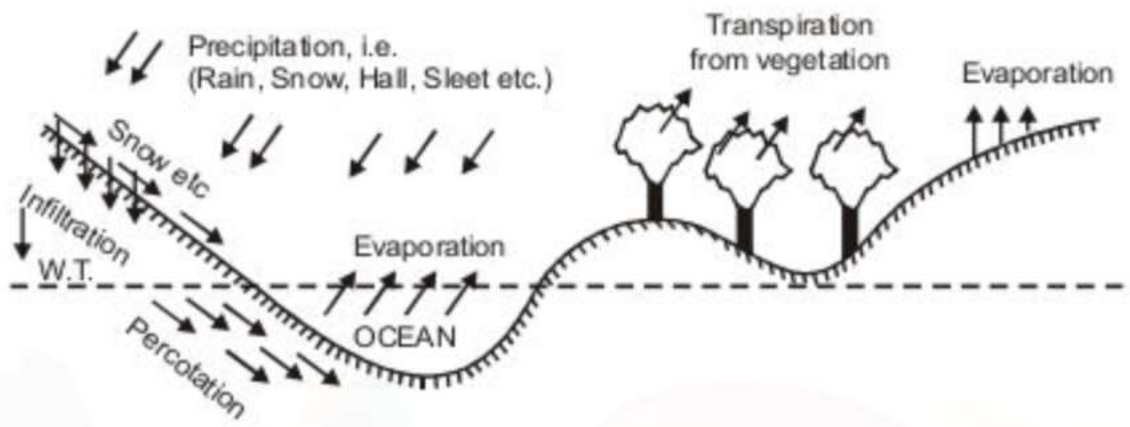
HYDROLOGY

HYDROLOGICAL CYCLE

Most of the earth's water sources, such as, rivers, lakes, oceans, and underground sources, etc. get their supplies from the rains, while rain water in itself is the evaporation from these sources. Water is lost to the atmosphere as vapour from the earth, which is then precipitated back in the form of rain, snow, hail, dew, sleet or frost, etc. This evaporation and precipitation continues and a balance is maintained between the two. This process is called *hydrological cycle*.

Divisions of Hydrological Cycles



Hydrological cycle consist of two main divisions :

1. **Surface Division** : *It consists of following :*
   (*i*) Transportation of water in some form
   (*ii*) Temporary storage
   (*iii*) Change from vapour to water
2. **Atmospheric Division :** *It consists of following :*
   (*i*) Surface run-off, infiltration or underground water flow
   (*ii*) Surface ground water, soil moisture storage, and
   (*iii*) Change from water to vapour or evaporation due to heat

PRECIPITATION

The water which comes back to the surface of the earth in its various forms like rain, snow, hail etc. is called *precipitation*. A major part of the precipitation occurs in the form of rain and a minor part of the precipitation occurs in the form of snow. Other forms of precipitation such as hail, sleet, mist, etc, are all very small and generally ignored.

Types of Precipitation

1. **Cyclonic Precipitation.** *It is of following two types :*
   (*i*) **Frontal type :** Front is a boundary joining warm moist air mass resultting in the precipitation of moist air mass.
   (*ii*) **Non frontal type :** In this cold air mass moves whereas moist air mass is stationary.
2. **Convective Precipitation.** It is caused due to upward movement of the air that is warmer than its surroundings. Generally it occurs in tropics, where on a hot day ground surface gets unequally heated causing the warmer air to lift up and the colder air comes to replace it. At higher altitudes it gets cooled and precipitates.
3. **Orographic Precipitation.** When moving warm air is obstructed by some barriers such as mountain, the moist air mass finds its way upwards where it gets cooled and precipitates.
   e.g : precipitation in western ghats in India.

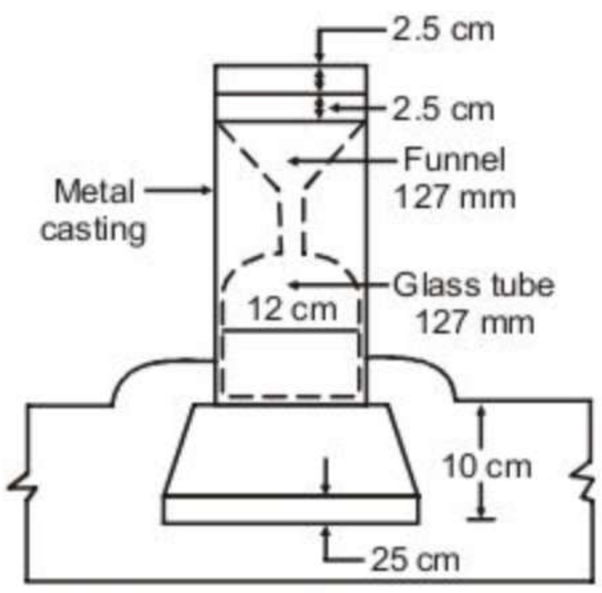
Measurement of Rainfall

Rainfall is measured by Raingauges.

