Lecture Notes on CVL 015: Irrigation Engineering

UNIT-1

(Necessity, Importance, Benefits, Ill-effects and Methods of irrigation.)

Irrigation is defined as the process of artificial application of water to soil for the purpose of supplying the moisture essential for full-fledged nourishment of the crops throughout the crop period in addition to the water already available to the crops from precipitation, soil moisture in the crop root zone from flooding and capillary rise from ground water.

It is an age-old **art** practiced by farmers, **science** for agricultural scientists, **commerce** for entrepreneurs, **engineering** for Irrigation Engineers/Civil Engineers, and **management** for Administrators

Irrigation Engineering is planning, survey, investigation, design, construction, operation and maintenance of an efficient, low cost, socio-economically, ecologically and environmentally viable irrigation system, including all the structures connected with irrigation at every phase.

Dry land farming is done by rain water retention only.

Rain-fed farming is done by rain water only as and when it occurs.

Irrigated farming is done by supplementation of irrigation artificially to soil in addition to soil water already available to crops because of precipitation, flooding and capillary action of ground water.

NECESSITY OF IRRIGATION: Adequate quantities of water should be readily available within the root zone of all kinds of plant life. Such water if not present in the soil naturally it may be applied by irrigation. Nearly one-third of the earth's surface receives less than 250mm of yearly rainfall, another one-third receives only 250 to 500mm of rainfall annually and even in the remaining areas rainfall is received within a few monsoon months during the year like monsoon rainfall in India from mid- June to mid- October. India has total land area 328 million hectares out of which the cultivated area is 208.5 million hectare and irrigated area of 72.1 million hectare (34.65% of cultivated area).

Following factors necessitate irrigation:

(i) Inadequate precipitation, (ii) Uneven distribution of precipitation, both spatial and temporal, (iii) Growing a number of crops during a year, (iv)Growing superior crops of high yielding varieties, and (v) Increase food, fodder and fibre production commensurate with requirement of the State/National population of human and cattle.

IMPORTANCE OF IRRIGATION: Irrigation in many countries is an old art-as old as civilization- but for the whole world it is a modern science- the science of survival. The pressure of survival and the need for additional food, fodder and fibre are necessitating a rapid expansion of irrigation throughout the world. Even though irrigation is of first importance in the more arid regions of the earth, it is becoming increasingly important in humid regions. Following factors illustrate importance of irrigation:

(i) It adds water to the soil to the supply the moisture essential for plant growth.

(ii) It saves the crops from drying during short duration droughts.

(iii) It cools the soil and its atmosphere and thus makes more favourable environment for healthy plant growth.

(iv) It washes out or dilutes salts in the soil.

(v) It reduces the hazards of soil piping and dying of plants due to frost action.

(vi) It softens tillage pans.

BENEFITS OF IRRIGATION: (i) Increase in food production, (ii) Protection from droughts and famines, (iii) Cultivation of superior (cash) crops like sugarcane, tobacco, cotton, etc. (iv) Addition of wealth of country due to revenue generation and export of food grains and other farm produces, (v) Increase in overall prosperity of people, (vi) Provide work for labour, more pisciculture, recreational facilities (boating, fishing, and swimming), (vii) Generation of hydro-electric power from canal falls, (viii) Domestic and industrial water supply, (ix) Inland navigation through canal system, (x) Improvement of communication, (xi) Plantation along canal banks, (xii) Increase in ground water recharge, (xiii) Aid in civilisation, (xiv) Social upliftment of people, (xv) Elimination of mixed cropping, and (xvi) Reduces damages due to floods.

ILL-EFFECTS OF IRRIGATION: Irrigation itself has no defects or ill-effects. The ill-effects associated with irrigation are caused due to over irrigation, bad farm management, improper tillage, and bad planning. The possible ill-effects are:

(i) Pollution of stream flows and ground water through seepage of nitrates and other toxic materials applied as fertilizers and pesticides in irrigated agriculture, (ii) Increase in breeding places mosquitoes spreading Malaria/ Dengue, (iii) Salt-efflorescence-Salinity & Alkalinity, (iv) Excessive seepage and water logging, (v) Damp climate resulting in marshy land and low production, (vi) Revenue loss due to large subsidy in canal irrigation, (vii) Loss of agricultural land due to construction of dams, reservoirs ,barrages, canal network, and (viii) Shifting of cultural monuments, roads, railway lines, etc. from the reservoir area.

METHODS OF IRRIGATION:

(TECHNIQUES OF WATER APPLICATION/DISTRIBUTION ON FARMS):

Objectives:

(i) Adequate amount of water is stored in root zone of plants, (ii) Uniform application of water is made possible, (iii) Minimum soil erosion takes place, (iv)Minimum wastage of water, and (v) Re-use of water is made possible.

FACTORS AFFECTING CHOICE OF METHOD OF IRRIGATION:

(i) Soil characteristics of land to be irrigated, (ii) Slope and roughness of surface, (iii) Size of stream supplying irrigation water, (iv) Available water supply and rate of advance, (v) Length of run and time required to irrigate, (vi) Crop water requirement and growth type, (vii) Infiltration rate of soil, (viii) Depth of root zone of plants, (ix) Depth of water table, (x) Possible erosion hazard, and (xi) Amount of water to be applied during each irrigation.

METHODS:

(i) Uncontrolled or Wild Flooding, (ii) Controlled or Free Flooding, (iii)Border strips Irrigation, (iv) Check Basin Irrigation, (v) Ring/Basin Irrigation, (vi) Furrow Irrigation, (vii) Corrugation Irrigation, (viii) Sub-surface Irrigation, (ix) Sprinkler Irrigation, and (x) Drip/Trickle/Ooze Irrigation.

(i) UNCONTROLLED OR WILD FLOODING: It is practiced where irrigation water is abundant and inexpensive and the purpose of application of flood flows is to recharge the crop root zone's soil moisture to grow a crop after the flood season, or when the value of the crop is small or the field is used for grazing. Water is spread or flooded over a rather smooth flat land without much control or prior preparation. Crop lands are irrigated without regard to efficiency or uniformity.

(ii) CONTROLLED /FREE FLOODING: Water is spread over the land, with proper methods to control the depth of application. Water is stopped when it reaches other end of the plot. Since the flow is not guided by ridges, there is wastage of water and does not ensure uniform depth of irrigation.

flooding can be achieved by free flooding, contour laterals, border strips or by checks or levees.

Free Flooding method, also known as *Irrigation by plots*, is commonly used in India. The field is divided into a number of small sized plots which are practically level. Water is admitted to these plots at the higher end and the supply is cut off as soon as the lower part of the plot nas received the sufficient depth of water. Oblong plots are preferred to the square ones. The size of plots depend on the porosity of the soil.

2·4. CONTOUR LATERALS

This method is applicable for steeper terrain. The field is cut by relatively dense network of small contour laterals, the spacing of

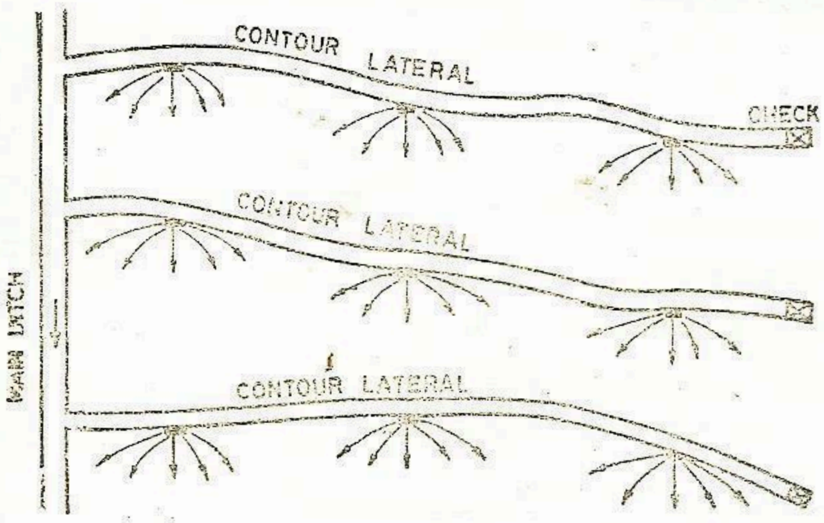

Fig. 2·2. Contour Laterals.

which depends upon the prominent grade of the field between two adjacent ditches or laterals, the uniformity of slope and the soil type.

2·5. BORDER STRIP METHOD

In the border strip flooding method, the farm is divided into a series of strips 10 to 20 metres wide and 100 to 300 metres long. These strips are separated by low levees or borders (low flat dikes) and run down the predominant or any other desired slope. To irrigate water (discharge varying from 0·014 to 0·028 cumecs) is turned from the supply ditch onto the head of the border. Water advances—confined and guided by two borders—in a thin sheet towards the lower end of the strip. The surface is essentially level between two borders so that the advancing sheet of water covers the entire width of the strip. The lengthwise slope varies from 0·5 to

1·5%. This method is especially suited to forage crops, its advantage being that for a relatively low investment a system can be developed which can afford the highest irrigation efficiency and lowest labour requirements. With highly mechanised farming, large area can be irrigated within a short time by border strip method. The length of border strip depends upon how quickly it can be wetted over its entire length. This, however, depends upon :

(*i*) Infiltration rate of the soil,
(*ii*) Longitudinal slope of the land, and
(*iii*) Size of irrigation stream available.

The following lengths are suggested for moderate conditions :

Types of soil	*Length of border strip*
(*i*) Sandy soil or sandy loam	60 to 90 m
(*ii*) Medium silt loam	90 to 150 m
(*iii*) Clay loam or clay soil	150 to 300 m

The first 6 to 12 m length of the strip should be made level to ensure uniform spreading of water.

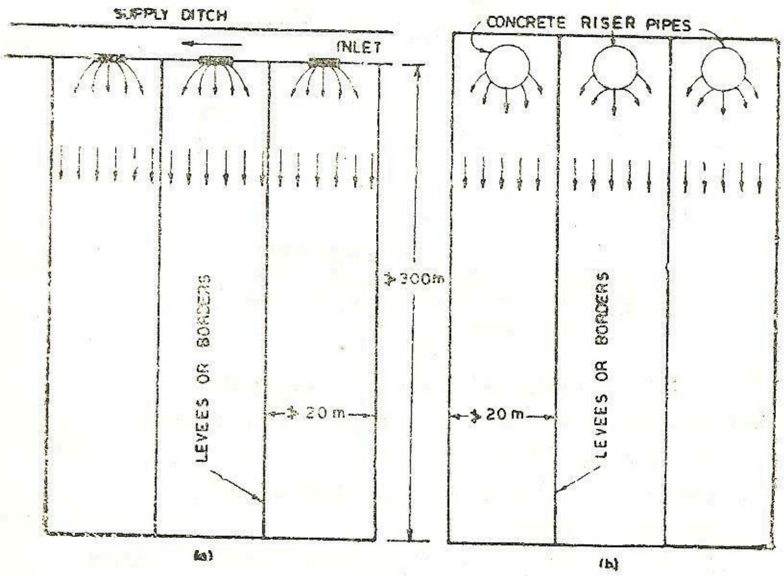

Fig. 2·3. Border Strip Method.

Water is diverted to the border strips from the following :

(*a*) *Earth or concrete ditches (canals)* : These run at a flat longitudinal grade. The water is discharged into the strips via border gates, aluminium syphons or plastic piping [Fig. 2·3(*a*)].

(*b*) *Under-ground concrete pipes through risers* : In this method, water is let into the strips by concrete risers, as shown in Fig. 2·3(*b*).

Analysis of time to cover a strip area

Size of irrigation stream applied to unit area of load be varied according to the rate of infiltration of water into the soil. When a large stream is applied to unit area of the soil of low infiltration rate, excessive surface runoff occurs. However, when a small stream is applied to a unit area of soil of high infiltration rate, excessive depths of water are lost by deep percolation. The relation between size of stream and time rate of water application over a given area of land can be most easily stated by means of a rational equation derived below :

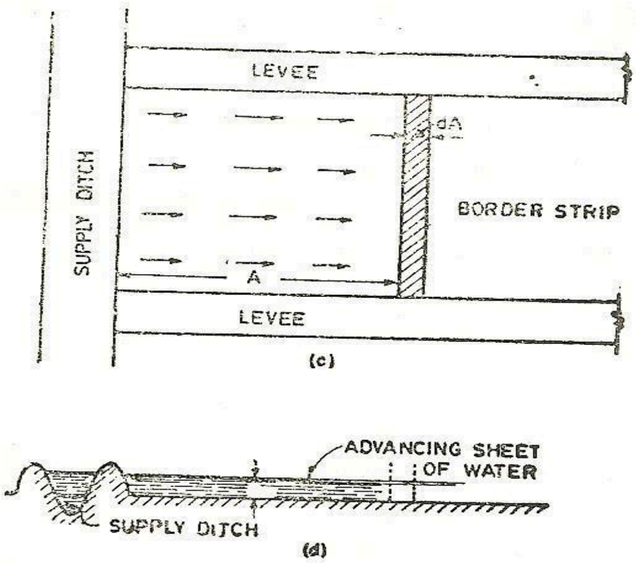

Fig. 2·4. Analysis of time in border strip method.

Let A=Area of land covered at any time t, in hectares

I=Rate of infiltration in m/hour

q=Quantity of water in hectare-metre/hour

t=Time in hours

y=Average depth of sheet of flowing water, in metres.

Total quantity of water flowing in small time interval dt is equal to the quantity of water infiltrated in this time dt over the area A plus the quantity of surface flow over the area dA. Thus

$$qdt = ydA + IA\ dt$$

or

$$qdt - IA\ dt = ydA$$

From which dt=(y.dA)/(q-IA)

Considering I and y as constants and integrating, we get

$t = -\ y/I[\ln(q-IA)]_0^A = y/I[\ln(q-IA) - \ln q]$

At t=0, A=0 and at t=t, A=A

$t=2.303(y/I) \log q/(q-IA)$

MAXIMUM AREA THAT CAN BE IRRIGATED FROM KNOWN I AND q VALUES:

$\log(q/(q-IA)=It/2.303y=x$

$10^x=q/(q-IA)$

$A=(10^x-1)q/I.10^x.I=q/I$ since $(10^x-1)/10^x=1$

$$\therefore \quad A = \frac{q}{I} \text{ hectares}$$

$$= \frac{0{\cdot}0108}{0{\cdot}05} = 0{\cdot}216 \text{ hectare.}$$

2·6. CHECK FLOODING

In the check flooding, a comparatively large stream discharges water into a relatively level plot surrounded by checks or levees. The levees are generally 2 to 3 m wide at the base, and not more than 25 to 30 cm high, so that it does not obstruct the operation of farm machinery. In a levelled ground, the plots are generally rectangular but if the ground has some initial slope, the checks or levees may follow the contours. Since water is supplied through large stream, the method is more suitable for permeable soils which must be puickly covered with water in order to prevent excessive percolation losses near the supply ditches. The method is also suitable for impermeable soils in which the percolation rate is so slow that infiltration would be inadequate in the time required for the sheet of water flowing over it.

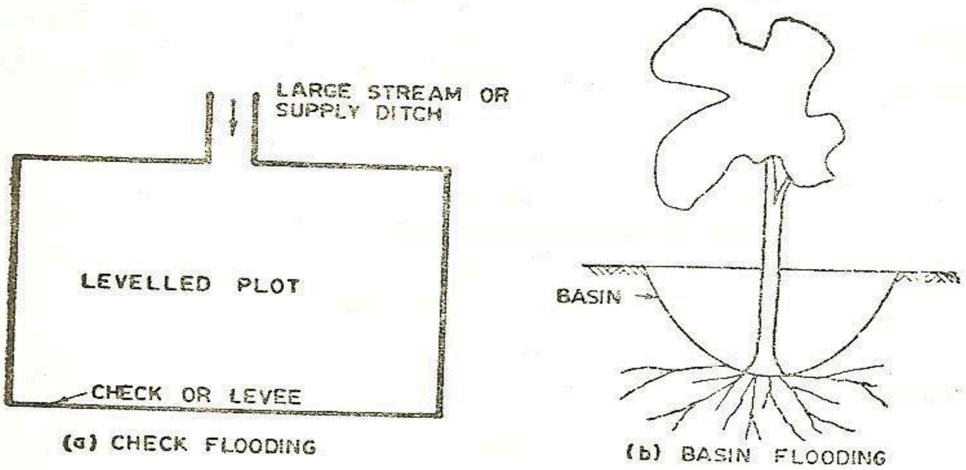

Fig. 2·5.

2·7. BASIN FLOODING

The basin flooding is a special form of check flooding adapted to orchards. The basins are formed for each tree ; in some cases one basin may be formed for two or more trees. Water is supplied to these basins through a supply ditch. In some cases, a number of basins are inter-connected. Portable pipes or large hoses may also be used in place of ditches.

2 8. THE ZIGZAG METHOD

It is a special method of flooding where water takes circuitous route before reaching the dead of end each plot. The whole area is divided into a number of square or rectangular plots ; each plot is then subdivided with the help of low bunds or levees. This method is suitable for relatively level plots. It is, however, highly unsuitable for farming operations with modern farm machinery.

