the recorded discharge. These two data are the basic requirement for the construction of unit hydrograph. The volume of direct run-off (in cumec) obtained from the hydrograph is converted to cm/sec according to the following method.

The discharge (in cumec) is diVided by the catchment area (in m^2) to get runoff in cm/sec.

$$\text{i.e. run-off} = \frac{m^3/sec}{m} = m/sec = m \times 100 \text{ cm/sec}$$

Thus the ordinates of the storm hydrograph are obtained and it is prepared accordingly. From the storm hydrograph, the unit hydrograph is .constructed. -

Construction of Unit - Hydrograph from isolated Storm At first a discharge hydrograph is prepared from the -discharge records of the catchment area. Here, the discharge (i.e. run-off) is expressed in cumec. This run-off is converted to cm/sec (as explained earlier) to get the ordinates of storm hydrograph and then storm hydrograph is prepared. From the storm hydrograph the average depth of run off is calculated, suppose it is D. Now, to get the ordinates of unit hydrograph the respective ordinates of storm hydrograph is multiplied by a factor 1/ D. The reduced ordinates are plotted at respective points to get the shape of the unit hydrograph

Construction of Unit Hydrograph for Other Durations The unit hydrograph for different duration may be constructed by the principle of superposition. Suppose, it is required to construct a 9 hr unit hydrograph from 3 hr unit hydrograph. Then 3 hr unit hydrograph is plotted thrice with a time lag of .3 hr. The ordinates of those three overlapping unit hydrograph are summed up to obtain a summation hydrograph of 9 hr. The ordinates of 9 hr summation hydrograph are divided by 3 to obtain the ordinates of 9 hr unit
hydrograph.

Construction of Unit Hydrograph for Other Durations The unit hydrograph for different duration may be constructed by the principle of superposition. Suppose, it is required to construct a 9 hr unit hydrograph from 3 hr unit hydrograph. Then 3 hr unit hydrograph is plotted thrice with a time lag of .3 hr. The ordinates of those three overlapping unit hydrograph are summed up to obtain a summation hydrograph of 9 hr. The ordinates of 9 hr summation hydrograph are divided by 3 to obtain the ordinates of 9 hr unit hydrograph.

FACTORS WHICH AFFECT THE HYDROGRAPH.

Factor	Hydrograph dominated by quickflow processes*	Hydrograph dominated by slowflow processes**
Climatic factors		
Precipitation (Intensity and duration of the storm)	High-intensity rainfall which exceeds the infiltration capacity of the soil. Large amount of rainfall	Low-intensity rainfall which is less than the infiltration capacity of the soil Small amounts of rainfall
Snow (Water stored as snow)	Fast snow melt as temperatures suddenly rise above zero	Slow snow melt
Evapotranspiration (temperature)	Low rates of evapotranspiration outputs due to low temperatures e.g. winter in Britain	High rates of evapotranspiration outputs due to high temperatures e.g. summer in Britain

Soil characteristics		
Soil moisture (Antecedent /pre-existing conditions)	Basin already wet from previous rain, water table high, soils saturated and so low infiltration/percolation	Dry soil-the soil store can hold much more water. Low water table. High infiltration/percolation
Permeability	Impermeable soil	Permeable soil
Drainage basin characteristics		
Drainage density	High drainage density (large number of streams per km).The higher the density the faster the water reaches the main river channel.	Low drainage density (small number of streams per km) means few streams and rivers and so water is more likely to enter the ground and move slowly through the basin.
Size of drainage basin	Small drainage basin tends to respond more rapidly to a storm than larger one, so the lag time is shorter.	
Slopes	Steep slopes promote surface runoff.	Gentle slopes allow infiltration and percolation.
Shape of drainage basin	Rainfall reaches the river more quickly from a round basin than from an elongated basin.	
Rock type	Impermeable rocks- e.g. clay, granite, restrict percolation and encourage rapid runoff	Permeable rocks-e.g. chalk and limestone, allow infiltration and percolation
Vegetation cover	Little vegetation cover Lack of interception and root development to open up the soil. Rapid movement through the system. Deciduous trees in winter.	Forest and woodland intercept much rainfall, and root development encourages infiltration. More water lost to evaporation from vegetation surfaces. Deciduous trees in summer.
Soil depth	Thin soil- e.g. upland areas allow little infiltration	Deeper soils provide a large soil store –e.g. slope bottoms and lowland areas.
Water stores	Lack of lakes and backwater swamps	Lakes and backwater swamps act as water stores, and slow the movement to the channel.
Human activity		
Forests	Deforestation	Reforestation
Urban development	Urban development creates impermeable concrete and tarmac surfaces and water quickly reaches the channel via storms drains.	Rural land uses intercept more precipitation and have more permeable land surfaces. High infiltration and percolation.