Raingauges

These are following two types :

1. **Non-recording type :** These rainguage only collect the rain and do not measure it. These are mostly used raingauge in India.
2. **Recording type or Automatic :** It gives a permanent rainfall record which is automatically recorded and does not need any measurement bottle to measure amount of rainfall. Amount of rainfall and its intensity gets mechanically recorded. The gauge normally consists of a rotating drum with a graph paper wrapped around. A curve showing cummulative rainfall is recorded against time. Slope of the curve gives intensity of rainfall during any given period. *e.g.*



SIMON's Non-recording Raingauge

(*i*) Tipping buchet type (*ii*) Weighing type (*iii*) Floating type

Estimating Missing Rainfall Data

Sometimes, rainfall amount, at a certain raingauge station, for a certain day or days, may be missing due to some absence of observed or instrumental failure. In such cases, it might be needed to estimate missing rainfall amount by approximating the value from the data of the nearby raingauge stations.

If N_1, N_2, N_3 .... N_m represent average annual rainfalls at stations 1, 2, 3, ..., m respectively and P_1, P_2, P_3, ... P_m represents their respective precipitation data of the day for which the data is missing at station x, then

$$P_x = \frac{P_1 + P_2 + \ldots + P_m}{m}$$

Provided N_1, N_2, ... N_m differs within 10% of N_x

When variation is more than 10%, then

$$P_x = \frac{1}{m}\left[P_1 \cdot \frac{N_x}{N_1} + P_2 \frac{N_x}{N_2} + \ldots + P_m \frac{N_x}{N_m}\right]$$

Optimum number of Raingauges

Determination of optimum number of raingauges required be installed in a given catchment. The basis behind such statistical calculations is that a certain number of raingauges stations are necessary to give average rainfall with a certain percentage of error.

$$\text{Optimum number of raingauges, } N = \left(\frac{C_v}{E}\right)^2$$

where, C_v = coefficient of variation of rainfall based one existing raingauges stations

E = allowable percentage error in the estimation of basic mean rainfall < 10 (adopt E = 10)

C_v can be computed as follows

(*i*) $\bar{P} = \frac{\sum P}{n}$,

where n is number of raingauge existing and ΣP is total rainfall.

(*ii*) $\bar{P}^2 = \frac{\sum P^2}{n}$

(*iii*) $\sigma = \sqrt{\frac{n}{n-1}\left[\bar{P}^2 - (\bar{P})^2\right]}$

(*iv*) $C_v = \frac{100\sigma}{\bar{P}}$

Methods to Convert Point Rainfall Values Into Average Rainfall Value

1. **Arithmetic Mean Method :** $\bar{P} = \frac{P_1 + P_2 + P_3 \ldots + P_n}{n} = \sum_{i=1}^{i=n} P_i$

   This method is satisfactory when stations are uniformly distributed over the area and rainfall rate does not differ much at various stations.

2. **Thiessen's Mean Method :** In this method, adjacent stations are joined by straight lines, thus dividing the entire area into a series of triangles. Perpendicular bisectors are erected on each of these lines, thus forming a series of polygons, each containing one and only one rainfall station. It is assumed that entire area within any polygon is nearer to the rainfall station that is included in the polygon than to any other rainfall station. The rainfall recorded al that station is, therefore assigned to that polygon.

   $$\text{Mean rainfall on basin, } P = \frac{A_1P_1 + A_2P_2 + A_3P_3 + \ldots + A_nP_n}{A}$$

   where P_1, P_2, P_3 ...... P_n represent rainfall at the respective stations whose surrounding polygons have the areas A_1, A_2, A_3, ... A_n, respectively and A is area of the basin

3. **Isohyetal Method :** Isohyets are the contours of equal rainfall. They are drawn on the map by using common sense, after the rainfall at each station is plotted. The area between adjacent isohyets either estimated on the graph paper or measured by a planimeter.

   Let A_1, A_2, A_3, ... A_n be the areas and average precipitation for these area be P_1, P_2, P_3, ... P_n; then

   $$\text{Mean precipitation on the basin, } P = \frac{P_1A_1 + P_2A_2 + P_3A_3 + \ldots + P_nA_n}{A_1 + A_2 + A_3 + \ldots + A_n}$$

EVAPORATION

It is the process in which a liquid changes to the gaseous state at the free surface, below the boiling point through the transfer of heat energy. Evaporation is a cooling process in that the latent heat of vaporisation must be provided by water body.

Factors Affecting Rate of Evaporation

(*i*) Vapour pressures at the water surface and air above
(*ii*) Air and water temperature
(*iii*) Wind speed
(*iv*) Atmospheric pressure
(*v*) Quality of water
(*vi*) Size of the water body
(*vii*) Humidity
(*viii*) Depth of water in water body

* Briefly the effect of these factors on amount of evaporation may be added as under.