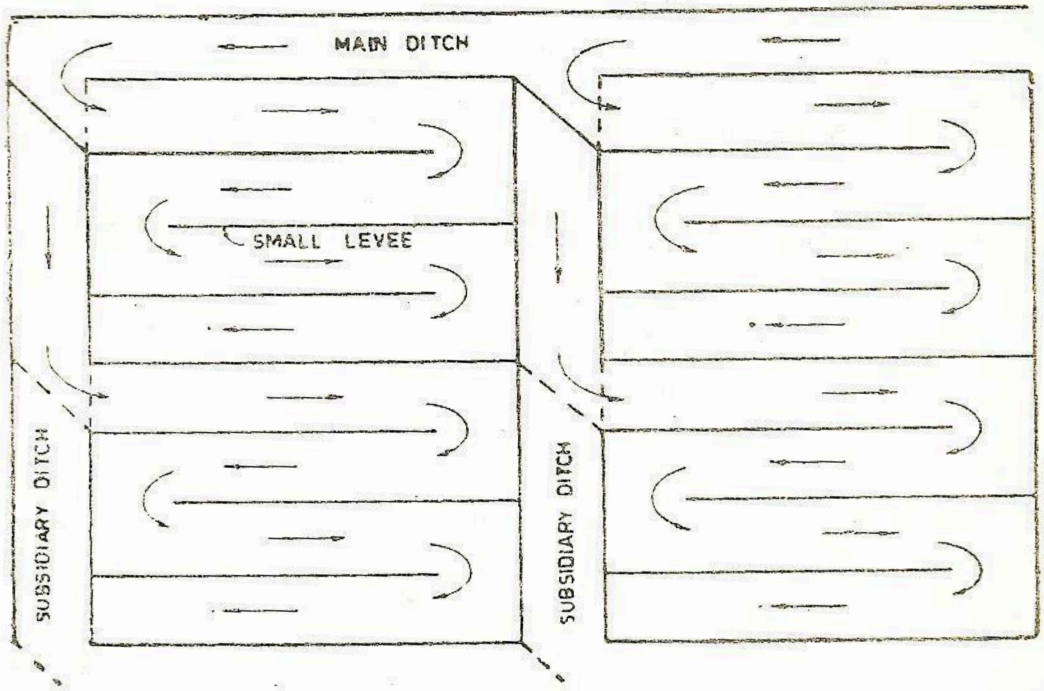

Fig. 2·6. The Zigzag Method.

2·9. FURROW METHOD

The furrow method of irrigation is very much used for row crops like maize, jowar, sugarcane, cotton, tobacco, groundnut, potatoes etc. In the other irrigation methods described so far, almost the entire land suface is wetted, but in this method only one half to one-fifth of the surface is wetted, and thus evaporation losses are very much reduced. A furrow consists of a narrow ditch between rows of plants. The length of furrows varies from 3·0 m or less for gardens to as much as 500 m for field crops, the common length being 100 to 200 m. If the furrows are of excessive length, deep percolation losses and soil erosion near the upper end of the field may result. The general slopes provided for furrows may vary from 0·2 to 5%.

Furrow spacing for corn, potatoes, sugarcane and other row crops is determined by the proper spacing of the plant rows, one irrigation furrow being provided for each row. The spacing of furrows is kept from 1 to 2 m in orchard irrigation. If the spacing

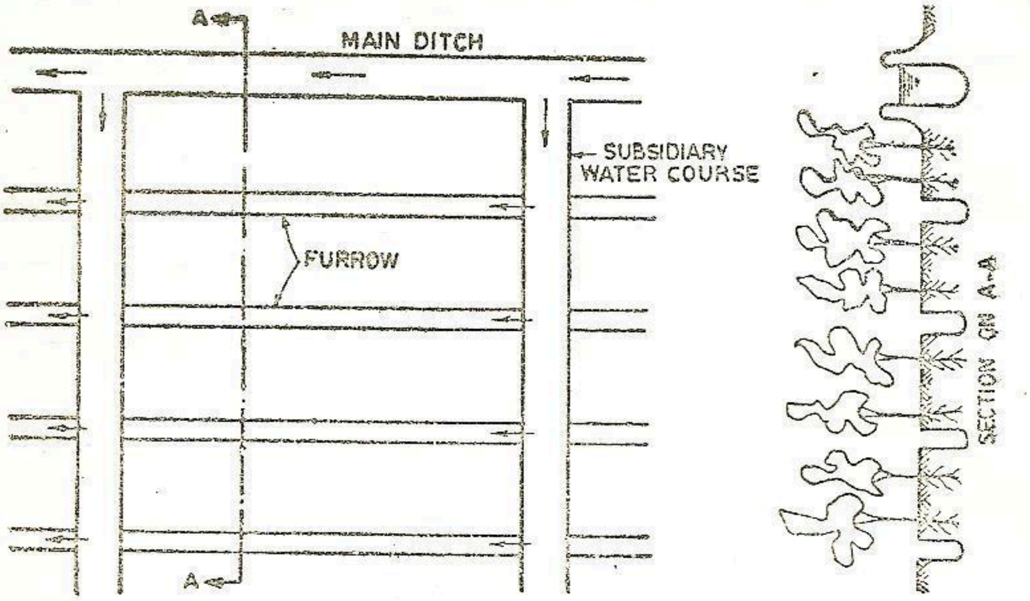

Fig. 2·7. Furrow Method.

is kept more, it is essential to check the distribution of moisture after each watering by auger boring. For soil of low permeability the depth of furrows may vary from 20 to 30 cm. It is essential in irrrigating the root crops (such as sugarcane etc.) to have furrows deep enough, and the stream in each small enough so that water cannot come in contact with the plant. The common size of furrow for row crops such as cotton, tobacco and potatoes is about 25 cm wide and 8 to 10 cm deep. Furrows are sometimes made before planting, at the time of planting or after plants have grown large enough not to be covered up. Often young plants are irrigated by small furrows until a good root system is developed. Thereafter the furrow is made larger.

Advantages of Furrow Irrigation

Furrow irrigation method has the following advantages :

(*i*) In the furrow irrigation, water contacts only 1/5 to $\frac{1}{2}$ of the land surface, thereby reducing pudding and crusting of the soil. Evaporation losses are also reduced.

(*ii*) Earlier cultivation is possible in heavy soil and may be adapted to use without erosion on a wide range of natural slope by carrying furrows across a sloping field rather than down the slope.

2·11. SUB-SURFACE IRRIGATION

The sub-surface irrigation method consists of supplying water directly to the root zone of the crop. The favourable conditions for the sub-surface irrigation practice are :

1. Impervious sub-soil at reasonable depth (say 2 to 3 m) or high water table.
2. Permeable soil such as loam or sandy loam in the root zone of the soil.
3. Uniform topographic conditions.
4. Moderate slopes.
5. Good quality irrigation water.

If all these favourable conditions are fulfilled and if proper precautions are taken to prevent alkali accumulation or excess water-logging, the method results in economical use of water, high crop yield and low labour cost in preparing the irrigation plots.

Water is supplied to a series of ditches half to one metre deep and 25 to 50 cm wide having vertical sides. These ditches are spaced from 50 to 100 m apart. Water flows at a slow rate and seeps into the ground to maintain the water table at a height such that water from the capillary fringe is available to the crops. Proper drainage of excess water is permitted, either naturally or with the other drainage works to prevent water logging of the fields. Sometimes the upward capillary water flow from shallow water table may produce saline and alkali conditions and may make the land less productive. Under such circumstances, the sub-surface irrigation method had to be discontinued and irrigation has to be resorted by sprinkling method.

2·12. SPRINKLER IRRIGATION

The sprinkler method consists of applying the water in the form of a spray, somewhat as in ordinary rain, as is done in the garden lawn sprinkling. The greatest advantage of sprinkler irrigation is its adaptabilities to use under conditions where surface irrigation methods are not efficient. This method is more useful where :

(*i*) the land cannot be prepared for surface methods
(*ii*) Slopes are excessive
(*iii*) Topography is irregular
(*iv*) Soil is erosive
(*v*) Soil is excessively permeable or impermeable
(*vi*) depth of soil is shallow over gravel or sand.

Sprinkler system consists of the pump to provide the needed pressure, the main pipe lines and laterals, risers and sprinkler heads. Aluminium, polyethylene and steel pipes are used for the mains and laterals. Riser pipes on which the sprinkler heads are mounted are of mild steel. Sprinkler heads are made of brass or other alloys. Based on the arrangements for spraying irrigation water, the sprinkler irrigation system can be categorized as rotating head system and perforated pipe system. The rotating head type system are classified as Portable type, Semi-portable type, semi-permanent type, solid set type, Permanent system, and Centre pivot system.

In this system, the cost of land preparation and permanent water delivery system of channels or conduits is less. However, there is large initial investment in the purchase of the pumping and sprinkling equipment.

Sprinkler system can be classified under three heads :

(*i*) Permanent system,

(*ii*) Semi-permanent system, and

(*iii*) Portable system.

Earlier, stationary over-head perforated pipe installations were used. However, with the introduction of light weight steel pipes and quick couplers, portable sprinkler system were developed. In the permanent system, pipes are permanently buried in such a way that they do not interfere with tillage operations. In the semi-permanent system, the main lines are buried while the laterals are portable. Portable system have both portable mains lines and laterals. These systems are designed to be moved from around the farm from field to field. A pump usually lifts the water from the source, pushes it through the distribution system and through the sprinkler nozzel on the sprinkler heads mounted on rising pipes attached to the laterals. Turbine and horizontal centrifugal pumps are usually used. Sprinkler system usually is composed of perforated pipes or revolving head sprinklers and may be 'high pressure' (2·1 kg/cm^2) or "low pressure" (1·4 kg/cm^2) system. Generally, a perforated pipe system operates on the low pressure where as the revolving head sprinklers operate in both ranges depending on the type of rotary head used.

Advantages of Sprinkler Irrigation

(*i*) Erosion can be controlled

(*ii*) Uniform application for water is possible.

(*iii*) Irrigation is better controlled ; light irrigation is possible for seedling and plants which are very young.

(*iv*) Land preparation is not required. Labour cost is reduced. More land is available for cropping, as borders and ditches are not required. Surface run off is eliminated.

(*v*) Small streams of irrigation water can be used efficiently.

(*vi*) Time and amount of fertilizers can be controlled for application.

(*vii*) Crop damage from frost can be reduced.

(*viii*) It is a stand-by drainage pumping plant.

DRIP/TRICKLE/OOZE/MICRO-IRRIGATION:

It is based on the basic concept of irrigating only the root zone of the crop, rather than the entire land surface. Water flows from the emission points (nozzles) through the soil by capillary and gravity. The soil moisture content of the crop root zone is maintained at near optimum levels to facilitate optimum crop growth and production. This will involve frequent applications of small quantities of water. Losses due to evaporation and percolation are minimized. This method is highly economical and beneficial in acute water scarcity areas and salt problem areas to grow **orchards and plantation crops** like coconut, tea, coffee, cardamom, citrus, grapes, banana, papaya, mango, guava, pineapple, and watermelon; **row crops** like sugarcane, cotton, groundnut, strawberry and **vegetable crops** like tomato, potato, flower plants.

Drip irrigation system involves laying of system of head, mains, sub-mains, laterals and drop nozzles. Water oozes out of these small drip nozzles uniformly at slow rate at depth of root zone varying from 25 cm to 60 cm. drip nozzles are fixed on laterals at regular interval of about 0.5 meter to 1 meter discharging at very small rate of order of 2 two 10 litters per hours.

Head consists of a pump to lift water so as to produce the desert pressure of about 2.5 atmosphere for sarong proper flow of water through the system the lifted irrigation water is passed throw fertilizer tank, so as to mix the fertilizer directly in irrigation water and then throw a filter so as to remove the suspended particles to the water to avoid to clogging of drip nozzles Mains and sub-mains are small size pipe made of flexible material like black PVC. These are buried or laid on ground ,their sizes be sufficient to carry design discharge of the system Laterals are very small sized ,usually 1 cm to 1.3 cm diameter black PVC pipes taking of from mains or sub-mains .Laterals can usually be up to 50 meter long and one lateral is line is laid for each row of crops.

ADVANTAGES OF DRIP IRRIGATION: (i) 20 to 50% higher crop yield in fruit crops, vegetable crops, and commercial crops due to maintenance of optimum soil moisture in crop root zone throughout growing period of crop, (ii) Improved quality of harvested produce of crop, (iii)) Savings in irrigation water, (iv) Increased efficiency in fertilizer use, (v) Reduced energy consumption due to low operating pressure required, (vi) Tolerance to windy atmospheric condition, (vii) reduced labour cost, (viii) better control of disease and pest control, (ix)fusibility of irrigating undulating terrain and sloppy land, (x) suitability for common soils, (xi) Improve tolerance to salinity, (xii) promotes congenial soil physical condition in root zone, (xiii) Promote better infirmity in irrigation water application, (xiv) Easy in operation, (iv) Facilitates automation, and (16) Adopted to irrigate crop in green houses.

PROBLEMS IN DRIP IRRIGATION: (i) Emitter clogging, (ii) Restricted root development of crops, (iii) Salt accumulation at the root zone periphery, (iv) Damage from rodents and other animals, (v) High cost system.

UNIT-2

(HYDROLOGY: Definitions, hydrological cycles, Rainfall, Runoff, Flood Discharge)

DEFINITIONS:

Hydrology: Hydrology is the science of waters of the earth and earth's atmosphere, in all its forms, their occurrence, circulation, temporal as well as spatial deviation, their chemical and physical properties and their reaction with their environment, including their relation to living beings. The domain of hydrology embraces the full history of water on the earth including its quantitative use. However, it excludes oceanography and meteorology but draws support from them as well as from other allied sciences such as statistics, geology, fluid mechanics, physics, chemistry, etc.

Engineering Hydrology: Engineering Hydrology includes those segments of Hydrology pertinent to investigation, planning, design and operation of engineering projects for control, management and use of water. It deals with study of processes such as precipitation, surface retention (interception, depression storage, evaporation), infiltration, transpiration, natural as well as surface and sub-surface storages and runoff, and their interaction; estimation of temporal as well as spatial availability of surface and ground water resources, and study of problems such as floods, droughts, climate change, and strategies to combat them.

HYDROLOGIC CYCLE: Hydrologic cycle is a process, powered by the Sun's energy and Coriolis force, which moves water between the oceans, the sky, and the land. Sun evaporates water, and Coriolis force, by causing and controlling winds, circulates the evaporated water vapour, and thus helping in its re-precipitation at different places.This cycle is visualized as beginning with the evaporation of water from the oceans. Under the proper conditions, the vapour is condensed to form clouds, which in turn may result in precipitation. The greater part of the precipitation is retained in soil where it falls and is ultimately returned to the atmosphere by evaporation and transpiration by plants. A portion of this water finds its way over and through the surface soil to stream channels, while other water penetrates farther into the ground to become part of ground water. Under the influence of gravity, both surface streamflow and ground water move towards lower elevations and may eventually discharge into the ocean.

Although called a cycle, the process is much more complex than a mere cycle. All kinds of short-cuts and parallel processes take place in the circulation of water evaporated from the ocean and land surfaces, its transport through the atmosphere to the land and its return to the ocean via surface, sub-surface and atmospheric routes. For example, a drop of water evaporated from the ocean may precipitate back into the ocean without completing the entire cycle and water from some surface stream may percolate to the ground water, while in other cases ground water is a source of streamflow, particularly during non-monsoon period.Some precipitation may remain on the ground as snow for months before melting releases the water to streams or groundwater.

The global water cycle can be described with nine major physical processes which form a continuum of water movement. Complex pathways include the passage of water from the gaseous envelope around the planet called the atmosphere, through the bodies of water on the surface of earth such as the oceans, glaciers and lakes, and at the same time (or more slowly) passing through the soil and rock layers underground. Later, the water is returned to the atmosphere. A fundamental characteristic of the hydrologic cycle is that it has no beginning and it has no end. It can be studied by starting at any of the following nine processes: evaporation, condensation, precipitation, interception, infiltration, percolation, transpiration, runoff, and storage.

