WATER RESOURCES ENGINEERING

B.TECH

IN

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Introduction to Engineering Hydrology and Its Applications

Hydrology: It is the science which deals with the occurrence, distribution and movement of water on the earth's surface including that in the atmosphere and below the earth surface.

- Water occurs in the atmosphere is in the form of vapour.
- On the ground surface as water or ice.
- Below the earth surface as ground water occupying all the voids with in the geological stratum.

Hydrological Cycle and their Components

Hydrological Cycle:

Except for very deep ground waters, the total water supply of earth is in contact circulation from earth's surface to the atmospheric and back to the earth's surface. The earth's water circulatory system is known as hydrological cycle. (Or) hydrological cycle is the process of transfer of moisture from the atmosphere to the earth's surface in the form of precipitation and evaporation of water back to the atmosphere.

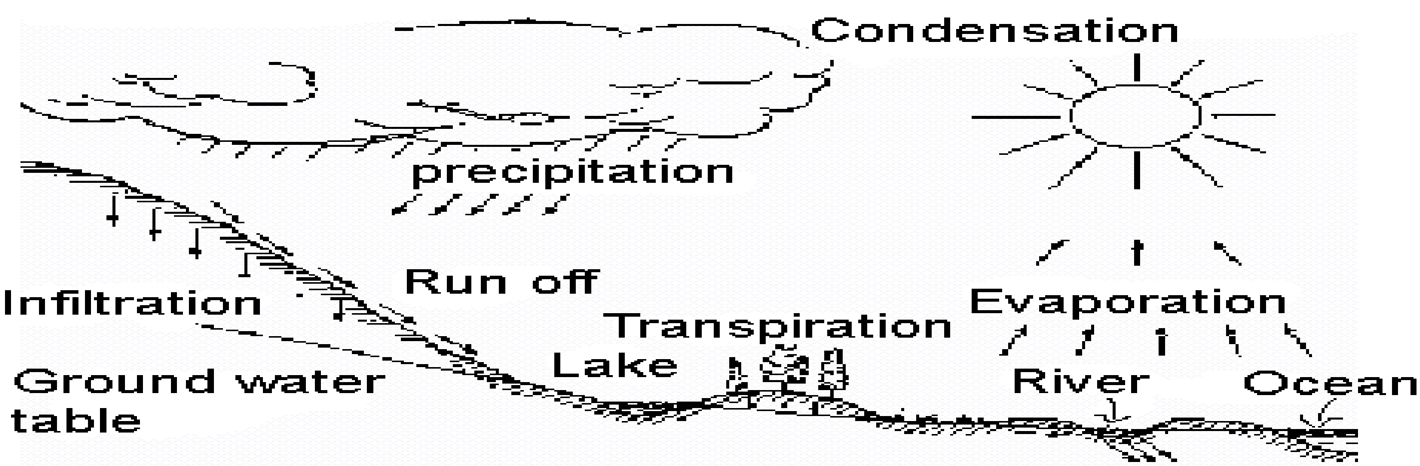


Diagram Showing Hydrological Cycle

Hydrological cycle consists of the following Processes.

1. Evaporation and Transpiration (E)

The water from the surface of the ocean, rivers and also from the moist soil evaporates. The vapours are carried over the land by air in the form of clouds. Transpiration is the process of water being lost from the leaves of the plants from their pores.

Total evaporation (E) including transpiration consists of the following:

a. Surface evaporation: Evaporation from moist soil

b. Water surface evaporation: Evaporation from river surface, from oceans

c. Evaporation from plants and leaves (Transpiration)

d. Atmospheric evaporation.

2. Precipitation (P)

Precipitation may be defined as fall of moisture from the atmosphere to the earth's surface in any form. Precipitation may be two forms

- Liquid Precipitation - rain
- Frozen form consist of - Snow, Hail, sleet, freezing rain.,

3. Run off (R)

Runoff is that portion of precipitation that is not evaporated.

When moisture falls to the ground in the form of precipitation, a part of precipitation will be evaporated by means of soil surface, water surface and plants. The remaining part of precipitation is available as a runoff which ultimately reaches ocean through surface and sub surface streams.

The run off may be classified as following:

➢ Surface Run-off

Water flow over the land surface and First it reaches the streams and rivers ultimately this quantity of water is discharged in oceans.