Factor	Effect an evaporation (E)
(*i*) Vapour pressure	E increases with increases in vapour pressure.
(*ii*) Air and water temperature	E increases with increase in Air & water temp.
(*iii*) Wind speed	E increases with increase in wind speed upto a limit.
(*iv*) Atmospheric pressure	E increases with decrease in atmospheric pressure.
(*v*) Quality of water	E decreases with increase in dissolved solids, salinity & humidity of water.
(*vi*) Size of water body	E increases with increase in size of water body.
(*vii*) Humidity	E decreases with increase in surrounding humidity.
(*viii*) Depth of water body	More depth reduces summer evaporation and increases winter evaporation.

Dalton's Law of Evaporation

The rate of evaporation is proportional to difference between saturation vapour pressure at the water temperature, p_w and the actual in the air p_a. Thus

$$E_L = C\,(p_w - p_a)$$

where, p_w and p_a are in mm of mercury and C is a constant

- Evaporation continues till $p_w = p_a$
- If $p_w > p_a$; condensation takes place
- A decrease in the barometric pressure, as in high altitude, increases evaporation.
- Rate of evaporation increases with an increase in the water temperature.
- The rate of evaporation increases with the wind speed up to a critical speed beyond which any further increase in the wind speed has no influence on the evaporation rate.
- When a solute is dissolved in water, the vapour pressure of the solution is less than that of pure water and hence causes reduction in the rate of evaporation.
- The effect of **heat storage** is essentially to change the seasonal evaporation rates and the annual evaporation rate. In comparision to a shallow depth water body, evaporation from deep water body is lesser in summer & more in winter

Estimation of amount of water evaporated from water surface

1. Using Evaporimeter Data

***(i)* Class A Evaporation pan or US Class A evaporation pan or class A land pan**

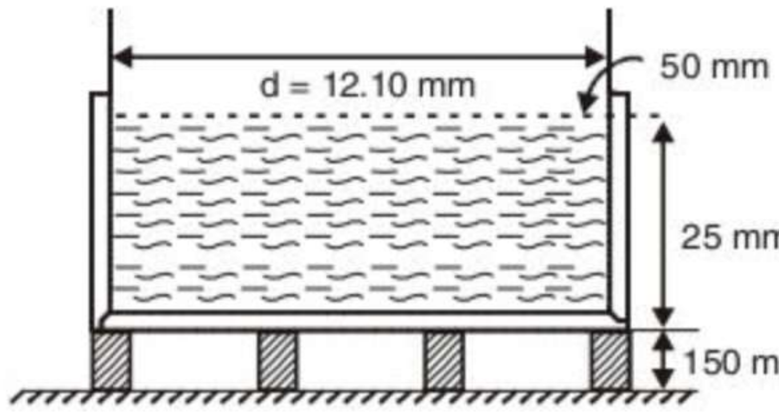
$$\text{Pan coefficient } C_p = \frac{\text{Lake evaporation}}{\text{Pan evaporation}}$$

Type of Pan	Average value of C_p
Class A pan	0.70
ISI pan	0.80
Colorado sunken pan	0.78
USGS floating pan	0.80

***(ii)* ISI standard pan** or **Modified class A Pan**

Diameter = 1220 mm; Depth = 255 mm

Pan is placed over a square wooden platform of 1225 mm width and 100 mm height to enable circulation of air underneath the pan.



***(iii)* Colorado sunken Pan**

This pan 920 mm square and 460 mm deep and buried into the ground within 100 mm of the pop.

***(iv)* US Geological Survey floating Pan**

WMO recommendation of minimum network of evaporate meter stations :

***(a)* Arid zones :** one station for every 30,000 km^2

***(b)* Humid Temperate :** one station for every 50,000 km^2 and

***(c)* Cold regions :** one station for every 1,00,000 km^2.

2. Empirical Evaporation Equations

General formula : $E_L = kf(u)(e_w - e_a)$

where E_L = lake evaporation in mm/day

e_w = saturation vapour pressure at the water-surface temperature in mm of Hg.

e_a = actual vapour pressure of overlying air at a specified height in mm of Hg.

$f(u)$ = wind-speed correction function

k = a co-efficient

Two commonly used empirical formulae

Mayer's formula $$E_L = K_M (e_w - e_a)\left(1 + \frac{U_9}{16}\right)$$

where, U_9 = monthly mean wind velocity in km/h at about 9 m above ground

K_M = co-efficient

= 0.36 for large deep water

= 0.50 for shallow water.

Rohwer's formula $$E_L = 0.771(1.465 - 0.000732 P_a)(0.44 + 0.0733 u_0)(e_w - e_a)$$

where, P_a = mean barometric reading in mm of Hg.

u_0 = mean wind velocity in km/h at ground level.

wind speed at any height h above the ground, $U_h = Ch^{1/7}$

3. Analytical Method

(i) Water-budget method

(ii) Energy-balance method

(iii) Mass-transfer method.

Reservoir Evaporation

Volume of water lost due to evaporation from a reservoir in a month is calculated as

$$V_E = A\,E_{pm}\,C_p \text{ (in m}^3\text{)}$$

where, A = average reservoir area during the month

E_{pm} = Pan evaporation loss in metre in a month

C_p = relevant pan co efficient.