Schematization of storages and processes of the terrestrial part of hydrologic cycle is shown below in Fig.1.1:

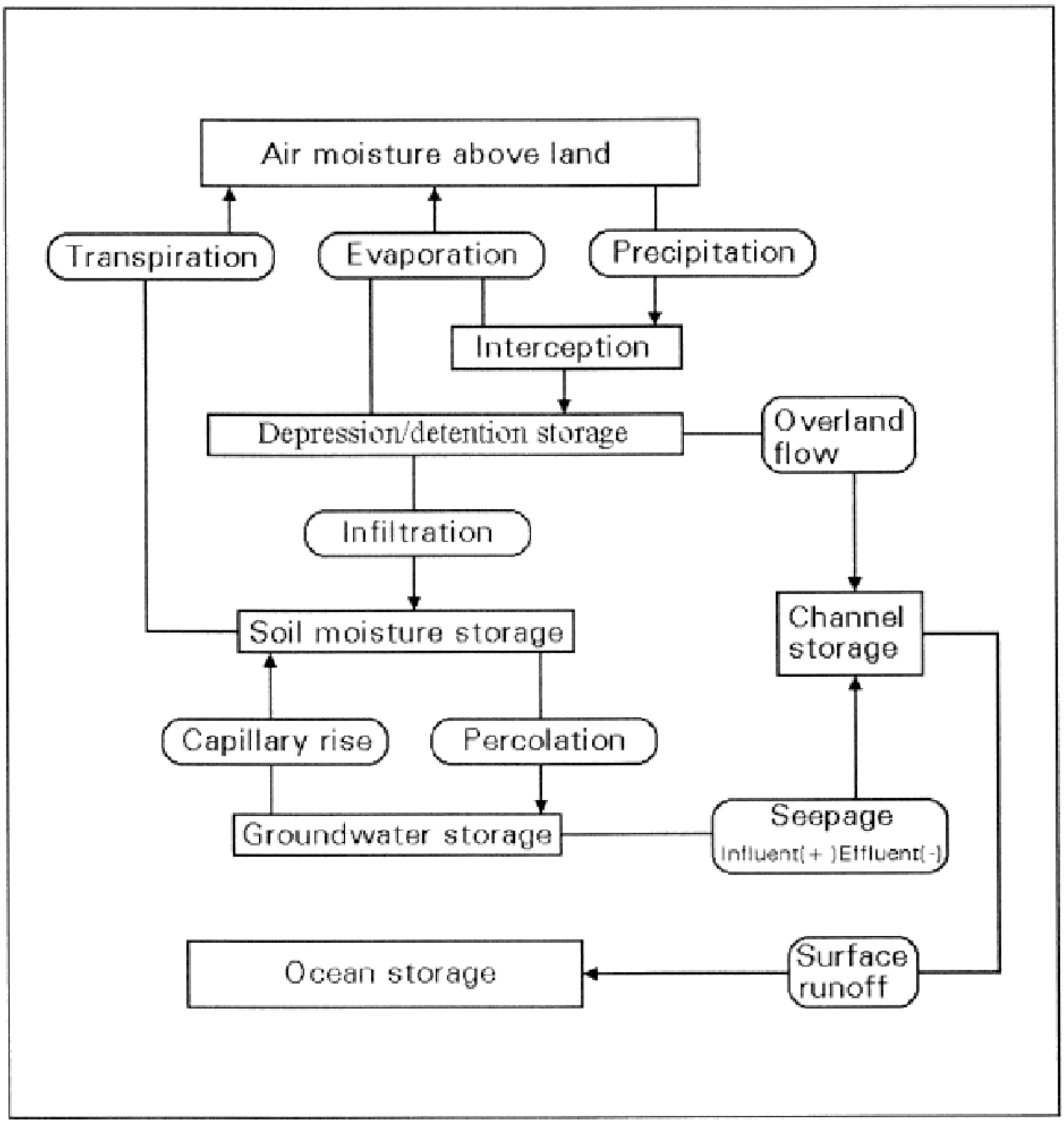

Fig.1.1 Schematization of storages and processes of the terrestrial part of hydrologic cycle

The qualitative representation of hydrologic cycle is illustrated below in Fig.1.2

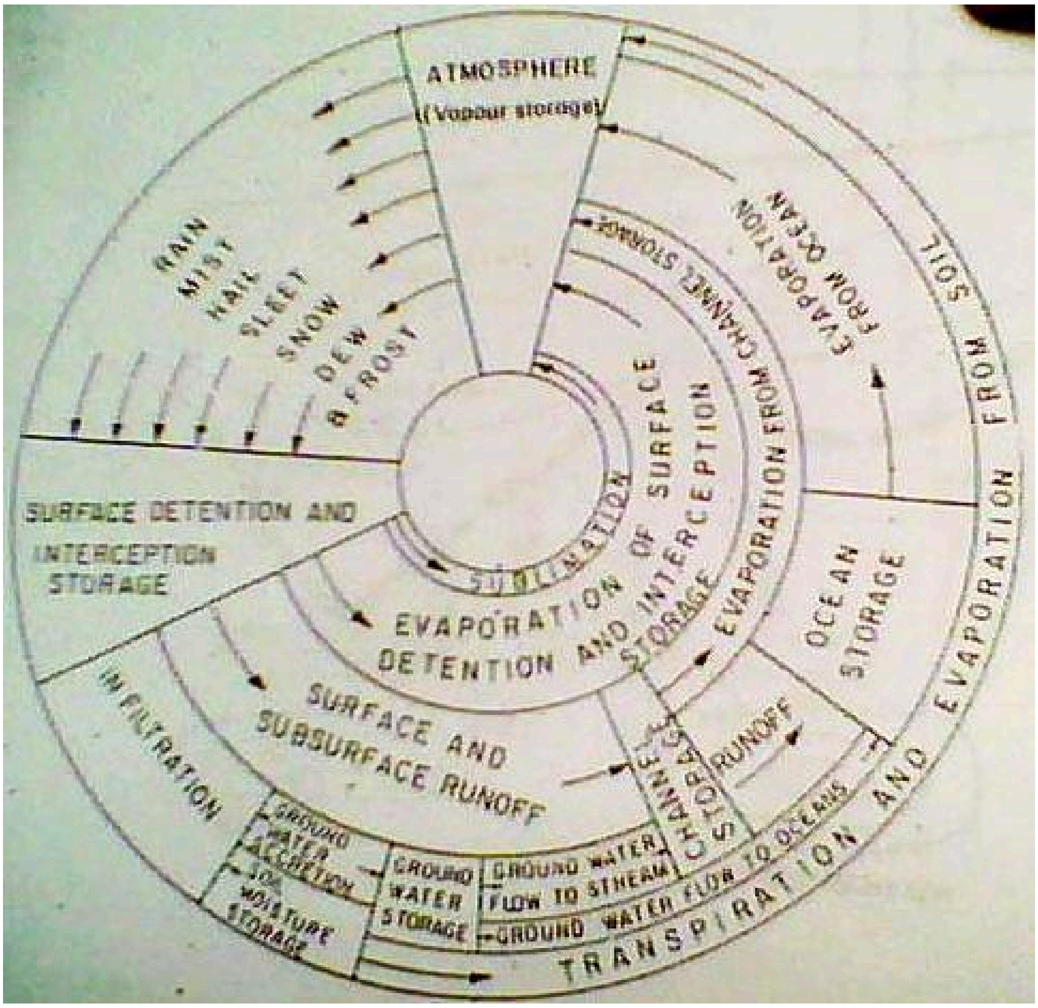

Fig.1.2 Qualitative representation of hydrologic cycle

Each path of the hydrologic cycle involves one or more of the following aspects: (i) transportation of water,(ii) temporary storage and (iii) change of state.Thus the main components of the cycle can be broadly classified as transpotation component (e.g. precipitation,evaporation,transpiration,infiltration,runoff, etc.) and storage component (e.g. depression storage, ponds,lakes,reservoirs,soil water storage,groundwater storage, etc.).

The descriptive representation of hydrologic cycle is illustrated below in Fig.1.3

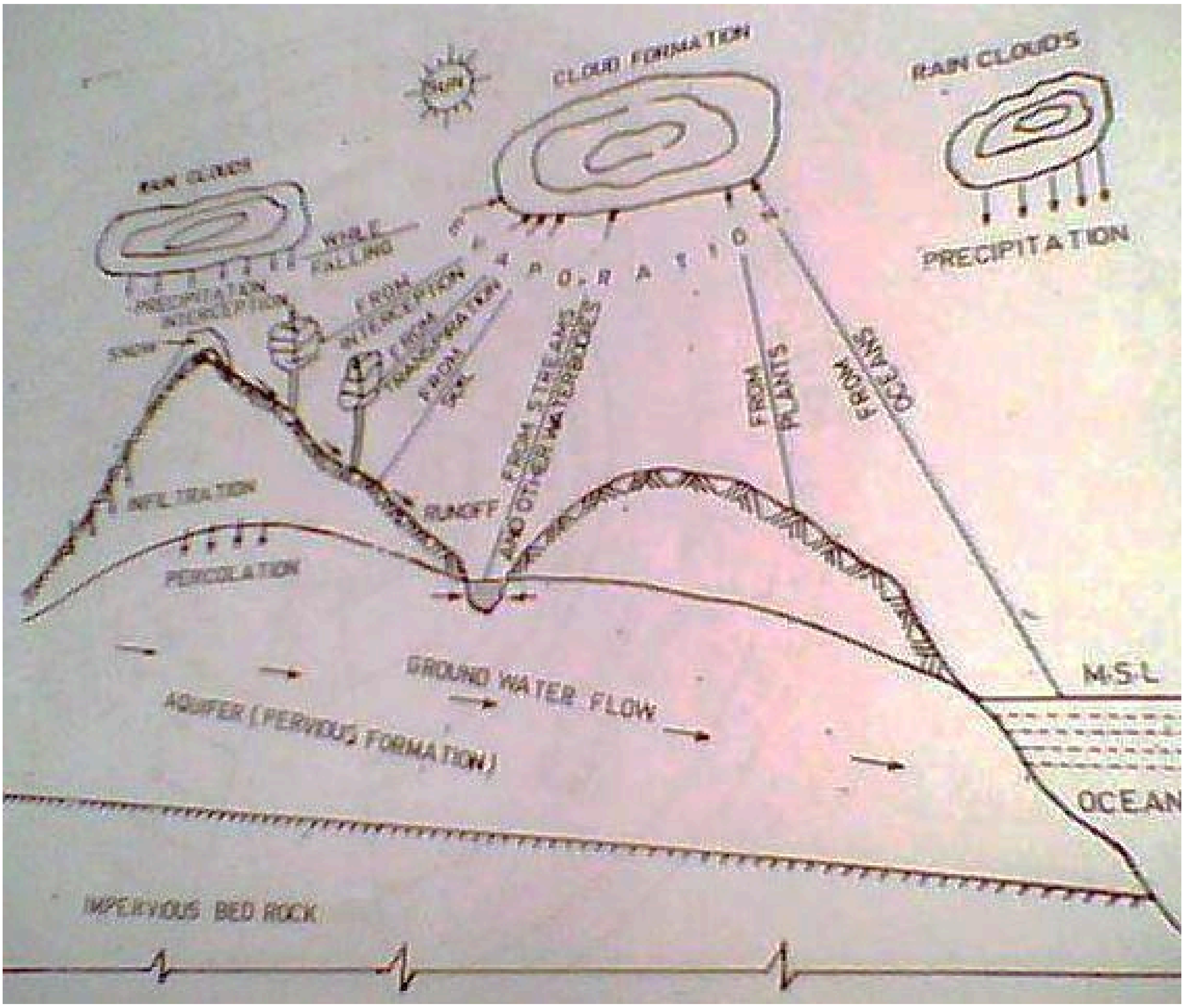

Fig.1.3 Descriptive representation of hydrologic cycle

The engineering representation of hydrologic cycle is illustrated below in Fig.1.4

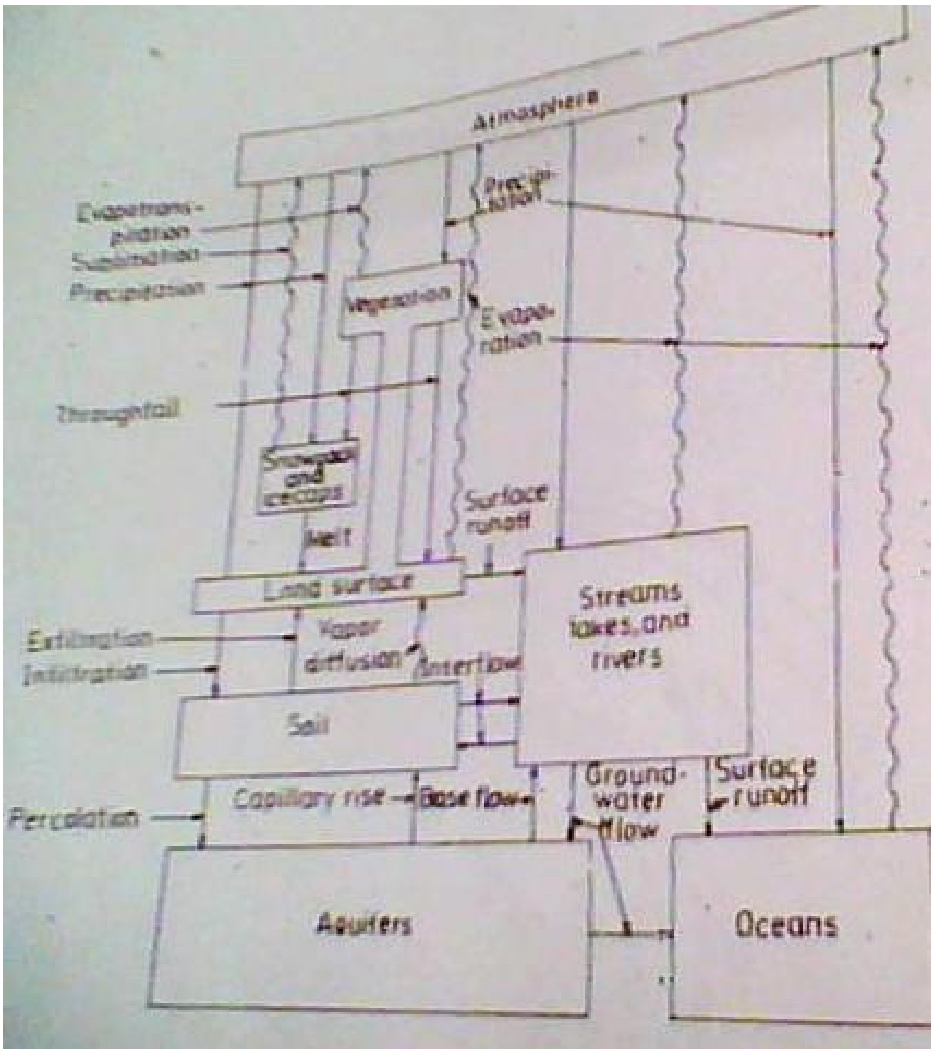

Fig.1.4 An engineering representation of hydrologic cycle

WATER BUDGET EQUATIONS

The quantities of water going through various individual paths of the hydrologic cycle can be described by the continuity equation known as water-budget equation or hydrologic equation.

For any catchment area, in an interval of time, the continuity equation for water in its various phases may be written as:

Mass Inflow- Mass Outflow=Change in mass storage. In other words, it can be expressed as:

$$P-R-G-E-T=\Delta S$$

where P=precipitation, R=surface runoff, G= net ground water flow out of the catchment, E= evapoation, T= transpiration, and ΔS=change in storage.

The storage S consists of three components as $S=S_s+S_{sm}+S_g$, where S_s=surface water storage, S_{sm}=water in storage as soil moisture, and S_g=water in storage as ground water. All the terms in above equations have the dimensions of volume but these can also be expressed as depth over the catchment area. It may be noted that the net import of water into the catchment, by action of man is assumed to be zero in the above equation.

For surface flow, the hydrologic budget can be written as:

$$P + R_1 - R_2 + R_g - E_s - T_s - I = \Delta S_s$$

where precipitation (P), surface-water inflow (R_1), and groundwater appearing as surface water (R_g) are inflows; surface-water outflow (R_2), evaporation (E_s), transpiration (T_s),and infiltration (I) are outflows; and all variables are volumes per unit of time.

For underground flow, the hydrologic budget can be written as:

$$I + G_1 - G_2 - R_g - E_g - T_g = \Delta S_g$$

where infiltration (I) and groundwater inflow (G_1) are inflows; groundwater outflow (G_2), groundwater appearing as surface water (R_g), evaporation from groundwater

(E_g), and transpiration from groundwater (T_g) are outflows. The combined hydrologic budget for a region is derived by summing the above two equations as follows:

$$P - (R_2 - R_1) - (E_s + E_g) - (T_s + T_g) - (G_2 - G_1) = \Delta (S_s + S_g)$$

If the subscripts are dropped and the quantities in parentheses are taken as net changes, the equation reduces to: $P - R - E - T - G = \Delta S$

This is the fundamental equation of hydrology. It is the basis for all hydrologic modeling. One of its uses is in calculating the combined evaporation and transpiration, or evapotranspiration (ET), for a region when estimates of other variables in the equation can be reasonably made. For example, in large river basins, (measured in thousands of square miles or kilometers), groundwater system boundaries often follow surface-water divides. In cases where this assumption can be considered valid, the groundwater flux into and out of the region can be assumed equal to zero (G = 0). In addition, over a long period of time (usually five or more years), seasonal excesses and deficits in storage often tend to balance out in large watersheds, and in such cases the average condition for ΔS may sometimes be assumed to be equal to zero. Under these two assumptions, the hydrologic equation becomes $P - R - ET = 0$ and by knowing P and R, a rough estimate of ET can be obtained.

INDIA'S WATER RESOURCES

India is a developing country with 16% of the World's population, 2.4% of the World's land resources and 4% of the World's fresh water. On an average, every year India gets 4,000 billion cubic meters (BCM, 1 BCM = 1 cu. km) of water by way of mostly rainfall and some snowfall. However, there are considerable spatial and temporal variations in the distribution of rainfall and hence in availability of water in time and space in the country. It is estimated that out of the 4000 BCM water, 1869 BCM is available water resource. Out of this the quantity that can be put to use (utilizable) is only 1123 BCM (690 BCM from surface water resources and 433 BCM from ground water resources). The water demand in the year 2000 was 634 BCM and it is going to be 1093 BCM by the year 2025. Efforts therefore, need to be made to increase the utilizable quantity by conservation, improving efficiencies and increasing supply sources.