➢ Inter flow (or) Sub-surface Run-off

It is the part of precipitation that infiltrates below the earth's surface. Infiltrates capacity depends on the geology of the basin, runs as a sub surface flow ultimately reaches to oceans through rivers and streams.

➢ Ground Flow (or) Base flow Run-off

It is also a portion of precipitation, which after infiltration, percolates down and joins the ground water reservoir. This ultimately reaches the oceans.

Precipitation = Evaporation + Run off

Measurement of Rain fall

Rain fall is the main source of water used for various purposes. Knowledge of rain fall quantity, intensity of rain fall & distribution of rain fall is extremely useful for irrigation engineering.

- ❖ The amount of rain fall is measured in centimeters (inches).which is falls on a level surface and is measured by rain gauges.
- ❖ The intensity of rain fall is the rain fall per unit time. It is expressed as cm/hr.

The following are the main types of rain Gauges used for measurement of rain fall.

- ❖ Non-automatic rain gauges

Non automatic rain gauges are non-recording type.

Eg: Symons rain gauge.

- ❖ Automatic rain gauges.

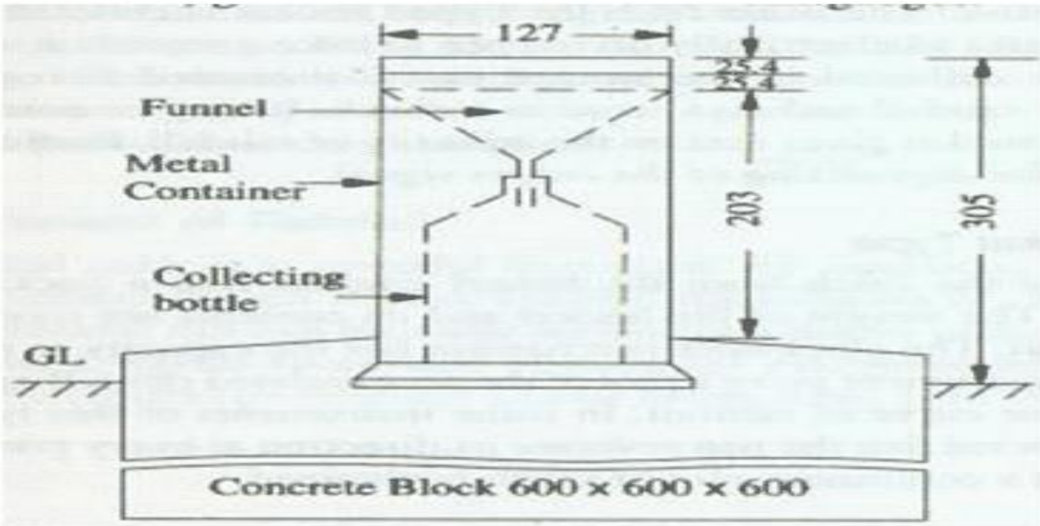
Automatic rain gauges are recording type. They are of three types,

- ➢ Weighing bucket type rain gauge.
- ➢ Tipping bucket type rain gauge.
- ➢ Float type rain gauge.

Symons rain gauge:

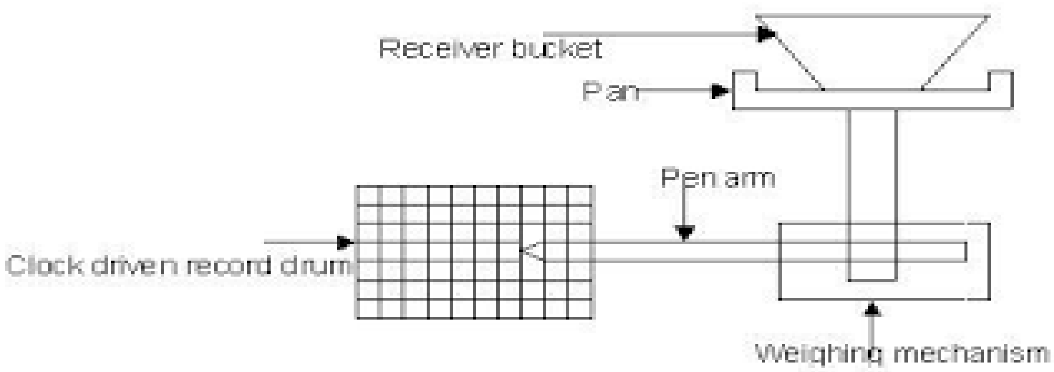
Symons rain gauge is commonly non recording type rain gauge in India and is used in meteorological department of government of India. It consists of cylindrical vessel 127 mm (or 5") in diameter with a base enlarged to 210 mm (or 8") diameter. The top section is a funnel provided with circular brass rim exactly 127 m (5") internal diameter. The funnel shank is inserted. in the neck of a receiving bottle which is 75 to 100 mm (3 to 4") diameter. A receiving bottle of rain-gauge has a capacity of about 75 to 100 mm of rainfall and as during a heavy rainfall this quantity is frequently exceeded, the rain should be measured 3 or 4 times in a day on day of heavy rainfall lest