Under Indian conditions, evaporation loss from a water body is about 160 cm in a year with enhanced values in arid region,

Methods of Reducing Evaporation Losses

The can be considered under three categories

(i) Reduction of surface area

(ii) Mechanical covers

(iii) Chemical films : Certain chemicals such as **cetyl alcohol (hexadecanol)** and **stearyl alcohol** (octadecanol)

Evapotranspiration (or Consumptive use of Water)
Transpiration is essentially confined to daylight hours and the rate of transpiration depends upon the growth periods of the plant. Evaporation on the other hand, continues all through the day and night although the rates are different.

If sufficient moisture is always available to complete meet the needs of vegetation fully covering the area, the resulting evapotranspiration is called **Potential Evapotranspiration** (PET).

The real evaporation occurring in a specific situation is called **Actual Evapotranspiration (AET).**

Field Capacity
It is the maximum quantity of water that the soil can retain against the force of gravity. Any higher moisture input to a soil at field capacity simply drains away.

Permanent Wilting Point
It is the moisture content of a soil at which moisture is no longer available to sustain the plants.

Available Water.
It is the difference between moisture available for plant growth and moisture at permanent wilting point.

When the soil moisture reaches the permanent willing point, the evapotranspiration reduces to zero.

Measurement of Evapotranspiration
It is measured either by using **lysimeters** or by the use of **field plots.**

Field Plot
Evapotranspiration = precipitation + irrigation input – runoff – increase in soil storage – ground water loss

Evapotranspiration Equations to Measure PET

1. Penman's equation : $$\text{PET} = \frac{AH_n + E_a\gamma}{A+\gamma}$$

based on sound theoritical reasoning and is obtained by combunations of energy balance and mass transfer approch.

2. Empirical formula : Mean annual PET (in cm) over various parts of the country is shown in the form of **Isopleths** (lines on a map through places having equal depths of evapotranspiration.). It is seen that annual PET ranges from 140 to 180 cm over most parts of the country. Annual PET is highest at Rajkot, Gujarat with a value of 214· 5 cm.

- **Interception process** and the **depression storage** are together called **initial loss.**
- It is estimated that, of the total rainfall in an area during a plant-growing season, the interception loss is about **10 to 20%**.
- It is found that coniferous trees have more interception loss than deciduous trees.
- Dense grasses have nearly same interception losses as full qrown trees.

INFILTRATION

When water falls on a given formation, a small part of it is first of all, absorbed by the top thin layer of soil, so as to replenish the soil moisture deficiency. Thereafter, any excess water moves downward where it is trapped in the voids and becomes ground water.

This process, whereby, water enters the surface strata of the soil and moves downward, towards the water table, is called *infiltration*.

Infiltration Rate

Actual prevailing rate at which water enters the given soil at any given time is called *infiltration rate*

Infiltration Capacity

Maximum rate of which a soil in any given condition is capable of absorbing water is called its *infiltration Capacity.*

$$\text{Infiltration capacity, } f = f_c + (f_o - f_c).e^{-kt}$$

where, f_c = value of infiltration after it reaches a constant value

f_o = Infiltration capacity at the start

f = Infiltration capacity at any time t

k = a constant

t = time from beginning of precipitation

Solving this equation we get, $$t = \frac{-1}{K\log_{10} e}\log_{10}(f-f_c) + \frac{1}{K\log_{10} e}\log_{10}(f_o-f_c)$$

which represent a straight line

Factors affecting Infiltration process

(*i*) Characteristics of soils (*ii*) Surface of infers (*iii*) Fluid characteristics

Measurement of Infiltration

It is carried by infiltrometer

These are following two types of infiltrometers :

1. Flooding type infiltrometer
2. Rainfall simulator

Infiltration Indices

It is average rate of loss such that volume of rainfall in excess of that rate will be equal to direct run-off.

Infiltration index can be used to estimate run-off coefficient.

$$\text{Run-off coefficient, } K = \frac{P - W}{P}$$

where, P = rainfall rate, W = W-index

Types of Indices

1. ϕ-index : It is the average rainfall above which rainfall volume is equal to runoff volume.

$$\phi = \frac{\text{Basin recharge}}{\text{Rainfall duration}} \quad \text{or} \quad \frac{P - R}{t}$$

It represents combined effect of interception, depression storage and infiltration.

2. W-Index : In an attempt to refine ϕ index, the initial losses are separated from total abstractions and an average value of infiltration rate called W-index.

$$W = \frac{P - R - \text{initial loss}}{t}$$

where, P = total precipitation (cm)

R = total run-off (cm)

t_r = duration of rainfall (hours)

W-index is equivalent to ϕ-index minus average rate of retention by depression storage

3. W_{min} - index : For very wet conditions,

ϕ and W index are called W_{min} index.

It is used to analyse maximum flood possibilities.

RUN-OFF

Rainfall and Run-off Correlations

$$R = \alpha I^{1.2}$$

$$\phi = \frac{I - R}{24}$$

where, R = run-off in cm from a 24 *h* rainfall of intensity 1 cm/day.

α = co-efficient (0.17 to 0.5)

In estimating maximum floods for design purposes, in the absence of any other data, ϕ-index value of 0.10 cm/h can be assumed.