APPLICATIONS OF ENGINEERING HYDROLOGY IN CIVIL ENGINEERING

The knowledge of this science is a must for every civil engineer, particularly the one who is engaged in the design, planning, construction and maintenance of any hydraulic structure such as structures for water supply and sanitation works, irrigation and drainage structures, urban drainage structures, bridges, and highway culverts, flood control structures, forecasting and warning operations, structures needed for management and enforcing of artificial recharge of ground water etc.

What flood levels and flows can be expected at any strategic point likely to affect the human beings, over a spillway, at a highway culvert, or in an urban storm drainage system? What minimum reservoir capacity will be sufficient to assure adequate water for irrigation or municipal water supply during droughts? How much quantity of water will become available at a reservoir site, when will it become available? What will be the available possible supplies at the reservoir site? What effect will reservoirs, levees and other control works exert on flood flows in a stream? What effects will be there on the river water levels after the construction of proposed reservoirs, levees, or any other controlling structures? Civil Engineers responsible for the planning, design, construction and maintenance of any hydraulic structures are required to answer these questions?

Designer needs only a single value of each parameter, while Planner requires data in probabilistic form in order to make meaningful socio-economic evaluations and an effective choice among the possible alternatives. Proper assessment of following factors are necessary:

(i) Capacity of storage structure, (ii) Magnitude of flood flows to enable safe disposal of excess flows, (iii) Minimum flow and quantity of flow available at requisite places and period, (iv) Interaction of flood wave and hydraulic structures such as levees, reservoirs, barrages, bridges etc.

Planning requires following four phases of analysis:

(i) Defining pre-project conditions as a base for project evaluation, (ii) Defining post-project conditions to determine the project effects, (iii) Development of an operation procedure, (iv) Definition of specific design events such as project design flood or spillway design flood.

PRECIPITATION

Precipitation is the process that occurs when any and all forms of water particles fall from the atmosphere and reach the ground. There are two sub-processes that cause clouds to release precipitation, the coalescence process and the ice-crystal process. As water drops reach a critical size, the drop is exposed to gravity and frictional drag. Falling drop leaves a turbulent wake behind which allows smaller drops to fall faster and to be overtaken to join and combine with the lead drop. The other sub-process that can occur is the ice-crystal formation process. It occurs when ice develops in cold clouds or in cloud formations high in the atmosphere where freezing temperatures occur. When nearby water droplets approach the crystals some droplets evaporate and condense on the crystals. The crystals grow to a critical size and drop as snow or ice pellets. Sometimes, as the pellets fall through lower elevation air, they melt and change into raindrops.

Water evaporates from exposed water surfaces like streams, rivers, oceans, ponds, and also from the lands and plants, in the form of water vapour which gets collected in the atmosphere and behaves like a gas obeying various gas laws .As the evaporation continues, the amount of atmospheric vapour goes on increasing. But since a space (atmosphere) can hold only a certain fixed amount of water vapour in the presence of a solid or a liquid surface, a state is reached when any further addition of vapour will get condensed on the surfaces. The water which comes back to the surface of the earth in its various forms like rain, snow, hail, sleet, etc. is known as precipitation.For precipitation to form, following things should happen:

(i) Atmosphere must have moisture, (ii) Sufficient nuclie must be present to aid condensation, (iii) Weather conditions must be good for condensation of water vapour to take place, and (iv) The products of condensation must reach the earth.

FORMS OF PRECIPITATION

Some of the common forms of precipitation are: rain, snow, drizzle, glaze, sleet and hail. A major part of the precipitation occurs in the form of rain, and minor part occurs in the form of snow.Other forms are negligibly small and generally ignored in the design of most of the hydrological works.

RAINS are liquid precipitation in the form of water drops of radius varying from 0.5mm to 2.5mm (500μm to 2500μm) and occasionally even larger size upto 6mm.

Sr. No.	Type of rain	Intensity of rain (mm)
1	Very light/Light rain	Trace to 2.4,2.5 to7.5
2	Moderate rain	7.6 to 35.5
3	Rather Heavy/Heavy/Very Heavy/Extremely Heavy rain	35.6-64.4,64.5-124.4,124.5-244.4, >244.5

SNOW consists of ice Cristals which usually combine to form flakes. When fresh, snow has an initial density varying from 0.06 to 0.15 gm/cm^3 and it is usual to assume an average density of 0.1 gm/cm^3. In India it occurs in the Himalayas.

DRIZZLE is a fine sprinkle of numerous water droplets of size from 0.1 mm to 0.5mm with such low settling rates and intensity less than 1mm/hr. that they appear to float in the air.

GLAZE is a freezing rain which falls from cloud as a liquid, but turns to ice on contact with freezing object. It forms as the ice coating, generally clear and smooth, and formed on exposed cold ground surfaces at around 0^{o}C, by the freezing of supercooled water deposited by rain or drizzle. Its specific gravity may be as high as 0.8 to 0.9.

SLEET is frozen or partially frozen raindrop in the form of ice pallets consisting of transparent, globular, solid grains of ice formed by the freezing of raindrops or refreezing of largely melted ice cristals falling through a layer of subfreezing air near the earth's surface. These pallets hit the ground so fast that they bounce off with a sharp click.

HAIL is a showery solid precipitation in the form of irregular pellets or balls of ice of size varying from 5mm to 50mm or even more upto 8mm. Hails occur in violent thunderstorms in which vertical currents are very strong.

Dew and **Frost** are not direct forms of precipitation.

MEASUREMENT OF PRECIPITATION

All forms of precipitation are measured on the basis of the vertical depth of water that would accumulate on a level surface if the precipitation remained where it fell. In the case of snowfall, an equivalent depth of water is used as the depth of precipitation. In India precipitation is measured in millimeters and tenths. India Meteorological Department (IMD) measures/gets measured rainfall every day at 08.30A.M. (IST) at various Raingauge stations throughout India and maitains its record.

Depth of rainfall (cm) = (Volume of water collected in cubic cm)/ (Area of aperature of the gauge in sq. cm.)

SELECTION OF SITE FOR RAINGAUGE STATION

(i) The ground must be level and in the open and the instrument must present a horizontal catch surface.

(ii) The gauge must be set as near the ground as possible to reduce wind effects but it must be sufficiently high to prevent splashing, flooding, etc.

(iii) The instrument must be surrounded by an open fenced area of atleast 5.5m x 5.5m.

(iv) No object should be nearer to the instrument than 30m or twice the height of the obstruction.

Non-Recording Gauges

The non-recording raingauges earlier used in India were the Symons' gauge (shown below in the Fig.1.5) comprising of a circular collecting area of 127mm diameter connected to a funnel. The rim of the collector is set in a horizontal plane at a height of 30.5 cm above the ground. The funnel discharges the rainfall catch into a receiving vessel. The funnel and the receiving vessel are housed in a metallic (copper) container. Water contained in the receiving vessel is measured by a suitably graduated measuring glass, with an accuracy up to 0.1mm.

Now IMD has changed over to the use of fibreglass reinforced polyester rain gauges, which is an improvement over the Symons' gauge. These come in different combinations of collector and bottle. The collector is in two sizes having areas of 200 sq cm sizes (159.6mm dia.) fitted in 400mm rainfall capacity container and 100 sq. cm. sizes (112.9mm dia.) fitted in 200mm rainfall capacity container. Details of these ORGs are given in IS: 5225-1969 and website of IMD and illustrated below in the Fig.1.6.The rain gauge is fixed on the ground with a concrete block of size 600mm x 600mm x 600mm.The details of installation are given in IS:4986-1968.

This rain gauge can also be used to measure snowfall. When snow is expected, the funnel and receiving bottle are removed and the snow is allowed to collect in the outer metal container. The snow is then melted and the depth of resulting water measured. Antifreeze agents are sometimes used to facilitate melting of snow. In areas where considerable snowfall is expected, special snow gauges with shields for minimizing wind effect and storage pipes to collect snow over longer durations are used.

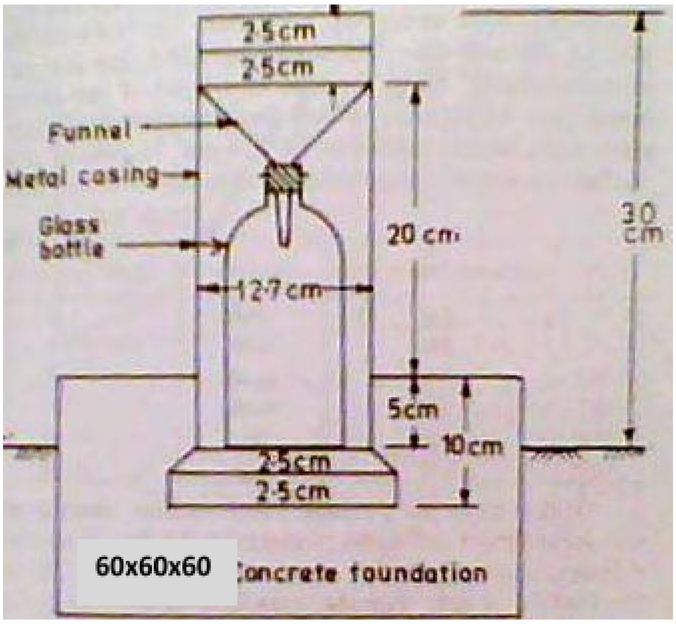

Fig.1.5 Symon's non-recording Raingauge

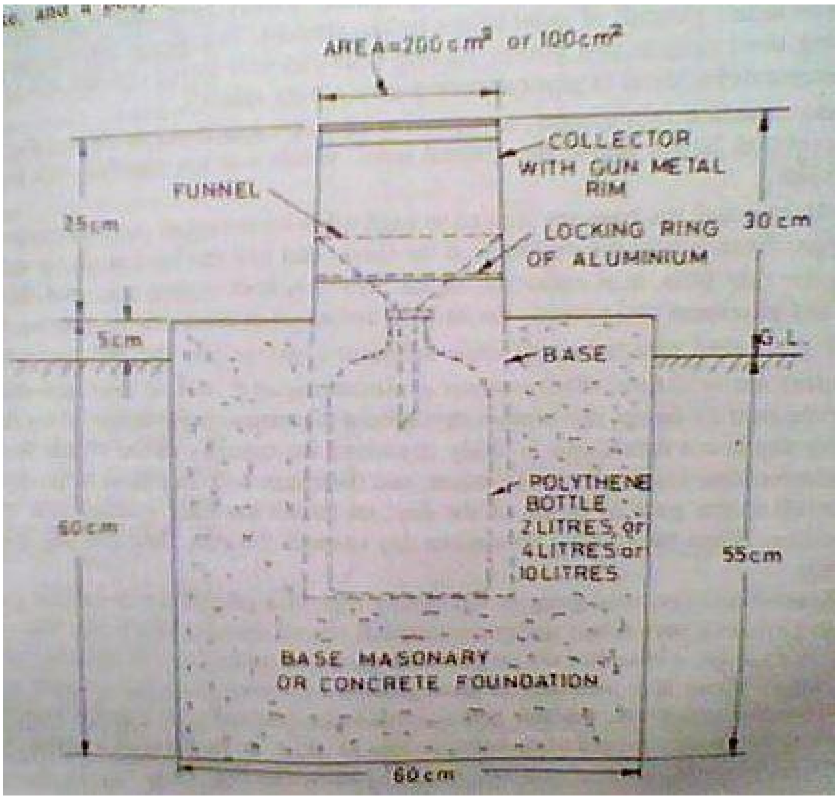

Fig. 1.6 Standard non-recording Rain gauge of IMD

RECORDING GAUGES

Recording gauges produce a continuous plot of rainfall against time and provide valuable data of intensity and duration of rainfall for hydrological study of storms. The following are some of the commonly used recording gauges:

FLOAT TYPE SRRG

Details of this type of Self Recording Rain Gauges (SRRG), used by IMD, are described in IS: 5235-1969. The rainfall collected by a funnel-shaped collector is led into a float chamber causing a float to rise. As the float rises, a pen attached to the float through a lever system records the elevation of the float on a rotating drum driven by a clock-work mechanism. A syphon arrangement empties the float chamber when the float has reached a pre-set maximum level. The vertical lines in the pen-trace correspond to sudden emptying of the float chamber by syphon action which resets the pen to zero level. It is obvious that the natural syphon type recording gauge gives a plot of the mass curve of rainfall.

TIPPING- BUCKET TYPE SRRG

In this type of SRRG the rainfall water caught in the collector is funneled into a pair of small buckets. These buckets are so balanced that when 0.25mm of rainfall collects in one bucket, it tips and brings the other one in position.The water from the tipped bucket is collected in a storage can. The tipping actuates an electrically driven pen to trace a record on clock-wise driven chart. The water collected in the storage can is measured at regular intervals to provide the total rainfall and also serves as a check. It may be noted that the record from the tipping bucket gives data on the intensity of rainfall. Further, the instrument is ideally suited for digitalizing of the output signal.

WEIGHING-BUCKET TYPE SRRG

The catch of precipitation from the funnel empties into a bucket mounted on a weighing scale. The weight of the bucket and its contents are recorded on a clock-work-driven chart. The clock- work mechanism has the capacity to run for as long as one week. This instrument gives a plot of accumulated rainfall against the elapsed time, i.e. the mass curve of rainfall.

TELEMETERING RAINGAUGES

These rain gauges are of recording type and contain electronic units to transmit the data on rainfall to a base station both at regular intervals and on interrogation. The tipping-bucket type, being idealy suited, is usually adopted for this purpose.

RADAR MEASUREMENT OF RAINFALL

The meteorological radar is a powerful instrument for measuring the areal extent, location and movement of rain storms. Further, the amounts of rainfall over large areas can be determined through the radar with a good degree of accuracy. Radars of 3 or 5 cm wave lengths are generally used for detection of clouds, lighter rainfalls, or snowfalls; whereas, 10cm wave length radars may suffice for detecting heavy rains and cyclone surveillance.

MEASUREMENT OF DEPTH OF SNOWFALL

A graduated stick or staff is used to measure the depth of snow at a selected place.Snowstakes are permanent graduated posts used to measure total depth of accumulated snow at a place. Snow boards are 40cm side square boards used to collect the snow samples. These are placed horizontally on a previous accumulated snow and after a snowfall event the snow samples are cut off from the board and depth of snow and water equivalent of snow are derived and recorded.

RAINGAUGE NETWORK

WMO have recommended following minimum densities (sq.km. per rain gauge station) for general hydro meteorological purposes:

1. For flat regions of temperate, Mediterranean, and tropical zones: Ideal-600-900, Acceptable:900-3000 sq.km. per station.

2.For mountainous regions of temperate, Mediterranean, and tropical zones: Ideal:100-250, Acceptable:25-1000 sq.km. per station.

3.For small mountainous islands with irregular precipitation: 25 sq.km. per station.

4.For arid and polar zones:1500-10,000 sq.km. per station depending on the feasibility.

5. At least 10% of the total raingauges should be of self-recording type in order to know the intensities of rainfall.

IMD has recommended following minimum densities (sq.km. per rain gauge station) from practical considerations of Indian conditions for general hydro meteorological purposes:

1. In plains: 520 sq.km. per station.

2.In regions of average elevation 1000m: 260-390 sq.km. per station.

3. In predominantly hilly areas with heavy rainfall: 130 sq.km. per station.

ADEQUECY OF RAINGAUGE STATIONS

If there are already some rain gauge stations in a catchment, the optimum number of stations that should exist to have an assigned percentage of error in the estimation of mean rainfall is obtained by statistical analysis as N=$[\frac{Cv}{\varepsilon}]^2$ where N=optimum number of stations, ε=allowable degree of error in the estimate of the mean rainfall and C_v= coefficient of variation of the rainfall values at the existing m stations (in per cent).If there are m stations in the catchment each recording rainfall values $P_1, P_2, \ldots\ldots. P_i, \ldots P_m$ in a known time, the coefficient of variationC_v is calculated as

$$C_v=\frac{100x6m-1}{\bar{P}} \text{ where } б_{m-1} = \sqrt{\frac{\sum_1^m (Pi-\bar{P})^2}{(m-1)}} \sqrt{\frac{\sum_1^m (Pi-\overline{P)2}}{(m-1)}} \text{=standard deviation}$$

In calculating N from above equation it is usual to take ε=10%.

PROBABLE MAXIMUM PRECIPITATION (PMP)

PMP is the maximum depth of precipitation over a basin for a given duration that may possibly occur at any time of the year over the area under consideration which would produce a flood flow with virtually no risk of being exeeded, i.e.Maximum Probable Flood (PMF).Such a precipitation would result from the possible severest storm, that may result from the worst possible combinations of hydrological conditions in the area, called as Probable Maximum Storm(PMS).The development of PMP for a given region is an involed procedure and requires the knowledge of an experienced hydrometeorologist. Basically two approaches are used: (i) Meteorological methods, and (ii) the statistical study of rainfall data.

PMP can be estimated by maximising the different parameters, such as wind velocity, humidity, etc. of an observed severe storm, over the given region.It is usually derived by (i) taking results of depth-area-duration analyses of precipitation in major storms that have or could have occurred in the area of interest, (ii) adjusting them for maximum moisture charge and rate of moisture inflow, and (iii) enveloping the adjusted values for all storms to obtain the depth-area-duration curves of PMP. Occasionally, when enough storm data for a given region is not available, PMP can be estimated by adopting a severe storm over a neighbouring catchment, and transposing it to the catchment under consideration. Storm patterns are not transposed in mountainous regions because it is not possible to adjust rainfall accurately for orographic influences.