	Low infiltration/percolation	
Agricultural practices	Poor agricultural practices – poor soil structure, trampling by animals.	Good agricultural practices which encourage soil aeration and protect the soil surface.

* ***Quickflow processes:*** That component of the rain input which is delivered to the stream by surface runoff/overland flow, or rapid soil transfer. They give a high peak and rapid rise on the hydrograph.

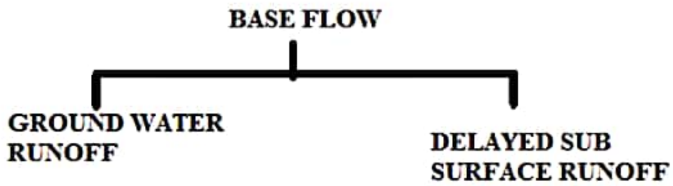
** ***Slowflow processes:*** Processes such as slow throughflow and groundwater flow, which transmit water slowly to the river channel.

2.9 S-HYDROGRAPH

S-hydrograph may be defined as a hydrograph which is constructed by summing up the ordinates of a series of unit hydrographs of same unit duration. So, it is also known as 'summation hydrograph'. This hydrograph represents the direct surface discharge resulting from successive storms of 1 cm in unit duration (i.e. 2 hr, 3 hr, 4 hr ..., etc.), for longer period. This hydrograph has continuously rising limb in the form of letter *S* until a con-
stant value of discharge is reached. Let the base time (i.e. duration) of unit hydrograph be *T* and unit duration be t_r, the discharge Will be constant, at a time equal to $(T - t_r)$ hours (Fig. 3.27). Again the constant discharge is given
where,

Q = Constant discharge in cumec, A = Area of catchment in sq. km, t_r = Unit duration in hrs.

2.10 BASE FLOW



The ground water contribution to the stream is known as base flow. It consists of two portions,.(i) the ground water directly flows to the stream (ii) the rain water first infiltrates into the ground and then flows laterally to the stream even after the precipitation has stopped

N***egative Base Flow*** When the water level of the stream is lower than thewater table before the commencement of heavy rainfall, the around water flowsto the stream. But when the water level of the stream rises 'boy the water table during the heavy rainfall, the stream water flow towards the ground water. This is known as negative base flow

Separation Of Base Flow

From the given data (discharge and time) the hydrograph is drawn which represents the total 'fun-off which comprises direct run-off. The base flow is to be separated to get the actual' run off. The base flow Separation is described as

(i) The curve *AB* is extended to Meet the vertical line (passing through the , point C at peak flow) at point *F*. The line *FD* is joined. The area of the dotted portion indicates the base flow .
(ii) Again the point is obtained on the recession limb of the hydrograph at *N* days after the peak flow, the value is calculated as

$$N = 0.83\ A^{0.2}$$

where, A = Area of drainage basin in sq. km.

POSSIBLE QUESTIONS

1. Explain in detail about the hydrological cycle with neat sketches.
2. The normal annual rainfall at station A,B,C and D in a basin are 80.97,67.59,76.28 and 92.01 cm respectively. In the year 1975, the station D was inoperative and the stations A,B and C records annual precipitation of 91.11,72.23 and 79.89 cm respectively. Estimate the rainfall at station D in that year.
3. What is meant by precipitation? Explain about types and forms of precipitation in detail
4. A catchment has 6 rain gauge stations. In a year,the annual rainfall recorded by the gauge as follows.

Station	A	B	C	D	E	F
Rainfall (cm)	82.6	102.9	180.3	110.3	98.8	136.7

   For a 10% error in the estimation of the mean rain fall,calculate the optimum number of stations in the catchment.
5. What are the different types of Rain gauges are available? Explain any two in detail
6. What are the different types of recording type rain gauges & its advantages
7. Explain in detail about the hydrological cycle with neat sketches.
8. What is meant by hydrograph? What are the different factors affecting it? also explain about unit hydrograph.
9. Explain about rain gauge network.
10. What are the different types of Rain gauges are available? Explain any two in detail
11. Explain shortly about base flow separation
12. Write short notes about Evaporation and Infiltration process
13. What are the different types of recording type rain gauges & its advantages
14. What are the factors affecting hydrograph