A part of the precipitation flowing of a catchment area through a surface channel is called *run-off*.

Types of Run-off

1. Direct run-off. It enters a stream immediately after the precipitation.

2. Base flow. It is delayed flow reaching the stream as ground water.

Water Budget Equation

Mass inflow – Mass outflow = Change in mass storage.

If density of the inflow, outflow and storage volume are the same, then

$$V_i - V_o = \Delta S$$

where, V_i = inflow volume of water into the problem area during time period

V_o = outflow volume of water from the problem area during time period.

ΔS = change in the storage of water volume over and under given area during given period.

In hydrologic calculations, volumes are expressed as average depths over catchment area.

Rainfall, evaporation and runoff volumes are expressed in units of depth over the catchment.

An expression for the water budget of a catchment for a time interval Δt is written as

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

where, P = precipitation

R = surface run-off

G = net ground water flow out of the catchment

E = evaporation

T = transpiration

ΔS = change in storage.

Units of all term is written either volume unit or depth unit.

Infiltration, does not occur explicitly in the water budget, as infiltration, which is a loss to the runoff process is a gain to the ground water system.

Flow-Duration Curve.

Flow-duration curve is a plot of *stream discharge* against the percentage of time the flow is equalled or exceeded.

Flow-Mass Curve.

It is a plot of cumulative discharge volume against time plotted in chronological order.

Flow mass curve is an integral curve of the hydrograph.

STAGE OF A RIVER

It is defined as its water surface elevation measured above a datum.

Measurement of Stage

1. Staff gauge

2. Wire gauge

3. Automatic stage recorders

(*i*) **Float-gauge recorder :** A stilling well is required when the stage measurement is made by employing a float gauge recorder.

(*ii*) **Bubble gauge**

Stage Data

The stage data is often presented in the form of a plot of stage against chronological time called *stage hydrograph*.

STREAM FLOW MEASUREMENT

1. Direct Methods

(*i*) **By current meters**

A **current meter** is so designed that its rotation speed varies linearly with the **stream velocity** V at the location of the instruct.

Calibration equation : $V = aN_s + b$

where V = stream velocity at the instrument location in m/s

N_s = revolutions per second of the meter and

a, b = constants of meter. $a = 0.65$ and $b = 0.03$

Sounding weight, $W = 50\ \bar{v} d$ (in Newton)

$\bar{v}$ = average stream velocity in the vertical in m/s

d = depth of flow in the vertical in m.

Accurate determination of the stream velocity is done by current meter.

Types of Current Meters

(*a*) Vertical-axis meters (*b*) Horizontal-axis meters

(*ii*) By Floats

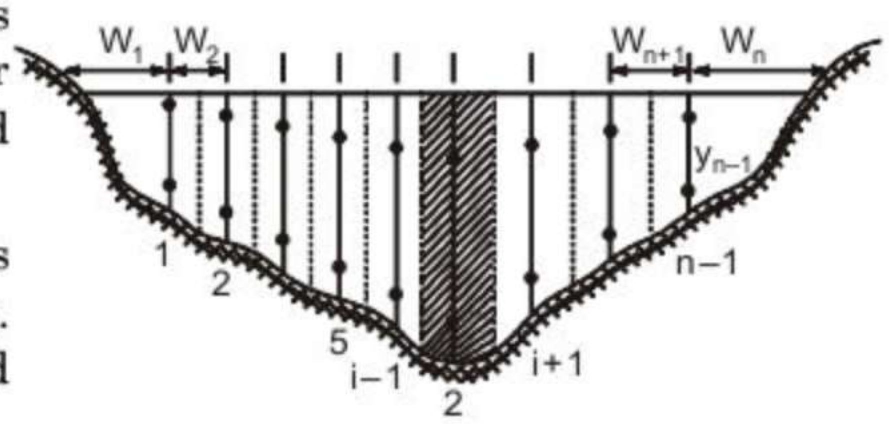
Approximate stream velocities can be determined by floats.

$$\text{Surface velocity} = \frac{\text{Distance travelled by float}}{\text{time taken}}; \quad \text{or} \quad V_s = \frac{S}{t}$$

(*iii*) Area-velocity Method (Standard Current Meter Method)

This method of discharge measurement consists essentially of measuring area of cross-section of the river at a selected section called *gauging site* and measuring velocity of flow through the cross-section.