Statistically, PMP for a point and given duration is expressed as the mean of the annual series plus K standard deviation and can be expressed as PMP= P+K.б where P= mean of annual maximum rainfall series, б= standard deviation of the series and K= a frequency factor which depends upon the statistical distribution of the series, number of years of record and the return period. The empirically derived value of K varies with rainfall duration and inversely with the mean of the series and ranges between 5 and30 and in India is usually in the neighbourhood of 15. PMP estimates for north- Indian plains vary from 37 to 100 cm for one-day rainfall. IMD and Indian Institute of Tropical Meteorolgy have prepared guiding curves, showing isohyetal lines for maximum storm depths that may result for 1day, 2days and 3 days maximum rainfall.

Based on the rainfall records available all over the world, a list of world's greatest recorded rainfalls of various durations can be assembled. When this data is plotted on a log-log paper, an enveloping straight line drawn to the plotted points obeys the equation: $P_m=42.16D^{0.475}$ where P_m= extreme rainfall depth in cm and D=duration in hours. The values obtained from this equation are of use in PMP estimations.

EVAPOTRANSPIRATION

In studying the hydrologic balance for a catchment area,one is concerned with the evaporation from all water,soil,snow,ice,vegetation,and other surfaces plus transpiration; the total of these processes are known as Evapotranspiration.

Transpiration is the process by which water leaves the body of a living plant and reaches the atmosphere as water vapour. The difference in concentration between the sap in the root cells of a plant and the soil water causes an osmotic pressure which moves soil water throughthe root membrane into the root cells. High salinity of the soil solution and/or high moisture tension in the soil may prevent or greatly reduce the osmtic transfer.Once inside the root, the water is transferred through the plantto the intercellular space within the leaves.Air enters the leafthrough the stromata, openings in the leafe surface, and the chloroplasts within the leaf use carbon dioxide from the air and a small portion of the available water to manufacture carbohydrates for plant growth (photosynthesis). As air enters the leaf, water escapes through the open stomata; this is the process of transpiration. The ratio of the water transpired to that used in forming plant matter is very large (upto 800% or more). Consumptive Use is the total evaporation from an area plus the water used directly in building plant tissues.

While transpiration takes place, the land area in which plants stand also lose moisture by the evaporation of water from soil and water bodies. Since in the process of vegetation growth, it is generally not feasible to separate the transpiration and its connected evaporation from the plants surroundings, a combined measure is obtained and this is called Evapotranspiration.If sufficient water is always available to completely meet the needs of vegetation, fully covering the area, the resulting evapotranspiration is called Potential Evapotranspiration (PET).It essentially depends on the climatic factors. The real evapotranspiration occuring in a specific situation is called ActualEvapotranspiration.

MEASUREMENT OF EVAPOTRANSPIRATION

The measurement of evapotranspiration for a given vegetation type can be carried outin two ways; either by using lysimeters or by the use of field plots.

LYSIMETERS

A lysimeter ssis a special watertight tank containing a block of soil and set in a field of growing plants.Th e plants grown in the lysimeter are the same as in the surrounding field. Evapotranspiration is estimated in terms of the amount of water required to maintain constant moisture conditions within the tank measured either volumetrically or gravimetrically through an arrangement made in the lysimeter.It should be designed to accurately reproduce the soil conditions,moisture content, type and size of the vegetation of the surrounding area.They should be so buried that the soil is at the same level inside and outside the container. Lysimeter studies are time-consuming and expensive.

FIELD PLOTS

In special plots all the elements of the water budget in a known interval of time are measured and the evapotranspiration determined as:

Evapotranspiration=[Precipitation+Irrigation input-Runoff-Increase in soil storage-Ground water loss]

Measurements are usually confined to precipitation, irrigation input, surface runoff,and soil moisture. Ground water loss due to deep percolation is difficult to measure and can be minimised by keeping the moisture condition of the plot at the field capacity. This method provides fairly raliable results.

ESTIMATION OF EVAPOTRANSPIRATION

Most simple and commonly used methods of estimation of evapotranspiration are:

(i) Blaney- Criddle Equation

(ii) Thornthwaite Formula

(iii) Penman's equation

(i) Blaney- Criddle Equation

The potential evapotranspiration in a crop-growing season is given by E_T=2.54KF and $F=\Sigma P_h \bar{T}\,\bar{T}_f/100$ where E_T=PET in a crop season in cm, K=an empirical coefficient depending on the type of the crop and stage of growth, F=sum of monthly cosumptive factors for the period, P_h=monthly percent of annual day-time hours dpending on the latitude of the place,and $\bar{T}\,\bar{T}_f$ =mean monthly temperature ^{0}F.Values of K depend on the month and locality.This formula is largely used by irrigation engineers to calculate the water requirement of crops, which is taken as the difference between PET and the effective precipitation.

Monthly Daytime Hours percentages,P_h, for use in Blaney-Criddle formula

North latitude(degree)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
0	8.50	7.66	8.49	8.21	8.50	8.22	8.50	8.49	8.21	8.50	8.22	8.50
10	8.13	7.47	8.45	8.37	8.81	8.60	8.86	8.71	8.25	8.34	7.91	8.10
15	7.94	7.36	8.43	8.44	8.98	8.80	9.05	8.83	8.28	8.26	7.75	7.88
20	7.74	7.25	8.41	8.52	9.15	9.00	9.25	8.96	8.30	8.18	7.58	7.66
25	7.53	7.14	8.39	8.61	9.33	9.23	9.45	9.09	8.32	8.09	7.40	7.42
30	7.30	7.03	8.38	8.72	9.53	9.49	9.67	9.22	8.33	7.99	7.19	7.15

35	7.05	6.88	8.35	8.83	9.76	9.77	9.93	9.37	8.36	7.87	6.97	6.86
40	6.76	6.72	8.33	8.95	10.02	10.08	10.22	9.54	8.39	7.75	6.72	6.52

Values of K for selected crops

Crop	**Average value of K**	**Range of monthly values**
Rice	1.10	0.85-1.30
Wheat	0.65	0.50-0.75
Maize	0.65	0.50-0.80
Sugarcane	0.90	0.75-1.00
Cotton	0.65	0.50-0.90
Potatoes	0.70	0.65-0.75
Natural Vegetation: Very dense Dense Medium	 1.30 1.20 1.00	

Light	0.80	

(ii) THORNTHWAITE FORMULA

This formula was developed from data of eastern USA and uses only the mean monthly temperature together with an adjustment for day-lengths. The PET is given bythis formula as

$E_T=1.6L_a[10\bar{T}\bar{T}/I_t]^a$

Where E_T=mean PET in cm, L_a=adjustment for the number of hours of daylight and days in the month, related to the latitude of the place, $\bar{T}\bar{T}$=mean monthly air temperature 0 C, I_t=the total of 12 monthly values of heat index=$E_1^{12}i$, where $i=(T/5)^{1.514}$, a= an empirical constant=$6.75x\ 10^{-7}\ I_t^3-7.71x10^{-5}I_t^2+1.792x\ 10^{-2}\ I_t$ +0.49239

(iii) PENMAN'S EQUATION

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

Penman's equation is based on sound theoretical reasoning and is obtained by a combination of the energy balance and mass transfer approach.Penman's equation, incorporating some of the modifications suggested by other investigators is

PET= $\frac{AHn+Ea\gamma}{A+\gamma}$ $\frac{AHn+Ea\gamma}{A+\gamma}$ where PET=daily potential evapotranspiration in mm per day,A=slope of the saturation vapour pressure vs temperature curve at the mean air temperature,in mm of mercury per ^{0}C, H_n=net radiation in mm of evaporable water per day,E_a=parameter including wind velocity and saturation deficit,γ=psychrometric constant=0.49mm of mercury/^{0}C.

The net radiation is the same as used in the energy budget and is estimated by the following equation:

Hn=Ha(1-r)[a+b$\frac{n}{N}$ $\frac{n}{N}$]-бT$_a^4$(0.56-0.092)$\sqrt{ea}$ $\sqrt{ea}$)[0.10+0.90$\frac{n}{N}$ $\frac{n}{N}$] where H_a= incident solar radiation outside the atmosphere on a horrizontal surface, expressed in mm of evaporable water per day, a=a constant depending upon the latitude φ and is given by a=0.29cosφ, b=a constant with an average value of 0.52, n=actual duration of bright sunshine in hours, N=maximum possible hours of bright sunshine,r=reflection coefficient whose values are given below:

Surface	Range of r values
Close ground crops	0.15-0.25
Bare lands	0.05-0.45
Water surface	0.05
Snow	0.45-0.95

Б=Stefan-Boltzman constant=2.01x10-9 mm/day,T_a=mean air temperature in degrees kelvin=273+^{0}C,e_a=actual mean vapour pressure in the air in mmof mercury.

The parameterEa is estimated as Ea=0.35[1+$\frac{u2}{160}\frac{u2}{160}$] (ew-ea) in which u_2=mean wind speed at 2 m above ground in km/day,e_w=saturation vapour pressure at mean air temperature in mm of mercury,e_a=actual vapour pressure.

For the computation of PET, data on n,e_a,u_2, mean air temperature and nature of surface (r) are needed which can be obtained from actual observations or through available meteorological data of the region. It may be noted that penman's equation can be used to calculate evaporation from water surface using r=0.05.This equation is widely used in India,the UK,Australia and in some parts of USA.

INITIAL LOSSES:

INTERCEPTION

Interception is that amount of precipitation water which is intercepted by vegetative foliage, buildings, and other objects lying over the land surface. Various factors that affect interception are (i) storm factor, (ii) plant factor, (iii) season of the year, and (iv) prevailing wind.

UNIT HYDROGRAPH & ITS ANALYSES

The hydrograph of outflows from a small basin is the sum of the elemental hydrographs from all the subareas of the basin modified by the effect of transit time through the basin and storage in the stream channel. Since the physical characteristics of the basin-shape, size, slope, etc. are constant, one might expect considerable similarity in the shape of hydrographs from storms of similar rainfall characteristics. This is the essence and concept of unit hydrograph introduced by Sherman in 1932 as a tool for estimating hydrograph shape. The unit hydrograph is a typical hydrograph for the basin. It is called unit hydrograph because, for convenience, the runoff volume under the hydrograph is commonly adjusted to 1 cm equivalent depth over the catchment.

It would be wrong to imply that one typical hydrograph would suffice for any basin. Although the physical characteristics of the basin remain comparatively constant ,the variable characteristics of storms such as duration of rainfall ,time-intensity pattern, areal distribution of rainfall, and amount of rainfall cause variations in the shape of the resulting hydrograph.

A unit hydrograph is defined as the hydrograph of direct runoff resulting from one unit depth (1 cm, or 1 mm, or 1 inch) of rainfall excess occurring uniformly over the basin and at a uniform rate for a specified duration**.** The duration assigned to a unit hydrograph should be the duration of rainfall producing significant runoff, determined by inspection of hourly rainfall data.

Basic Assumptions:

(i) **Time invariance:** The direct –runoff response to a given effective rainfall in a catchment is a time-invariant. It implies that the DRH for a given effective rainfall in a catchment is always the same irrespective of when it occurs.

(ii) Linear response: The direct-runoff response to the rainfall excess is assumed to be linear i.e. ordinates of flow are proportional to volume of runoff for all storms of a given duration.

(iii) Time Base: For a storm of same duration but with a different amount of runoff, the hydrograph of direct runoff is assumed to have the same time base as the unit hydrograph.

Derivation of Unit Hydrograph:

The unit hydrograph is best derived from the hydrograph of a storm of reasonably uniform intensity, duration of desired length, and a relatively large runoff volume. The first step is to separate the base flow from direct runoff. The volume of direct runoff is the determined, and the ordinates of the direct runoff hydrograph are divided by observed runoff depth. The adjusted ordinates form a unit hydrograph.

A unit hydrograph derived from a single storm may not be representative, and it is therefore desirable to average unit hydrographs from several storms of about the same duration. Compute the average peak flow and time to peak and unit hydrograph is then sketched to conform to the shape of other graphs, passing through the computed average peak, and having the required unit volume.

CONVERSION OF UNIT HYDROGRAPH DURATION

Method of Superposition

There is frequently a need to convert an existing unit hydrograph for one storm duration to another- shorter to better cope with spatial and intensity variations, or longer to reduce required computations and possibly in recognition of the coarseness of the available data.If two t_R- hr (duration) unit hydrographs, one lagged by t_R hr with respect to the other, are added, the result is the characteristic hydrograph for 2 units of rainfall excess and 2.t_R-hr duration. Dividing the ordinates by 2 yields the 2.t_R-hr unit hydrographs. In other words, the n. t_R-hr unit hydrograph is the average of n t_R-hr unit hydrograph, each lagged t_R hr with respect to the previous one.

S-Curve or Summation Curve Method

The S- curve is the hydrograph that would result from an infinite series of unit runoff increments. Each S-curve applies to a specific duration within which each unit of runoff is generated. The S-curve is constructed by adding together a series of unit hydrographs, each lagged t_R hr with respect to the preceding one. If the time base of the unit hydrograph is T hr, then a continuous rainfall producing one unit of runoff every period would develop a constant outflow at the end of T hr. Thus only T/t_R unit hydrographs need be combined to produce an S curve which should reach equilibrium at flow $qe=2.78A/t_R$ where qe is in cumec, A is drainage area in sq. km., the runoff in cm and t_R is again the unit duration.Commonly, the S curve tends to fluctuate about equilibrium flow. This means that the initial unit hydrograph does not actually represent runoff at a uniform rate over time t_R. Thus S-curve serves as an approximate check on the assumed duration of effective rainfall for the unit hydrograph.

The difference between two S curves with initial points displaced by t'_R hr gives a hydrograph for the new duration t'_R. Since the S curve represents runoff production at a rate of one unit in t_R hr, the runoff volume represented by this new hydrograph will be t'_R/t_R units.Thus the ordinates of the unit hydrograph for t'_R hr are computed by multiplying the S curve differences by the ratio t_R/t'_R.

SYNTHETIC UNIT HYDROGRAPH

Synthetic unit hydrographs are derived for ungauged catchements.This rquires a relation between the physical geometry of the area and the resulting hydrographs.Three approaches have been used:

(i) Formulas relating hydrograph features to basin characteristics (time of peak, peak flow, and time base of the unit hydrograph), (ii) Transposition of unit hydrographs, (iii) Storage Routing.

SNYDER'S METHOD

Snyder developed a set of empirical equations for synthetic unit hydrographs in 1938 based on a study of a large number of catchments in the Appalanchian Highlands in eastern USA. Basin lag (time interval from mid-point of unit rainfall excess to the peak of the unit hydrograph),$t_p=C_t(LL_{ca})^{0.3}$ where t_p is in hours, L=basin length measured along the river from the basin divide to the gauging stationin km, L_{ca}= distance along the main water course from the gauging station to a point opposite to the watershed centroid in km,C_t=a regional constant representing watershed slope and storage. According to Snyder its value ranged from 1.35 to 1.65 but studies elsewhere indicate the variation as 0.3 to 6.0.Linsley et al found that the basin lag tp is better correlated with the catchment parameter $[LL_{ca}/\sqrt{S}]$ where S= basin slope. Hence the modified formula is $t_p=C_{tL}[LL_{ca}/\sqrt{S}]^n$ where C_{tL} and n are basin constants. Value of n was found to be equal to 0.38.Values of C_{tL} were 1.715 for mountainous drainage areas, 1.03 for foot-hill drainage areas and 0.50 for valley drainage areas.

Snyder adopted a standard duration t_r hours of effective rainfall given by $t_r=t_p/5.5$

The peak discharge Q_{ps} in cumec of a unit hydrograph of standard duration t_r hour is given by Snyder as $Q_{ps}=2.78C_p\ A/t_p$

Where A=catchment area in sq.km. and C_p=a regional constant whose value ranges from 0.56 to 0.69 for Snyder's study area and is considered as an indicator of the retention and storage capacity of the watershed.Like C_t, the value of C_p also vary quite considerably depending on the characteristics of the region and the vary from 0.31 to 0.93.

Snyder adopted as the time base of the unit hydrograph (days), $T=3+3t_p/24$ = $(72+3t_p)$ hours. It gives reasonable estimates of time base for large catchments, but may give excessively large values for small catchments.

The constants adopted here are dependant on the procedure used to separate base flow from direct runoff.The above equations define the three factors necessary to construct the unit hydrograph for duration t_r, which Snyder took as $0.18t_p$. For any other duration t_R he used an adjusted lag

$t_{pR}=t_p+(t_R-t_r)/4=(21/22)t_p+t_R/4$

The best way to apply such methods is to derive coefficients from gaged streams in the vicinity of the problem basin and use these for the ungaged stream, i.e. transposition of unit hydrographs.

To assist in the sketching of unit hydrographs, the widths of unit hydrographs in hours at 50% and 75% of peak have been found for US catchments by US Army

Corps of Engineers. These are correlated to the peak discharge intensity and are given by $W_{50}=5.87/q^{1.08}$ and $W_{75}= W_{50}/1.75$

After obtaining the values of Q_p, t_R, t'_p, W_{75}, W_{50} and T from Snyder's equations, a tentative unit hydrograph is sketched. An S-curve is then developed and plotted.As ordinates of the unit hydrograph are tentative, the S-curve thus obtained will have kinks.These are then smoothened and a logical pattern of the S-curve is sketched.Using this S-curve the t_R hour unit hydrograph is then derived back. Further, the area under the unit hydrograph is checked to see that it represents 1 cm of runoff. The procedure of adjustment through the S-curve is repeated till satisfactory results are obtained. It may be noted that out of the various parameters of the synthetic unit hydrograph the least accurate will be the time base and this can be changed to meet other requirements.