the receiver fill should overflow. A cylindrical graduated measuring glass is furnished with each instrument, which reads to 0.2 mm. The rainfall should be estimated to the nearest 0.1 mm.



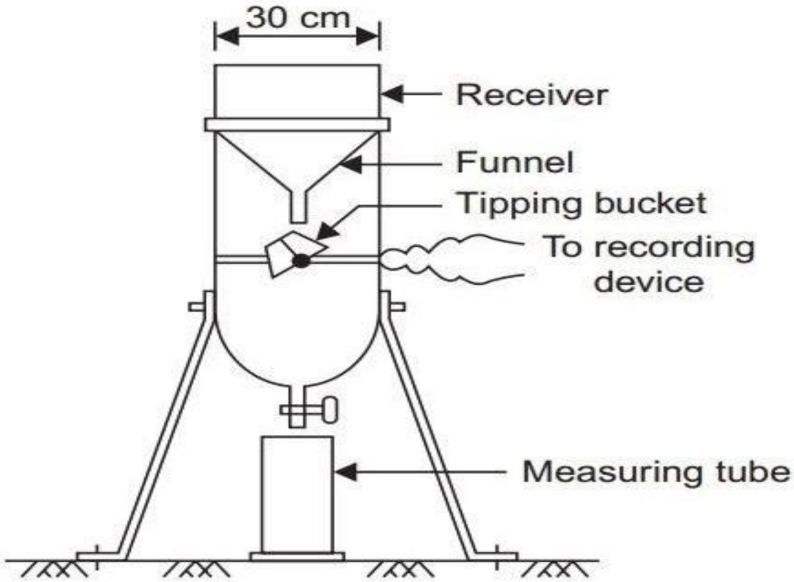
Weighing bucket type rain gauge:

It is self recording type rain gauge this is used to determine the rate of rainfall (or) intensity of rain fall over a short period of time. The weighing bucket rain-gauge essentially consists of a receiver bucket supported by a spring or lever balance or any other weighing mechanism. The movement of the bucket due to its increasing weight is transmitted to a pen which traces the record on a clock- driven chart.



Tipping bucket type rain gauge:

The tipping bucket type rain-gauge consists of 30 cm diameter sharp edge receiver. At the end of the receiver is provided a funnel. A pair of buckets are pivoted under the funnel in such a way that when one bucket receives 0.25 mm (0.01 inch) of precipitation it tips, discharging its contents into a reservoir bringing the other bucket under the funnel. Tipping of the bucket completes an electric circuit causing the movement of pen to mark on clock driven revolving drum which carries a record sheet.



Tipping bucket gauge

Float Type Automatic Rain-gauge:

The working of a float type rain-gauge is similar to the weighing bucket type gauge. A funnel receives the rain water which is collected in a rectangular container. A float is provided at the bottom of the container. The float is raised as the water level rises in the container, its movement being recorded by a pen moving on a recording drum actuated by a clock work. When the water level in the container rises so that the float touches the top, the siphon comes into operation, and releases the water; thus all the water in the box is drained out.