For purposes of discharge estimation, cross-section is divided into a large number of subsections by verticals. The average velocity in these subsections are measured by **current meter** or **floats**.



$$\text{Total discharge, } Q = \sum_{i=1}^{N-1} \Delta Q_i$$

where, ΔQ_i = discharge in the ith segment

= (depth of the ith segment) × ($\frac{1}{2}$ width of the left + $\frac{1}{2}$ width of right) × (average velocity at ith vertical)

$$\Delta Q_i = y_i \left(\frac{W_i}{2} + \frac{W_{i+1}}{2} \right) \cdot V_i$$

For i = 2 to N – 2,

$$\Delta Q_i = \bar{V}_1 . \Delta A_1 = \bar{V}_1 \times \frac{\left(W_1 + \frac{W_2}{2} \right)^2}{2W_1} \times y_1$$

$$\Delta Q_{n-1} = \bar{V}_{N-1} . \Delta A_{N-1} = \bar{V}_{N-1} \frac{\left(W_N + \frac{W_{N-1}}{2} \right)^2}{2W_N} \times y_{N-1}$$

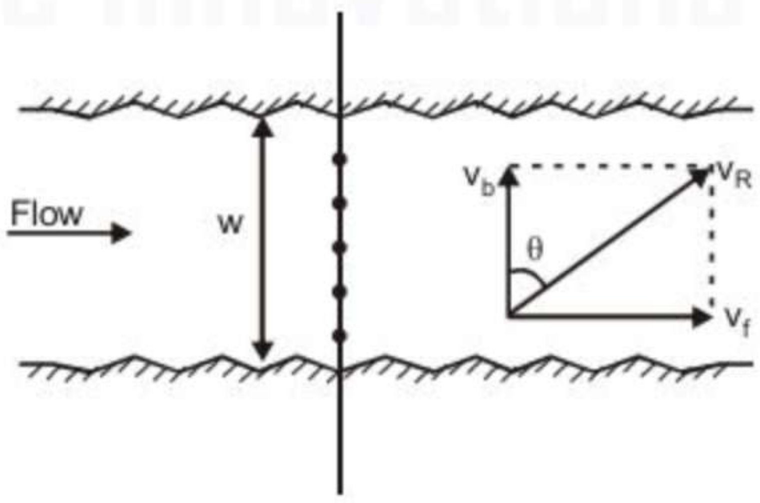
If a gauging section is having shifting control due to backwater effects, then a secondary gauge downstream of the section is needed.

(*iv*) Moving Boat Method

On very wide and fast moving surface of the stream (like gauge) moving boat technique prove very helpful.

$v_B = v_R \cos\theta$ and $v_f = v_R \sin\theta$

$W = v_b \, \Delta t$



Assuming current meter to measure average velocity in the vertical, flow in the sub-area between two verticals i and $i + 1$,

$$\Delta Q_i = \left(\frac{y_i + y_{i+1}}{2} \right) w_{i+1} v_f$$

where depths are y_i and y_{i+1} respectively

$$\Delta Q_i = \left(\frac{y_i + y_{i+1}}{2} \right) v_b \, \Delta t \, v_f = \left(\frac{y_i + y_{i+1}}{2} \right) v_R \cos\theta \times v_R \sin\theta \, \Delta t = \left(\frac{y_i + y_{i+1}}{2} \right) v_R^2 \sin\theta \cos\theta \, \Delta t$$

$\therefore \quad Q = \Sigma \Delta Q_i$

Essential Measurements

(*a*) Velocity and direction of the current meter

(*b*) Depths and the time interval between depth readings.

(v) Dilution technique of Streamflow Measurement

This method has major advantage that discharge is estimated directly in an absolute way. It is a particularly attractive method for small turbulent streams.

Example :

Chemical : Sodium Chloride, Sodium Dichromate

Fluorescent Dyes : Rhodamine-WT, Sulpha Rhodamine B Extra

Radioactive isotope : Bromine-82, Iodine-132

(vi) Electromagnetic Method

(vii) Ultrasonic Method

2. Indirect Methods

(i) Flow Measuring Structure or **Hydraulic Structure**

$$\text{Discharge, } Q = f(H)$$

where, H = water surface elevation measured from a specified datum

For wear, $Q = kH^n$

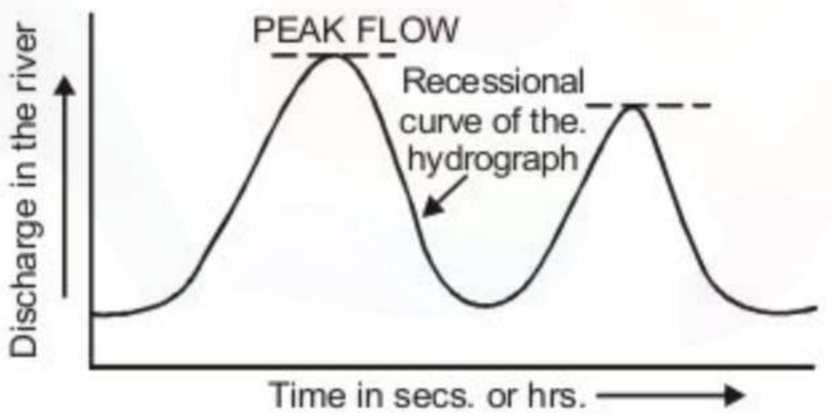
where, H = head over the weir

k, n = system constants

(ii) By Slope Area Method

Hydrographs

It is graphical representation of the discharge flowing in the river, past any given section. Hence, it can easily represent sudden fluctuations in the river discharge due to a heavy storm.