TRANSPOSITION OF UNIT HYDROGRAPHS

One technique for transposition of unit hydrographs makes use of a dimensionless unit hydrograph which masks the effect of basin size and essentially eliminates the effect of shape, except as they are reflected in the estimate of basin lag and runoff volume.In this the ordinate is the discharge expressed as a ratio to peak discharge (Q/Qp) and the abscissa is the time expressed as a ratio of time to peak (t/t_{pk}).

INDIAN PRACTICE

The Central Water Commission after a study of a large number of catchments in India of varying sizes in the range of 25 to 500 sq.km has recommended the following relations for developing synthetic unit hydrographs.The peak discharge of a D-hour unit hydrograph Q_{pd} in cumec is

$Q_{pd}=4.44A^{3/4}$ for $S_m>0.0028$

And $Q_{pd}=222A^{3/4}S_m^{2/3}$ for $S_m<0.0028$

Where A=catchment area in sq. km. and S_m=weighted mean slope given by

$S_m=[L_{ca}/(L_1/\sqrt{S}_1+L_2/\sqrt{S}2+\ldots\ldots+L_n/\sqrt{Sn})]^2$ in whichL_{ca} =distance along the river from the gaging station to a point opposite the centre of gravity of the area.$L_1,L_2\ldots\ldots L_n$=lengthof main channel having slopes $S_1,S_2\ldots\ldots S_n$ respectively obtained from topographic maps.

The lag time in hours (i.e. time interval from mid-point of the rainfall excess to the peak of 1 –hour unit hydrograph is given by

$T_{p1}=3.95/[Q_{pd}/A]^{0.9}$

For design purposes the duration of rainfall excess in hours is taken as D=1.1 t_{p1}

The time to peak is determined by Snyder's equation, $t_p=C_t(LL_{ca})^{0.3}$

INSTANTANEOUS UNIT HYDROGRAPH (IUH)

Any unit hydrograph has a particular D-hour duration. The shape of different unit hydrographs depend upon the particular value of D. As D is reduced, the intensity of rainfall excess being equal to 1/D increases and the unit hydrograph becomes more skewed.

As the duration of the unit hydrograph approaches zero, the instantaneous unit hydrograph by definition, the flow sequence represents the outflow from the instantaneous application of the unit rainfall excess over the catchment. IUH is a fictitious , coceptual unit hydrograph which represents the surface runoff from the catchment due to an instantaneous precipitation of the rainfall excess volume of 1 cm.

Mathematically, the rate of direct runoff at time t is given by

$$q_t = \int_{t_0}^{t} I(\tau)u(t - \tau)d\tau$$

in which I(τ)is the IUH ordinate at time τ, u is the intensity of rainfall excess at time (t-τ), and τ is time in the past. In other words, the flow is determined by weighing the antecedent rainfall excess, where the weight applied to the rainfall occuring τ hr ago is IUH ordinate τ hr after the beginning of rainfall.

IUH can be derived from an S-curve or by routing the time –area diagram of the catchment.

FLOOD

A flood is an unusually high stage of water in a river – normally the level at which the river overflows its banks and inundates the adjoining areas. At a given location in a stream, flood peaks vary from year to year and their magnitude constitutes hydrologic series which enable one to assign a frequency to a given flood-peak value. The magnitude of flood peaks can be estimated by following alternative methods:

(i)Rational method, (ii) Empirical formulae, (iii) Unit Hydrograph method, (iv) Flood-Frequency studies.

RATIONAL METHOD

The Rational formula is applicable to small-sized (<50 sq.km.) catchments only and is generally used for the design of storm water drains and other structures like small culverts and bridges handling runoff from small areas.The peak value of runoff is given by the equation:

Q_p= (1/3.6) C ($i_{tc,p}$) A for $t>t_c$

where Q_p=peak discharge in cumec, C=coefficient of runoff (Runoff/Rainfall), $i_{tc.p}$ =mean intensity of precipitation (mm/hour) for a duration equal to t_c and an exceedence probability P, A=area of the catchment in sq.km. t_c =time of concentration i.e. time taken for a drop of water from the farthest part of the catchment to reach the outlet. If the rainfall continues beyond t_c, the runoff will be constant and at the peak value.

It may be noted that the word rational is rather a misnomer as the method involves determination of parameters t_c and C in a subjective manner.The three parameters: t_c,,$i_{tc.p}$, and C are described below:

Time of Concentration, t_c

For small drainage basins, the practice in USA is to consider the time of concentration approximately equal to the lag time of peak flow, $t_c= t_p=C_{tL}[LL_{ca}/\sqrt{S}]^n$ where n=0.38, C_{tL}=1.715 for mountainous areas, 1.03 for foot-hill drainage areas and 0.50 for valley drainage areas.

For small plots having no defined flow channels, and from which runoff occurs as laminar overland flow,Izzard has suggested overland flow time or inlet time

,$t_o=[111.b.(L_o)^{1/3}]/(K.p)^{2/3}$ where L_o=Length of overland flow in meters,p=Rainfall intensity in cm/hour, K=Runoff coefficient, b= a coefficient, whose value is given by $b=(0.000275p+C_r)/(S_o)^{1/3}$ where S_o=slope of the surface,C_r=Retardance coefficient (0.007 for smooth asphalt surface,0.012 for concrete pavement, 0.017 for tar and gravel pavement,0.046 for closely clipped soil, and 0.060 for dense blue grass turf).

However, for the design of hydraulic structures, Kirpich devised an equation in 1940 as

$t_c=0.01947\ L^{0.77}\ S^{-0.385}$ where t_c=time of concentration in minutes, L=maximum length of travel of water in meters,S= slope of the catchment=$\Delta H/L$ in which ΔH= difference in elevation between the most remote point on the catchment and the outlet.

For a small drainage basin having flow channels in it, t_c would be equal to the longest combination of overland flow time called Inlet time and channel flow time which exists anywhere in the basin.Channel flow time is generally taken as the length of the longest channel divided by the average flow velocity in the channel at about bankfull stage.

Critical Rainfall Intensity, $I_{tc.p}$

The critical rainfall intensity in cm/hour is generally taken as the average rate during the time of concentration t_c and the desired probability of exceedence P (i.e. return period T=1/P) and is determined from the rainfall- frequency–duration relationship for the given catchment atrea. This will usually be a relationship in the form of equation $i=KT^x/\ (t_c+a)^m$ in which K,a,x and m are constants.Published rainfall maps exibiting this form of relationship are consulted to evaluate i. In USA, P is generally taken as 0.05 to 0.10.For Indian conditions K=40 to 120, x=0.1 to 0.7 , a= 0.1 to 1.5 and n=0.75 to 1.00.Return period (years) for storage and diversion dams having permanent spillways is taken as 50 to 100 , for earth dams having natural spillways as 25 to 50 years, stock water dams as 25, small permanent masonry and vegetated spillways as 10 to 15,terrace outlets and vegetated waterways as 10 and field diversions as 15.

Runoff Coefficient, C

The coefficient, C represents the integrated effect of the catchment losses and hence depends upon the nature of the surface, surface slope and rainfall intensity. Some typical values of C are given below:

Sr. No.	Type of Area	Value of C
A.	Urban area (P=0.05 to 0.10)	
	Lawns: Sandy soil, flat,2%	0.05- 0.10
	Sandy soil,steep,7%	0.15-0.20
	Heavy soil, average, 2.7%	0.18-0.22
	Residential areas:	
	Single family areas	0.30-0.50
	Multy units, attached	0.60-0.75
	Industrial areas:	
	Light	0.50-0.80
	Heavy	0.60-0.90
	Streets	0.70-0.95
B.	Agricultural Areas	
	Flat: Tight clay;cultivated	0.50
	Woodland	0.40
	Sandy loam;cultivated	0.20

	Woodland	0.10
	Hilly: Tight clay;cultivated	0.70
	Woodland	0.60
	Sandy loam;cultivated	0.40
	Woodland	0.30

In determining peak flow rates, most applications of the Rational formula utilize the following steps:

(i) Estimate the time of concentration of the drainage area.

(ii) Estimate the runoff coefficient.

(iii) Select a return period,T_r and find the intensity of rain that will be equaled or exceeded, on an average, over every T_r years.

(iv)Determine the peak flood flow from the equation $Q_p=\frac{1}{3.6}CiA$.

Some design situations produce larger peak flows if design storm intensities for durations less than t_c are used.Substituting intensities for durations less than tc is justified only if the contributing area term in the equation is also reduced to accommodate the shortened storm duration.

The above mentioned Rational formula assumes a homogeneous catchment surface. If however, the catchment area is non-homogeneous but can be divided into distinct sub areas each having a different runoff coefficient, then the runoff from each sub area is calculated separately and merged in proper time sequence. Sometimes, a non-homogeneous catchment is so cmplex that distinct subareas can not be separated. In such cases a weighted equivalent runoff coefficient $C_e=\Sigma_1^N C_i A_i /\Sigma A_i$ is used where A_i is the areal extent of the sub area i having a runoff coefficient C_i and N is number of sub areas in the catchment.

EMPIRICAL FORMULAE

These are basically regional formulae based on statistical correlation of the observed peak and important catchment properties like area.These are applicable only in the region from which they were developed and when applied to other areas they can at best give approximate values.

DICKENS FORMULA (1865)

$Q_p=C_D A^{3/4}$ where Q_p = maximum flood discharge in cumec, A= catchment area in sq.km., C_D=Dickens constant (6 for north Indian plains, 11-14 for north Indian hilly regions,14-28 for central India, and 22-28 for Coastal Andhra and Orissa).

RYVES FORMULA (1884)

$Q_p=C_R A^{2/3}$ where Q_p= maximum flood discharge in cumec, A=catchment area in sq.km. and C_R=Ryves constant (6.8 for areas within 80 km from east coast,8.5 for areas which are 80-160 km from east coast,and 10.2 for limited areas near hills).

This formula was originally developed for the Tamil Nadu region and is in use in Tamil Nadu, parts of Karnataka and Andhra Pradesh.

INGLIS FORMULA (1930)

$Q_p=124A/ [\sqrt{(A+10.4)}]$ where Q_p is flood peak in cumec and A is catchment area in sq.km.This formula is based on flood data of catchments in western Ghats in Maharastra.

FULLER'S FORMULA (1914) derived for catchments in USA

$Q_{Tp}=C_f A^{0.8}(1+0.8 \log T)$ where Q_{Tp} is maximum 24-hr flood with a frequency of T years in cumec, A is catchment area in sq. km. and C_f is a constant varying from 0.18 to 1.88.

ENVELOPE CURVES

Kanwarsain and Karpove (1967) have developed enveloping curves on log-log graph paper representing the relationship between the peak- flood discharge and the catchment area for north as well as southIndian conditions for large catchment areas in the range of 10^3 to 10^6 sq. km. Based on the maximum recorded floods throughout the world, Baird and McIllwraith (1951) have recommended following equation:

$Q_{mp}=3025A/(278+A)^{0.78}$ where Discharge is in cumecs and area in sq. km.

UNIT HYDROGRAPH METHOD

The Unit hydrograph technique can be used to predict the peak flood hydrograph if the rainfall producing the flood, infiltration characteristics of the catchment and appropriate unit hydrograph are available.For design purposes, extreme rainfall situations are used to obtain the design storm.The known or derived unit hydrograph of the catchment is then operated upon by the design storm to generate the desired flood hydrograph.

FLOOD-FREQUENCY STUDIES

The values of the annual maximum flood from a given catchment area for large number of successive years constitute a hydrological data series called the annual series.The data are then arranged in decreasing order of magnitude and the probability P of each event being equalled to or exceeded is calculated by the plotting-position formula

P=m/N+1 where m=order number of the event and N=total number of events in the data.The recurrence interval, T (also called the return period or frequency) is calculated as T=1/P.

Chow (1951) has shown that most frequency distribution functions applicable in hydrologic studies can be expressed by the following equation known as general equation of hydrologic frequency analysis: $x_T=\bar{x}+K\sigma$ where x_T=value of the variate x of a randum hydrological series with a return period T, $\bar{x}$ =mean of the variate, σ=standard deviation, K= frequency factor which depends upon the return period, T and the assumed frequency distribution.

STATISTICAL ANALYSIS

Statistical distributions are usually demonstrated by use of samples numbering in thousands.No such samples are available for streamflow and it is not possible to state with certainty that a specific distribution applies to flood peaks.Numerous distributions have been suggested on the basis of their ability to fit the plotted data from the streams.Despite much efforts, tests that there is no best distribution for floods. Intuitively atleast, there is no reason to expect that a single distribution will apply to all streams worldwide. Commonly used frequency distribution functions for the prediction of extreme flood values are: (i) Gumbel's extreme-value distribution, (ii) Log-Pearson type III distribution, (iii) Log normal distribution.

GUMBEL'S METHOD

Gumbel was the first to suggest the use of the extreme-value distribution for floods. His argument was that each year of record constituted a smple of a sample of 365 values and the annual flood was the maximum value from the sample.He defined the flood as the largest of the 365 daily flows and the annual series of flood flows constituting a series of the largest values of flows.According to his theory of extreme events, the probability of occurrence of an event equal to or larger than a value x_o is

$P(X\geq x_o) = 1-e^{-[e]^{-y}}$ in which y is a dimensionless variable given by $y=\alpha(x-a)$, $a=\bar{x}-0.45005\sigma_x$ and $\alpha=1.2825/\sigma_x$

Thus $y=[1.285(x-\bar{x})/\sigma_x]+0.577$ where $\bar{x}$=mean and σ_x=standard deviation of the variate X.In practice it is the value of X for a given P that is required and the probability equation is transposed as

$Y=-\ln[-\ln(1-P)]$

Noting that the return period T=1/P and designating y_T=the value of y, commonly called the reduced variate, for a given T

$y_T=-[\ln.\ln T/T-1]=-[0.834+2.303\log\log T/(T-1)]$.The value of the variate X with a return period T is

$x_T=\bar{x}+K\sigma_x$ where $K=(y_T-0.577)/1.2825$

For practical use $y_T=-[0.834+2.303\log\log T/(T-1)]$ and $K=y_T-y_n/S_n$ where yn=reduced mean for $N\rightarrow\infty$ $y_{n\rightarrow}0.577$ and S_n=reduced standard deviation for $N\rightarrow\infty$ $S_{n\rightarrow}1.2825$.

These equations are used under the following procedure to estimate the flood magnitude corresponding to a given return period based on an annual flood series.

1. Assemble the discharge data and note the sample size N. Here the annual flood value is the variance X. Find $\bar{x}$ and σ_{n-1} for the given data.

2. Determine y_n and S_n.

3. Find y_T for a given T

4. Find $K= y_T-y_n/S_n$

5. Determine the required x_T by equation $x_T=\bar{x}+K\sigma_{n-1}$

To verify whether the given data follow the assumed Gumbel's distribution, the following procedure may be adopted:

The value of x_T for some return periods T<N are calculated by using Gumbel's formula and plotted as a semi-log, log-log, or Gumbel probability paper. The use of Gumbel probability paper results in a straight line for x_T vs T plot. Gumbel's distribution has the property which gives T=2.33 years for the average of the annual series when N is very large.Thus the value of a flood with T=2.33 years is called the mean annual flood.In graphical plot this gives a mandatory point through which the line showing variation of x_T with T must pass. For the given data, values of return periods for various recorded values, x of the variate are obtained by the relation T= (N+1)/m and plotted on the graph described above.

LOG-PEARSON TYPE III DISTRIBUTION

This distribution is extensively used in USA. In this the variate is first transformed into logarithmic base 10 and the transformed data is then analysed.If X is the variate of a random hydrologic series, then the series of Z variates where z=log x are first obtained.For this Zseries, for any recurrence interval T the general equation of hydrologic frequency analysis : $x_T=\bar{x}+K\sigma$ gives $z_T=\bar{z}+K_z\sigma_z$ where K_z =a frequency factor which is a function of recurrence interval T and the coefficient of skew C_s, and

σ_z =standard deviation of the Z variate sample=$\sqrt{\sum(z-\bar{z})^2/(N-1)}$ and

Cs=coefficient of skew of variate Z=$[N\sum(z-\bar{z})^3]/(N-1)(N-2)(\sigma_z)^3$

The variations of K_z=f(Cs,T) can be obtained from table.After finding z_T, the corresponding x_T is obtained by equation z=log x as x_T=antilog(z_T).

When the skew is zero i.e. Cs=0, the log-pearson TypeIII distribution reduces to log normal distribution which plots as a straight line on logarithmic probability paper.