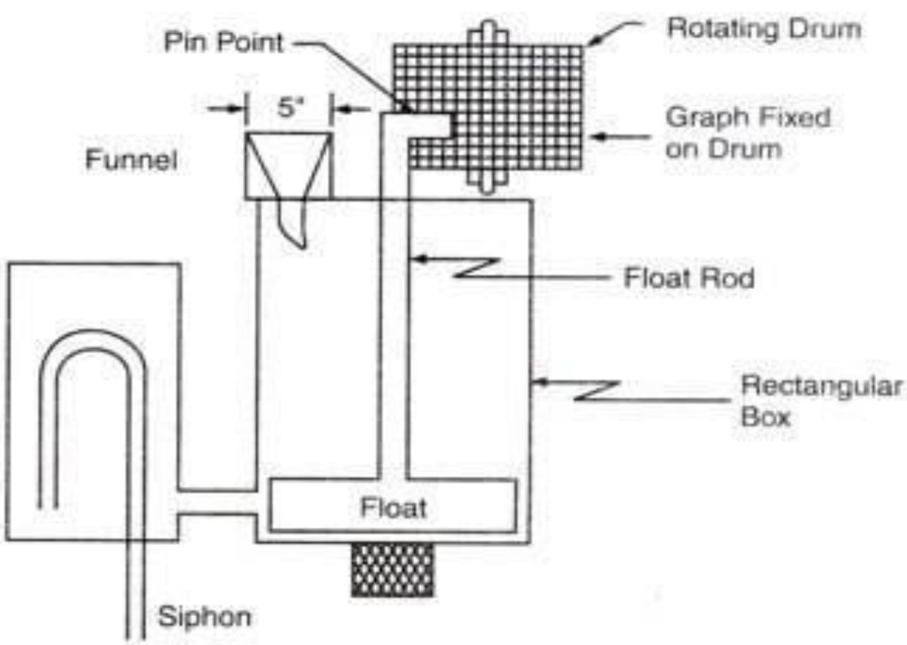


Fig. 2.5. Recording type rain-gauge

Site Selection For Rain Gauge:

- The rain gauge should be installed on a plain surface.
- The distance between rain gauge and nearest objective should be at least twice the height of the objective
- The rain gauges should not be provided side and top of the hill.

Advantages of Recording type rain fall over non Recording type rain ruage:

- Rain fall is recorded automatically and hence no attender is necessary.
- By using automatic rain gauge records the intensity of rain fall, where as in the case of non automatic rain fall rain gauges, only rain fall depth is measured.
- Rain fall is recorded automatically, that's why it can be placed even inaccessible points also.
- Human errors are avoided.

Disadvantages

- It is costly.
- Fault may be developed in electric &mechanical mechanism for recording the readings.

Optimum number of rain Gauges:

The optimum number of rain gauges depending up on the coefficient of variation (CV) of the mean annual rain fall values at the existing stations and available gauge error (e).

Optimum numbers of rain gauge stations are equal to (Cv/e) 2.

Cv = coefficient of variation

e = error expressed in (%)

$Cv = \sigma / \bar{p}$

Where, σ = standard deviation= $\sqrt{\Sigma (p-\bar{p})/n-1}$.

$\bar{p}$ =average annual rainfall over the catchment area= $\Sigma p/n$.

n = number of existing rain gauge stations

Σp = sum of annual rain fall of total rain gauge stations

The additional rain gauges required = m - n

m = Optimum numbers of rain gauge stations & n = existing numbers of rain gauge stations

1) Determine the optimum number of rain gauges in a catchment area from the following data:

a) Number of existing rain gauges = 8

b) Mean annual rain fall at the gauges=1000, 950, 900, 850, 800, 700, 600, & 400 mm.

c) Permissible error =6%.

Sol:

Optimum numbers of rain gauge stations = $(Cv/e)^2$.

$Cv = (\sigma / \bar{p}) x100$

$\bar{p} = \Sigma p/n. =(1000+950+900+850+800+700+600+400)/ 8 = 6200 / 8 = 775mm$

Standard deviation $\sigma =\sqrt{[\Sigma(p- \bar{p}) /(n-1)]}$

$\Sigma (p-\bar{p})2 =(1000-775)^2 +(950-775)^2 +(900-775)^2 +(850-775)^2 +(800-775)^2 + (700-775)^2 +(600-775)^2 +(400-775)^2$

Standard deviation σ = 200

Cv = (200/ 775) x100 = 25.8%

Optimum numbers of rain gauge stations = (Cv/e) 2. = 25.8/6 =18.4 say 19

Additional rain gauges = m – n = 19 -8 = 11numbers.