It consists of flow in three Phases of Run-off

1. Surface run-off
2. Interflow
3. Base flow.

Thus two different storms in a given catchment produce hydrographs differing from each other. Similarly identical stormes in two catchments produce hydrographs that are different.

Hydrograph is the graphical representation of the discharge flowing in the river vs. time elapased.

It has three Characteristics Regions

(i) Rising limb – dimatic factors control it

(ii) Crest segment

(iii) Recession limb : Shape of this part of the hydrograph is independent of storm characteristics and depends entirely on the basic characteristics.

Storage of Water in Basin

It exists as following :

(i) *Surface storage :* It includes both surface detention and channel storage.

(ii) *Interflow storage.*

(iii) *Ground water storage i.e.,* base-flow storage.

Recession of a storage can be expressed as, $Q_t = Q_0 K_r^{\,t}$

where, Q_0 = Initial discharge

Q_t = discharge at a time interval of t days with Q_0 being initial discharge

K_r = recession constant < 1.

and $$Q_t = Q_0 e^{-at}$$

where $$a = -ln K_r$$

Base Flow Separation

Base flow is to be deducted from the *total storm hydrograph* to obtain *surface flow* hydrograph.

Surface runoff hydrograph obtained after the base-flow separation from flood hydrograph is also called *direct run-off hydrograph* (*DRH*).

Effective Rainfall

When initial loss and infiltration losses are subtracted from hyetograph, then resulting hyetograph is called *effective rainfall hyetograph (ERH)*. It is also called *hyetograph of rainfall excess or supra rainfall*.

$$\left.\begin{array}{l}\text{Direct Run-off Hydrograph (DRH)}\\ \text{Effective Rainfall Hyetograph (ERH)}\end{array}\right\}\text{same total quantity but different units}$$

$$\text{DRH} = \text{Area of catchment} \times \text{ERH}$$

$$\text{Rainfall excess} = \text{Run-off depth}$$

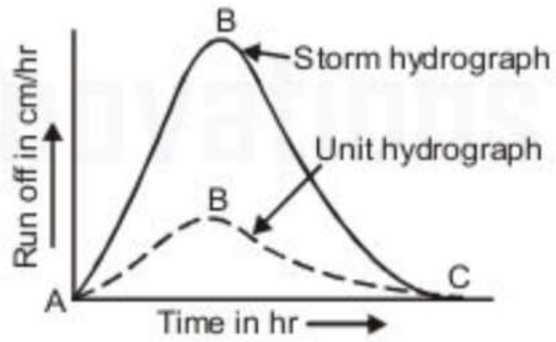
Factors Affecting Flood Hydrograph

1. **Physiographic Factors**
2. **Climatic factors :** The controlling rising limb is determined by catchment area only. Recession limb is independent of storm characteristics.

Physiographic factor	Climatic factor
1. Basin characteristics *(i)* Shape *(ii)* Size *(iii)* Slope *(iv)* Nature of the valley *(v)* Elevation *(vi)* Drainage density	**1. Storm characteristics** *(i)* Precipitation *(ii)* Intensity *(iii)* Duration *(iv)* Magnitude *(v)* Movement of storm
2. Infiltration characteristics *(i)* Land use and cover *(ii)* Soil type and geological condition *(iii)* Lakes, swamps and other storage	**2.** Initial loss
3. Channel characteristics *(i)* Cross-section *(ii)* Roughness *(iii)* Storage capacity	**3.** Evapo transpiration

UNIT HYDROGRAPH

The hydrograph of direct runoff resulting from one unit depth (1 cm) of rainfall excess occuring uniformly over the basic and at a uniform rate for specified duration (D) is called *D-hour unit hydrograph*. The area of unit hydrograph is equal to a volume given by 1 cm over the catchment.



Basic Assumptions

1. **Time invariance.** Direct runoff hydrograph for a given excess rainfall in a catchment is always the same irrespective of when it occurs.
2. **Linear Response.** The direct runoff response to the rainfall excess is assumed to be linear.

   If an imput $x_1(t)$ causes an output $y_1(t)$ and an input $x_2(t)$ causes an output $y_2(t)$, then an input $x_1(t) + x_2(t)$ gives an output $y_1(t) + y_2(t)$.

Derivation of Unit Hydrograph

1. The area under each storm hydrograph is evaluated.
2. Depth of excess runoff is obtained by dividing volume of the direct runoff by the catchment area.
3. Ordinates of various storm hydrograph are divided by respective excess runoff to obtain ordinates of unit hydrograph.

Note : Unit hydrograph cannot give precise results for areas greater than 5000 km^2.

lower limit of hydrograph = 200 ha

Application of Unit Hydrograph

Using basic principles of the unit hydrograph, one can easily calculate DRH in a catchment due to a given storm if an appropriate unit hydrograph was available.