REGIONAL FLOOD FREQUENCY ANALYSIS

When the available data at a catchment is too short to conduct frequency analysis, a regional analysis is adopted. In this a hydrologically homogenous region from the statistical point of view is considered. Available long time data from neighbouring catchments are tested for homogeneity and a group of stations satisfying the test are identified. This group of stations constitutes a region and all the station data of this region are pooled and analysed as a group to find the frequency characteristics of the region.The mean annual flood Q_{ma}, which corresponds to a recurrence interval of

2.33 years is used for non-dimensionalising the results. The variation of Q_{ma} with drainage area and the variation of Q_T/Q_{ma} with T where Q_T is the discharge for any T, are the basic plots prepared in this analysis.An independent relation defining the mean annual flood in terms of basin characteristics is the required.Often this is a simple relation brtween mean annual flood and drainage area, although other parameters such as basin slope, mean elevation, percentage of area of area in lakes, A probability curve for an ungauged basin is then constructed by first determining the mean annual flood and then converting the ratio scale of the regional –frequency curve to flow by multiplying the ratios by the estimated meam annual flood. The weakness of this approach lies in the assumption that all the streams will show the same variance of Q_T/Q_{ma} (slope of the cummulative frequency function).Statistical tests may indicate that several streams could have the same function,but they can never prove the functions are identical.Differences between frequency curves of small streams may be real differences arising from different regimes.They may, on the other hand be apparent differences arising from the variability of short samples.

If the regional approach is used, considerable care should be taken to select streams as nearly similar in hydrologic characteriticsas possible.They should have similar vegetal cover, land use, topographic conditions,and geologic characteristics, and the range of the drainage area should not be excessive.They should also have similar rainfall and evapotranspiration characteritics.

DESIGN STORM

To estimate the design flood for a project by the use of a unit hydrograph, one needs the design storm. This can be the storm-producing PMP for deriving PMF or a standard project storm (SPS) for calculation of standard project flood (SPF).The following procedure is adopted in India:

(i) The duration of the critical rainfall is first selected. This will be the basin lag if the flood peak is of interest.If the flood volume is of interest, the duration of the longest storm experienced in the basin is selected.

(ii) Past major storms in the region which conceivably could have ocurredin the basin under study are selected. DAD analysis is performed and the enveloping curve representing the maximum depth-duration relation for the study basin is obtained.

(iii) Rainfall depth for convenient time intervals are scaled from the enveloping curve.These increments are to be arranged to get a critical sequence which produces the maximum flood peak when applied to the relevant unit hydrograph of the basin.The critical sequence of rainfall increments can be obtained by trial and error.Alternatively, increments of precipitation are first arranged in a table of unit hydrogrph ordinates, such that (a) the maximum rainfall increment is against the maximum unit hydrograph ordinate,(b) the second highest rainfall increment is against the second highest unit hydrograph ordinate and so on, and (c) the sequence of rainfall increments arranged above is now reversed, with the last item first and first item last.The new sequence gives the design storm.

(iv) The design storm is then combined with hydrologic abstractions most conducive to high runoff, viz. low initial loss and lowest infiltration rate to get the hyetograph of rainfall excess to operate uponthe unit hydrograph.

DESIGN FLOOD

The PMF is used in situations where the failure of structure would result in loss of life and catastrophic damage and as such complete security from potential floods is sought.On the other hand, SPF is often used where the failure of structure would cause less severe damage.Typically the SPF is about 40% to60% of the PMF for the same drainage area.The CWC has recommended as follows:

Sr. No.	Structure	Recommended Design Flood
1.	Spillways for major and medium projects with storages more than 60MCM	(a) PMF determined by unit hydrograph and PMP (b) If (a) is not applicable or possible ,adopt Flood-Frequency method with T=1000years
2.	Permanent Barrages and minor dams with capacity less than 60MCM	(a) SPF determined by unit hydrograph and SPS which is usually the largest recorded storm in the region (b) Flood with a return period of 100 years Adopt (a) or (b) whichever gives higher value.
3.	Pick-up Weirs	Flood with a return period of 100 or 50 years depending on the importance of the project.
4.	Aqueducts	Flood with T=50 years for waterways and Flood with T=100years for foundations and freeboard
5.	Project with very scanty or inadequate data	Empirical Formulae

IS: 11223-1985: Guidelines for fixing spillway capacity have made following recommendations:

Class	Gross Storage(MCM)	Hydraulic Head (m)	Inflow Design Flood
Small	0.5 to 10.0	7.5 to 12.0	100-year flood
Intermediate	10.0 to 60.0	12.0 to 30.0	SPF
Large	>60.0	>30.0	PMF

UNIT-3

(Functions of water, various crops, crop seasons, crop rotation, Delta, Duty and Base Period of crops. Factors affecting irrigation water requirement of crops.)

FUNCTIONS OF IRRIGATION WATER IN PLANT GROWTH:

(i) Provide essential moisture in the soil required for proper tillage of land, (ii) Provide essential moisture required for proper germination of seed, (iii) Cool down the soil temperature for proper germination of seeds, (iv) Act as solvent for nutrition present in soil for absorption by roots through osmosis, (v) Activates useful bacteria to convert available chemical compounds in soil into the forms usable by plants in association with air, (vi) Activate some soils present in soil to provide nourishing food product, (vii) It washes out or dilutes undesirable salts in soil, (viii) It saver plants from death because of frost action during extreme winter, (ix) It provides humidity control required for tobacco, and (x) All chemical and biological processes including photosynthesis require presence of water.

VARIOUS CROPS UNDER DIFFERENT CROP SEASONS

- **MONSOON (KHARIF) CROP SEASON** (June-July to October-November)
  - FOOD CROPS: Paddy (Rice), Maize, Great Millet (Juar), Spiked Millet (Bajra), Pulses (Arhar, Urd, Moong), Soyabean, Sorghum, Pearl Millet
  - NON-FOOD CROPS: Cotton, Groundnut, Sesame (Til), Ladies Finger, Cauliflour, Cabbage, Kheera, Green Chilli, Fodder
- **WINTER (RABI) CROP SEASON** (Nov.-Dec. to March-April)
  - FOOD CROPS: Wheat, Barley (Jau), Gram (Chana), Peas, Potatoes, Safflower
  - NON-FOOD CROPS: Mustard, Rapeseed, Linseed (Alsi), Tobacco, Fodder, Carrot, Onion, Tomatoe
- **HOT-WEATHER (ZAID) CROP SEASON** (April-May to June)
  - Vegetables
  - Fruits

ANNUAL CROPS

- Sugarcane (Feb-March to Dec-March next year)
- Arhar (Pulses) (July to May)

Different crops require different amount of soil moisture during different stages of their growth. Rainfall may be untimely and not in required quantity as and when required by the crop for its optimum growth.

Total Geographical Area of India = 328.73 Million hectares
" Culturable Command Area " = 184.35 " "
" Gross cropped Area " = 189.74 " "
Estimated Ultimate Irrigation Potential = 140.00 " "
Gross Irrigated Area = 78.34 " "
Extent of Irrigation in India: Surface Water = 49%
Ground Water = 51%
Canal irrigation = 37%
Tank irrigation = 15%

India's population may stabilised at 1350 million in 2025 and likely food production required is 223 – 264 Million Tonnes with irrigation Potential of 102 Million ha – 140 Million ha.

Average crop yield from irrigated agriculture = 2.5 Tonnes/hectare
" " " " un-irrigated " = 0.5 Tonnes/hectare

AVERAGE ANNUAL RAINFALL IN INDIA = 1140 mm
" " RUNOFF " " = 167 Million-hectare-meters
" " UTILISABLE SURFACE WATER RESOURCE = 80 " "
Existing Irrigation Potential = 120 Mha-m (60 Surface + 60 Ground Water)

Crop yield (quintel/hectare) with major crop as rice in India = 14
Pakistan = 16
China = 28
Japan = 38
South Korea = 42.5

PRODUCTIVITY OF NEW HIGH-YIELDING VARIETIES

Crops	Water required (cm)	Crop Yield (quintel/hectare)	Productivity (Kg/ha/mm water)	
RICE	120	45	3.75	$\left(\frac{45\times100}{120\times10}=3.75\right)$
Great Millet (Jowar)	56	45	9.0	
Spiked Millet (Bajra)	50	40	8.0	
MAIZE	62.5	50	8.0	
WHEAT	40	50	12.5	

CROP ROTATION: It is a practise of growing dissimilar type of crops in the same field in sequential crop seasons to avoid built up of pathogens and pests, balance fertilizer demand to avoid excessive depletion of soil nutrition. It helps maintain soil structure, supply organic matter and nitrogen to the soil, improve tilth, moisture holding capacity of the soil, quality of crop products and increase in yield.

Wheat, barley etc. are shallow rooted crops; while cotton, tobacco etc. are deep-rooted ones. Nutrition is derived from upper and lower layers of soil by crop rotation.

Crop rotation is done with the inclusion of a legumes, which adds nitrogen to the soil and protects crops from diseases. Replenishments of nitrogen through use of green manures is also accomplished in sequence with cereals and other crops. Prevalent cropping patterns in different regions of India are given below:

(a) Northern Region: Rice, Maize, Wheat, gram
(b) Southern Region: Rice, cotton, groundnut, sugarcane, ragi, bajra, tobacco, wheat, gram
(c) Western Region: Jowar, Bajra, Cotton, Gram, Sugarcane
(d) Eastern Region: Rice, Mustard, Cereals, Sugarcane, Ground nut.

CROPPING PATTERNS:

Groundnut – Sorghum
Sorghum – Gram
Soyabean – Maize
Maize – Mungbean

Rice – Gram
" – Mustard
" – Groundnut
" – Sorghum
" – Wheat

Pearl Millet – Gram
" – Mustard
" – Sorghum
Cotton – Wheat
" – Gram
" – Sorghum
" – Safflower
" – Groundnut

Maize – Wheat
" – Gram
Sugarcane – Wheat
Sorghum – Groundnut
Groundnut – Rice
Sorghum – Wheat
" – Gram

GROSS COMMANDED AREA: The total area that can be brought under irrigation command by gravity flow of a canal, without considering the water supply available is called the GCA.

CULTURABLE COMMANDED AREA: The GCA less the area not fit for cultivation (like fallow lands, rocky, marshy areas, alkaline and saline soils, local ponds, village, roads, railway, schools and other infrastructures) gives the CCA.

→CULTURABLE CULTIVATED AREA DURING A CROP SEASON

INTENSITY OF IRRIGATION: The % of CCA under different crops irrigated during different seasons is called the intensity of irrigation.

CROP PERIOD: The number of days between sowing and harvesting of a crop is called its growing season or crop period.

BASE PERIOD (B): The number of days between the first watering at the time of sowing and the last watering before harvesting is called the base period (B) day.

DELTA (Δ): It is the total depth of water applied at different waterings at certain intervals throughout the growing season of a crop to bring the crop to maturity as if the total quantity ~~suppli~~ supplied were to stand above the surface without percolation or evaporation. $\Delta = \sum d_a = \frac{\text{Seasonal consumptive use of the crop}}{\text{Irrigation Efficiency}}$

DUTY (D): The area that can be irrigated from 1 cumec of water flowing throughout the base period of the crop is called its flow duty. Since the consumptive use is different at different stages of growth of a crop, if average duty figures are taken for calculation, allowance has to be made for the period of peak water use (KOR period during flowering stages of crops (say 20% extra for the period of peak demand) in the design of canals and outlets.

Duty goes on increasing as water flow because of continuous conveyance losses. Duty at the outlet of a field channel is called 'Outlet Factor'.

RELATION BETWEEN DUTY & DELTA $\quad Q \cdot t = A \cdot \Delta$

$$1 \frac{m^3}{sec} \times B \times 24 \times 60 \times 60 \text{ seconds} = (D \text{ ha} \times 10^4) \text{ sq.m} \times \Delta \text{ m}$$

$$86400 B \ m^3 = 10^4 \times D \cdot \Delta \ m^3$$

Hence $D = \frac{8.64 B}{\Delta}$ where B is in days, Δ in meters, D in ha/cumec.

$$D = \frac{\text{Irrigated cropped Area}}{\text{Quantity of water required}}$$

FACTORS AFFECTING DUTY (i) Method and systems of irrigation (ii) Mode of applying water to crops (iii) Method of cultivation (iv) Time and frequency of tilling (v) Type of crop (vi) Base period of crop (vii) Climatic condition of area (viii) Quality of water (ix) Character of soil and sub-soil of canal and irrigated fields.

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COMPARISON OF DIFFERENT METHODS OF IRRIGATION

Sr. No.	Characteristics	CHECK FLOODING	BORDER-STRIP FLOODING	FURROW IRRIGATION	SPRINKLER IRRIGATION	DRIP IRRIGATION
1.	Water Requirement	Very high	Moderate	Low	Lesser	Least
2.	Evaporation losses	Very high	High	Less	High	Negligible
3.	Suitability for soil	Clay	Mix of silt & clay	Mix of silt	all types	all types including saline soils
4.	Soil surface wetting	100%	100%	20-25%	100%	Least wetting
5.	Rate of growth	Good	Good	Low	Better	Highest
6.	Suitability for crops	Rice	Wheat, Barley	Potato	Widespread application including tea and coffee gardens	Vegetables and orchards
7.	Adjustment of water application	Nil	Nil	Nil	Good through pressure control	Very easy by use of different nozzle sizes
8.	Uniformity of irrigation	~~Non~~ uniform	Non-uniform	25% uniformity	50% uniformity	90% uniformity
9.	Automation of application	Nil	Nil	Nil	Complete automation.	Economical and convenient control
10.	Fertiliser application	Nil	Nil	Nil	Yes	Yes
11	System and component parts	Nil	Nil	Size can be changed	Stationary or Portable	Stationary
12	Effect of wind velocity	Nil	Nil	Nil	Strong wind interferes, particularly when in opposite direction. Evaporation increases	Not much
13.	Percolation of water	High	High	High	Less	Minimum
14.	Land levelling requirements	Yes	Yes	Yes	No	No
15	Land utilisation	Water courses checks require land	Water courses border strip	7.5% land is lost in field channel	More land is available for cultivation	Maximum land becomes available for cultivation
16.	Crop yield	Lesser	Lesser	Lesser	Higher	Highest
17.	Cost	Low but labour cost high	Low but labour cost high	Low initial but high operation labour cost	High initial cost.	Moderate
18	Irrigation Application Efficiency	15-35%	55-75%	30-60%	60-87%	85-95%

FACTORS AFFECTING IRRIGATION WATER REQUIREMENT:

(i) Amount and rate of precipitation during a crop season, (ii) Temperature variations in any particular locality affecting consumptive use, (iii) Hours of day light increasing evapotranspiration, (iv) Stage of growth of crop, (v) Humidity of locality affecting evapotranspiration, (vi) Movement of wind, (vii) Growing season influencing use of water by plants, (viii) Water quality, (ix) Soil characteristics, including fertility, permeability and pH affecting consumptive use.

UNIT-4 : SURVEY

Importance of survey, various types of surveys, Reasonability and Feability of projects.

<u>IMPORTANCE OF SURVEY</u>: The importance of surveys and investigations lies in collection of data for selection of a suitable site for location of dam, reservoir, canal alignment, cross-drainage works etc. for realistic planning, design, construction and management of any water resources development project. The selection of a site suitable for location of a reservoirs depends on:

(i) The river valley at the site should be narrow so that the length of the dam is less but it should open out in the upstream side to provide a large basin for reservoir.

(ii) The surrounding hills, constituting rim of reservoir, should be water tight so that there is no leakage of water from any part of the rim or its wetted area.

(iii) The minimum land and property is submerged in the reservoir.

(iv) Adequate capacity of reservoir commensurate with demand is available.

(v) Deep reservoir be formed for low land cost per unit of capacity, lesser evaporation loss and lesser weed growth.

(vi) No objectionable minerals or salts are present in the reservoir area.

(vii) Easy accessibility of site and suitable land for project colony.

The scale of survey intensifies depending on the type of report of the project to be prepared, viz. Pre-feasibility, Feasibility, Detailed Project Report, Construction-stage report, Evaluation Report etc.

<u>VARIOUS TYPES OF SURVEYS</u>: (i) Reconnaissance Survey (ii) Topographic survey (Cartographic data), (iii) Meteorological and Hydrological surveys, (iv) Geophysical, Geotechnical, Seismic surveys (v) Archaeological and Mineral surveys, (vi) Right of way survey, (viii) Communication surveys, (ix) Soil, Land use, Agricultural survey, Command Area Surveys (x) Construction Materials survey, (xi) Environmental and Ecological Survey, (xii) Rehabilitation and Resettlement surveys.

Generally Project Formulation requires following chapters:

(i) Justification of the project
(ii) Basin development
(iii) Inter-state and International aspects
(iv) Surveys and investigations
(V) Hydrology
(vi) Reservoir Planning
(vii) Irrigation, Hydro-electric Power, Navigational Potential
(viii) Design of Civil structures
(ix) Design of Electrical and Mechanical works
(X) Construction Programme and Plant Planning
(xi) Project Organisation
(xii) Infrastructural facilities
(xiii) Environmental and Ecological Aspects
(xiv) Cost Estimates
(xv) Allocation of cost
(xvi) Economic Evaluation
(xvii) Future use of buildings
(xviii) Irrigation Planning & Management
(xix) Diversion of Forest Land
(XX) Rehabilitation and Resettlement

MINIMUM REQUIREMENT OF TOPOGRAPHICAL SURVEYS:

Sr.No.	DESCRIPTION	EXTENT OF SURVEYS	Scale/Contour Interval	REMARKS
1.	River Surveys (L-section)	(i) Upstream L-Section upto MWL+5m or to a point upto which the back water effect is likely to extend from axis of structure, which ever is less	1:10,000 H 1:100 V	Levelling at 50m interval along the fair-weather deep channel.
		(ii) Downstream 10km from axis of structure or upto nearest headworks, whichever is less.	-do-	-do-
		(iii) Along the axis of structure	1:2500 H 1:100 V	-do-
2.	Reservoir Area Survey	Contour Plan covering an area upto an elevation of Maximum W.L. + 5m	1:2500 H Contour Interval of 1meter	Levelling grid interval of 50meters.