Estimation of missing rainfall data

Missing rainfall data of the rain gauge stations can be calculated from the mean annual rainfall of the existing rain gauge stations called index stations. From the determination of missing rainfall data we know the mean annual rainfall of all the rain gauge stations, including the station with missing rainfall data.

- The normal annual rainfall of a station is the average value of the annual rainfall over a i specific period 30years.
- The normal annual rainfall is updated every 10 years.

The missing rainfall data can be calculated by using the following methods:-

1. Comparison method

2. Normal ratio method

3. Isohyetal method

Comparison method:

The missing data can be estimated by comparing the mean annual rainfalls of missing rainfall station X with that of an adjacent rain gauge station A.

$P_X / P_A = N_X / N_A$

Where PX and PA precipitation of stations X and A &N_X and N_A mean annual rainfall of stations X and A

Normal ratio method:

X is the missing rainfall of rain gauge station

A.B, C is the adjoining rain gauge stations

(a) When the mean annual rainfall at each of the Index station A, B, and C is with in 10% of the mean annual rainfall of the station X is Simple Average value of three.

$P_X = 1/3(P_A + P_B + P_C)$

(b) When the mean annual rainfall at each of the Index station differs from the station X by more then 10%, the normal ratio method is used.

$P_X = N_X/3\ (P_A/N_A + P_B/N_B + P_C/N_C\ )$

Symbol N is used for mean annual rainfall, when there are m Index stations

$P_X = N_X/m\ (P_A/N_A + P_B/N_B + P_C/N_C + \text{----}\ P_M/N_M\ )$

Isohyetal method:

Isohyets are the Counters of equal rain fall depth. An Isohyets map is prepared fom the record of various rain gauge stations by interpolation.

(1)The rain gauge station X was inoperative for apart of a month during which a storm occurred .The storm rain fall recorded at the three surrounding stations A,B and C was 75mm,59mm and 85mm respectively. if the average annual rainfall of the station A,B,C and X are 750,650,850 and 700mm respectively estimate the storm rain fall of station X.

Sol: Given data, PA = 75mm NA = 750mm

PB = 59mm NB = 650mm

PC = 85mm NC = 850mm

NX = 700mm

Because the difference in average annual rainfall is more then 10%

PX = NX/3 (PA/NA + PB/NB + PC/NC) = 700/3(75/750 + 59/650 + 85/850) = 67.8mm

Computation of average rainfall over a basin

If a basin or catchment area contains more than one rain-gauge station, the computation of average precipitation or rainfall may be done by the following methods

1. Arithmatic average method.

2. Thiessen polygon method.

3. Isohyetal method.

Arithmatic Average Method

If the rainfall is uniformly distributed on its areal pattern, the simplest method of estimating average rainfall. is to compute the arithmatic average of the recorded rainfall values at various stations. Thus, if P1, P2, P3,......... Pn etc., are the precipitation or rainfall values measured at n gauge stations, we have

$P_{av} = (P_1 + P_2 + P_3 ...... Pn) / n = \Sigma P/n$

Arithmatic Average Method

Station No.	Precipitation(mm)	Average Precipitation
1	12.6	Pav = 72.8/5 = 14.6
2	18.8	
3	14.8	
4	10.4	
5	16.2	
	ΣP = 72.8mm	

Thiessen Polygon Method

The arithmatic average method is most approximate method since rainfall varies in intensity and duration from place to place. Hence rainfall recorded by each rain-gauge station should be weighed according to the area.. Thiessen polygon method is a more common method of weighing the rain-gauge observations according to the area. Thiessen polygon method is also called weighted mean method and is more accurate than the arithmatic average method.

Procedure

1. Join the adjacent rain-gauge stations, A, B, C, D, etc., by straight lines.
2. Construct the perpendicular bisectors of each of these lines

3. A Thiessen network is thus constructed. The polygon formed by the perpendicular bisectors around a station encloses an area which is everywhere closer to that station than to any other station. Find the area of each of these polygons. as shown in figure below.