3. DAM & DYKE Survey	Topographic Plan of site with contours, covering the area upto 4 times of the height of dam on upstream and d/s of axis OR to a minimum of 250m on upstream and 500m on d/s of axis, and extending upto MWL + 5m	1:2500 H Contour Interval of 1m	Levelling grid interval of 10m.
4. BARRAGE/WEIR Survey	Topographic Plan of site with contours covering an area upto 1Km on either side of the firm bank and 500m from upstream/downstream tip of guide bunds, parallel to flow.	-do-	Levelling grid interval of 50m or less depending on slope of land.
5. CANAL and WATER CONDUCTOR SYSTEM Survey	(i) Longitudinal Survey (ii) Cross-section at 50m interval (iii) Strip contour plan covering 250m on either side of centre line of canal or depending on requirement whichever is more	1:2500H 1:100V Contour Interval of 1meter	-do-
6. CANAL Structures (Cross-Drainage Works) Surveys	Grid Plan with contours of site to cover an area upto 300m on either side of the centre line of the canal – 100m d/s of the point of exit of water and 100m u/s of the point of inlet	1:2500 H Contour Interval of 1m	-do-
7. POWER HOUSE Survey	Contour Plan of site to cover full area of the components and alternate layouts. Areas to include 100m on all sides of the components.	1:2500 H Contour Interval of 1m	-do-

8. COMMAND AREA SURVEY	Contour Plan of the plain area	1:10,000 H	Contour Interval 0.25m
	Plateau areas	1:1,000H	" " 0.25m
	Hilly "	1:1,000H	" " 0.50m

Mark Maximum historical observed HFL

9. Project Area Survey	Area spread upto 5Km	1:5,000
	" " " 10Km	1:10,000
	" " >10Km	1:15,000

HYDROLOGICAL DATA SURVEY

Type of Information/Data	Desirable length of record (Years)
River Water Level	30
River Discharge	30
Sediment Flow and Grain size distribution	3
Water Quality	3
Pan Evaporation	3
Rainfall	30
SRRG data	30

TOPOGRAPHIC SURVEY AT VILLAGE LEVEL FOR IRRIGATION PURPOSE

Settlement village maps, called 'Shajra' or 'Chadar' maps in scale of 1:4000 (1"=1mile) prepared on a piece of fine long cloth showing boundary and number of each field, location of inhabitated areas, culturable and barren land, pastures, all infrastructural facilities - roads, schools, c.c., hospital etc.

Prepare a combined tracing of village Shajras in each small 'doab' between two drainage streams which would be commanded by a distributary on a common sheet covering entire command. Mark out contours after carrying out levelling in the area. Draw on the sheet a longitudinal line approximately in the centre of the doab and cross line at suitable intervals (200m in plains and closer interval in undulating land). Direction of line in the field can be laid out by identifying distinguishing features and ranging a straight line between the two. Proceed levelling along the line, distance to each staff positions measured or observed by stadia. Levels of crosslines, extending to the limit of the 'doab' on either side should be obtained and transcribed to the sheet in a similar manner.

REASONABILITY & FEASIBILITY OF PROJECTS

The successful joint use of storage space in a multi-purpose project depends on the extent to which the various purposes are compatible. These uses are:
(i) Drinking & Municipal Water Supply, (ii) Industrial Water Supply, (iii) Irrigation, (iv) Hydro-electric Power Generation, (v) Flood Management /Control, (vi) Navigation, (vii) Fish and wild life, (viii) Recreation (ix) Ecological purposes.

Since all projects are for the future, they must be planned not only to meet the present day requirements but also to meet the future needs. The projections for future ~~should~~ should not be simple extrapolation of past growth curves, because the social, economic and technological developments may cause significant change in the future growth rate as compared to the past growth rate. For rational planning all attempts should be made to estimate true economic demand rather than a fictitious demand.

Irrigation projects require large investments which can be economically justifiable only if it generates an economic surplus, including both direct and indirect benefits and costs.

ECONOMIC FEASIBILITY EVALUATION assesses the economic viability of a proposed project for the society as a whole, at the economic values. It helps in selecting a particular one from amongst the possible alternatives.

FINANCIAL FEASIBILITY EVALUATION assesses the financial conditions that will be encountered in developing and operating a project at the market price. It evaluates possible financial alternatives with respect to interest rates, repayment schedules and the maturity period of the loan.

CAPITAL RECOVERY FACTOR Consider an investment P made today which is earning interest @ i% per annum compounded yearly. At end of N years the amount P grows to amount $F = P(1+i)^N$ or $P = \frac{F}{(1+i)^N}$
The term $\frac{1}{(1+i)^N}$ is known as Discount Factor.

Let A be the amount to be recovered from beneficiaries of the project at the end of every year and it is invested to earn an interest @ i% per annum compounded yearly. It grows to an amount F at the end of N years

$$F = A + A(1+i) + A(1+i)^2 + \cdots + A(1+i)^{N-2} + A(1+i)^{N-1}$$

By multiplying above equation by $(1+i)$ we get

$$(1+i)F = A(1+i) + A(1+i)^2 + A(1+i)^3 + \cdots + A(1+i)^{N-1} + A(1+i)^N$$

By subtracting former equation from the later we get

$$iF = A[(1+i)^N - 1]$$

$$A = \left[\frac{i}{(1+i)^N - 1}\right] \times F$$

The term $\dfrac{i}{[(1+i)^N - 1]}$ is known as Sinking Fund Factor.

Introducing $F = P(1+i)^N$ in above equation

$$A = \left[\frac{i(1+i)^N}{(1+i)^N - 1}\right] P$$ = Annual instalment for recovery of the investment made for project

The term $\left[\dfrac{i(1+i)^N}{(1+i)^N - 1}\right]$ is known as Capital Recovery Factor.

IRRIGATION PROJECT COSTS include all the expenditure made to establish, maintain and operate a project. Costs are estimated on annual basis including both fixed and variable costs.

Total Annual Cost = Annual Recovery Cost + Annual O&M Cost

= [Capital Investment × Capital Recovery Factor] + Annual O&M Cost

ANNUAL BENEFITS It is the difference between agricultural production in the area after completion of the project minus the agricultural production in the area to be irrigated under pre-project condition. The production in the area to be irrigated under pre-project and post-project conditions and the yield per hectare under pre-project and post-project conditions and the prices to be used for the crops may be obtained from the State Agricultural Department.

BENEFIT-COST RATIO:

$$= \frac{\sum_{t=1}^{n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{C_t}{(1+i)^t}}$$

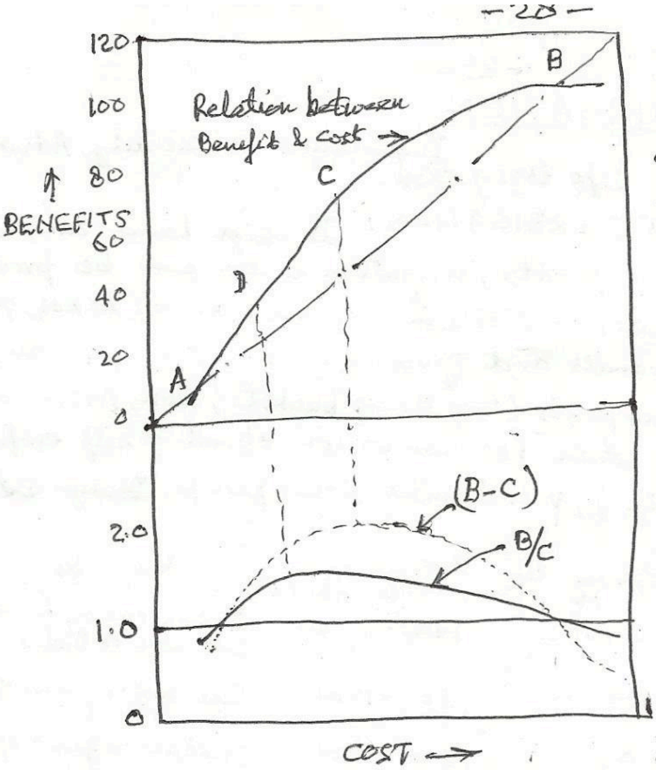
Where B_t = Benefit (Rupees) accrued in each year of project period used in analysis.

C_t = Cost (Rupees) incurred in each year of project period used in analysis

t = time period of project life reckoned in years

n = number of years of anticipated project life

i = Discount rate selected on the basis of cost of the capital.



Benefits exceed cost i.e. $\frac{B}{C} > 1.0$ from point A to B. The curve of $(B-C)$ i.e. net benefits shows a maximum at C. Thus beyond point C, each rupee of costs returns less than a rupee of benefits i.e. $\frac{\Delta B}{\Delta C} < 1$. The maximum $\frac{B}{C}$ ratio occurs at D and this should be the limit of project size if it is desired to obtain a maximum rate of return on investment. However, the investment from D to C will also be economical since the rate of return on the increment exceeds the minimum attractive rate of return.

INTERNAL RATE OF RETURN (IRR) It is the maximum interest that a project can pay for the resources used if the project is to recover its investment and operating costs. It is the discount rate i chosen, such that $\sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t} = 0$

It is generally used by the World Bank and other financing agencies because it is broad indicator of economic feasibility of a project, in so far as its contribution to the national economic development pertaining to the ~~national~~ investment.

TUTORIAL - III

Solution-4 $P = A\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right]$ Here $i = 0.08$, $N = 20$ years
$A = Rs\ 1 \times 10^6$

$= 1 \times 10^6 \left[\frac{(1+0.08)^{20} - 1}{0.08(1+0.08)^{20}}\right] = Rs.\ 9.82 \times 10^6$

Total Cost of lining $= Rs\ 10 \times 10^6 > P$ $\therefore$ Lining is economically not feasible.
Let N' be the estimated life of lining in years which would render it feasible.

$P = 1 \times 10^6 \left[\frac{(1+0.08)^{N'} - 1}{0.08(1+0.08)^{N'}}\right] \geq 10 \times 10^6$ for feasibility

Assuming $N' = 21$ years, $P = Rs\ 10.02 \times 10^6 > Rs\ 10 \times 10^6$

Hence if estimated life of lining is 21 years then it would become economically feasible.

Solution-5 Annual Cost $= 140000 + P\left[\frac{i(1+i)^N}{(1+i)^N - 1}\right]$ $P = Rs\ 24\,400\,000$

$i = 0.03$, $N = 50$ years

$= 140000 + 24\,400\,000\left[\frac{0.03(1.03)^{50}}{(1.03)^{50} - 1}\right]$

$= Rs\ 1090\,000$

Average Lives of Hydraulic Structures in years

DAMS	Reservoirs	Tanks	Tunnels	Wells	Turbines	Pumps	Canals
75-150	75	20-40	35	40-50	35	75	75

UNIT-8 LIFT IRRIGATION

Importance, Suitability, Advantages and Limitations of lift irrigation.

IMPORTANCE OF LIFT IRRIGATION: In high land areas, where water can not flow by gravity, irrigation water can be provided by lifting of surface water available in reservoirs, rivers, lakes, ponds, head reaches of main canals and groundwater through open (dug) well, tubewells by using manpower (Two swing baskets, don, Archemedian screw) animal power (water wheel, Persian wheel, spout of self-emptying type rope and bucket lift), wind mills, solar pumps, ~~Design~~ Diesel/ electric power pumps.

Device	Power used	optimum lift (m)	Average @ (litr/hour)	Remarks.
Swing basket	Two men	0.9-1.2	1400-19,000	Occasionally in eastern and south India.
Don	Single man	0.5-1.0	9,000-13,000	Eastern regions of India
Archemedian Screw	"	0.5-1.2	14,000-19,000	Deltaic regions of A.P.
Water wheel	one pair of bullocks and one man	1-1.2	40,000-60,000	North India
Self-emptying type rope and bucket lift (150-200 Litres cap.)	-do-	4-6	10,000-15000	Southern India, Deccan, Rajasthan area
Counterpoise bucket lift ढेंकली	Single man	~~1.2~~-4	6000-14000	~~Rajasthan~~, Bihar, South India, Deccan region
Solar Photo-voltic Pumping system		4.5		

Tubewells can be drilled along the drainage lines in canal irrigated tract, which intercepts the canal seepage and serves as an anti-water logging measure.

SUITABILITY ① lift irrigation can be installed directly on the farm (centrally) at any time with a small investment. Length of water course is less and can be lined with an economically lining material available locally. While canal irrigation schemes take a long time from interception to completion, with large financial outlays, and water is wastes by seepage and evaporation in long runs, canal water may not be available throughout the year. The farthest limits of command of lift irrigation is within 1.5 km.

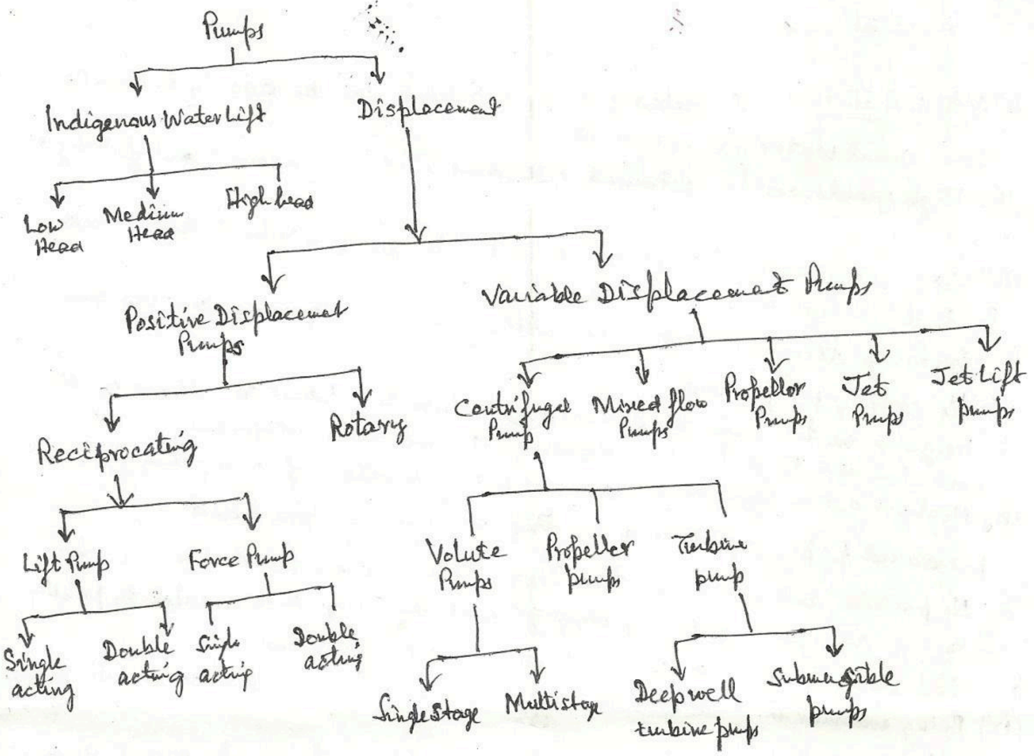
② More suitable for well distributed demand for irrigation throughout the year — the overhead charges of establishment and maintenance of tubewell being fixed and independent of running hours, the larger number of working hours in the year, the more economical will it be.

(iii) Suitable when electricity, diesel pumps are easily and cheaply available.

ADVANTAGES. (i) Isolated patches of land can be easily irrigated where canal water can not reach.
(ii) High yields can be obtained with good water management and fertilizer application.
(iii) Cash (commercial) crops can be reliably grown, which pay back for high initial investment made.
(iv) Intensive irrigation with conjunctive use, resulting in double and triple cropping is possible
(v) Irrigation water can be charged on volumetric basis resulting in the economical use of water and watering as and when required.
(vi) High irrigation efficiency and improved methods of irrigation like perforated pipe, sprinkler and drip ~~me~~ can be practiced.
(vii) No pollution and no evaporation losses. Sub-soil water table can be controlled and prevents water logging, soil salinity and alkalinity problems.
(viii) Not dependent on government owned canal waters.
(ix) Being warmer in cold weather and colder in hot weather, more suitable to crops.
(x) Does not fail in droughts unless drought continues for many years.

LIMITATIONS (i) Dependent on supply of electricity of adequate voltage and diesel power
(ii) Costlier than canal water (iii) Life of tube well is limited
(iv) Frequent break down of power and motor parts causes large scale interruptions.
(v) From a purely economic standpoint, the cost of raising water with man or animal power is substantially higher than those which are driven by electric motors and engines. Relative cost of engine-operated pumps is about 15-25% more than that of electric motor-driven pumps. The cost of lifting water by animal power is about 10-20 times more than with electric motors. Manually-operated water lifts are the costliest, being 3 to 4 times more than animal-drawn devices.
(vi) More manure (vii) Harmful salts (viii) Small Discharges

HIERACHY OF PUMPS



LIFT IRRIGATION