4. Multiply the area of each Thiessen polygon by the rain gauge value of the enclosed station.

5. Find the total area ΣA of the basin.

6. Compute the average precipitation or rainfall from the equation:

Pav = (A1 P1+ A2P2+ A3P3...... AnPn) / (A1 + A1 + A1 ..... An)

Thiessen Polygon Method

Thiessen Polygon Method

Rain-gauge station	Area of Thiessen Polygon (A)	Precipitation (P)	A*P
A	45 sq. km	30.8 mm	1386
B	38 sq. km	34.6 mm	1315
C	30 sq. km	32.6 mm	978
D	40 sq. km	24.6 mm	974
Sum	153 sq. km		4663

Pav = ΣAxP/ ΣA = 4663/153 = 30.5

EVAPORATION:

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

Evaporation from water surfaces (Lake evaporation):

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

$E = K (e_w – e_a)$

where E = daily evaporation, ew = saturated vapour pressure at the temperature of water

ea = vapour pressure of the air (about 2 m above), K = a constant.

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

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

where K′, a, b = constants and V = wind velocity.

EVAPORATION PANS:

(i) Floating pans.

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

(ii) Land pan.

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

(iii) Colarado sunken pan.

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

Pan coefficient—

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

TRANSPIRATION:

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

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

The experimental values (from the protected growth of the plant in the laboratory) have to be multiplied by a coefficient to obtain the possible field results.

Transpiration ratio is the ratio of the weight of water absorbed (through the root sys- tem), conveyed through and transpired from a plant during the growing season to the weight of the dry matter produced exclusive of roots.

For the weight of dry matter produced, sometimes, the useful crop such as grains of wheat, gram, etc. are weighed. The values of transpiration ratio for different crops vary from 300 to 800 and for rice it variesfrom 600 to 800 the average being 700.

Evaporation losses are high in arid regions where water is impounded while transpira- tion is the major water loss in humid regions.

EVAPOTRANSPIRATION

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

Estimation of Evapotranspiration

The following are some of the methods of estimating evapotranspiration:

(i) Tanks and lysimeter experiments

(ii) Field experimental plots

(iii) Installation of sunken (colarado)tanks

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

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

Factors Affecting Evapotranspiration

Fromthe above equationsit can be seen thatthe following factors affect the evapotranspiration:

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

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

(iii) The moisture level in the soil.

INFILTRATION:

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

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

$k = (f0 - fc) / Fc$

where f0 = initial rate of infiltration capacity

fc = final constant rate of infiltration at saturation

k = a constant depending primarily upon soil and vegetation

e = base of the Napierian logarithm

Fc = shaded area in Fig. 3.6

t = time from beginning of the storm

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

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

Methods of Determining Infiltration

The methods of determining infiltration are:

(i) Infiltrometers

(ii) Observation in pits and ponds

(iii) Placing a catch basin below a laboratory sample

(iv) Artificial rain simulators

(v) Hydrograph analysis

(i) Double-ring infiltrometer.

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

Tube infiltrometer.

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

INFILTRATION INDICES

The infiltration curve expresses the rate of infiltration (cm/hr) as a function of time. The area between the rainfall graph and the infiltration curve represents the rainfall excess, while the area under the infiltration curve gives the loss of rainfall due to infiltration. The rate of loss is greatest in the early part of the storm, but it may be rather uniform particularly with wet soil conditions from antecedent rainfall.

Estimates of runoff volume from large areas are sometimes made by the use of infiltra- tion indices, which assume a constant average infiltration rate during a storm, although in actual practice the infiltration will be varying with time. This is also due to different states of wetness of the soil after the commencement of the rainfall. There are three types of infiltration indices:

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

(i) φ-index—

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

(ii) W-index—

The W-index is the average infiltration rate during the time rainfall in- tensity exceedsthe infiltration capacity rate, i.e., where P = total rainfall, Q = surface runoff, S = effective surface retention, tR= duration of storm during which $i > fp$

Fp= total infiltration

The W-index attempts to allow for depression storage, short rainless periods during a storm and eliminates all rain periods during which $i < fp$. Thus, the W-index is essentially equal to the φ-index minusthe average rate ofretention by interception and depression storage, i.e., $W < \varphi$. Information on infiltration can be used to estimate the runoff coefficient C in computing the surface runoff as a percentage of rainfall i.e., Q = CP

$C = (i-W) / i$

(iii) fave-index—

In this method, an average infiltration loss is assumed throughout the storm, for the period $i > f$.