Consider a sequence of μ rainfall excess value $R_1, R_2, \ldots R_i \ldots R_n$, each of duration D-hour

At time t, direct runoff due to R_1, $Q_1 = R_1\, u(t)$

At time $(t - D)$, direct runoff due to R_3, $Q_2 = R_2 \cdot P\, u\,(t - D)$

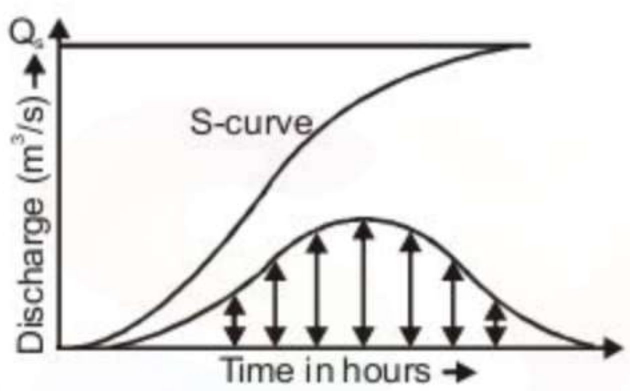
Similarly, $Q_m = R_m\, u[t - (\mu - 1)D]$

Thus at time t, total direct runoff, $Q_t = \sum_{i=1}^{\mu} R_i = \sum_{i=1}^{\mu} R_i\, u\left[t - (i-1)\,D\right]$

Methods to Develope Unit Hydrograph of Different Durations

1. **Method of Superposition.** If a D-h unit hydrograph is available, and it is desired to develop a unit hydrograph of n D hour, where n is an integer, it is easily accomplished by superionposing n unit hydrographs with each graph separated from previous one by D hours.
2. **S-curve Method.** If it is desired to develop a unit hydrograph of duration m D, where m is fraction, the method of superposition cannot be used.

   S-curve is a hydrograph produced by a continuous effective rainfall at a constant rate for a infinite period. It is a curve obtained by summation of an infinite series of D-h unit hydrograph spaced D-h apart.

   S-curve is due to a D-h unit hydrograph. It has an initial steep portion and reaches a maximum equilibrium discharge at a time equal to time base of the first unit hydrograph.

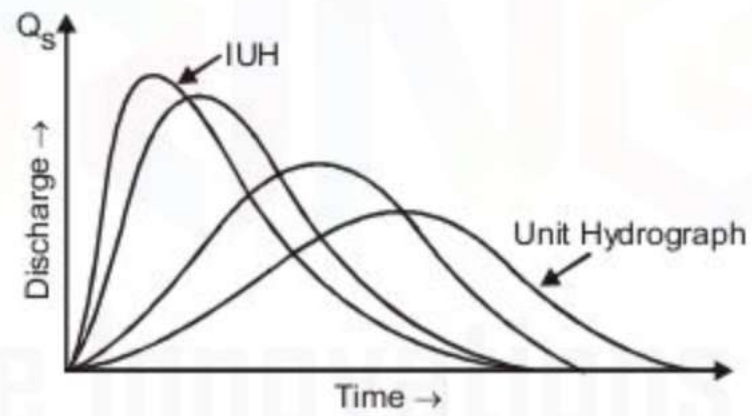
$$Q_s = \left(\frac{A}{D} \times 10^4\right) \text{ m}^3/\text{hour} = 2.778 \frac{A}{D} \text{ m}^3/\text{sec}$$

where, A = area of catchment in km^2

D = duration in hour of ER of the unit hydrograph.

Instantaneous Unit Hydrograph (IUH) – Clark's Model & Nash Model

It is a fictitious, conceptual unit hydrographs, which represents surface runoff from the catchment due to an instantaneous precipitation of the rainfall excess volume of 1 cm. IUH is designed as $u(t)$ or $u\,(0, t)$.



As D is reduced, the intensity of rainfall excess being equal to 1/D increases and unit hydrograph becomes more skewed. For a given catchment, IUH being indpendent of rainfall characteristics, is indicative of the catchment storage characteristics.

Ordinate of an IUH at any time t is slope of the S-curve of intensity 1cm/h at the corresponding time.

$$u(t) = \frac{1}{i}\frac{ds}{dt}$$

Synthetic Unit Hydrograph – Developed by SNYDER

To develop unit hydrograph to a catchment, detailed information about the rainfall and resulting flood hydrograph are needed. However, such inforamtion would be available only at few location and in a majority of a catchments, especially those which are at remote locations, the data would normally be very scanty. In order to construct unit hydrograph for such areas, empirical equations of regional volidity which relate salient hydrograph characteristics of the basin characteristics are availabe. Unit hydrographs derived from such relationshop are called *synthetic unit hydrograph.*

Basin Lag

It is the time difference between the centroids of the input (rainfall excess) and the output (surface run-off). For simplicity, Snyder has used a somewhat different definition of basin lag (t_p). He defined, t_p as the time interval from mid-point of unit rainfall excess to the peak of the unit hydrograph.

$$t_p = C_t\,(L\,L_{ca})^{0.3}$$

where t_p = basin lag in hours

L = length of main stream in the catchment upto the gauging site in km.

L_{ca} = distance along the main stream from gauging site to a point on the stream which is nearest to the centroid of the basin in km.

C_t = a regional consistent representing watershed slope and storage.

Synder adopted a standard duration t_r hours of effective rainfall given by

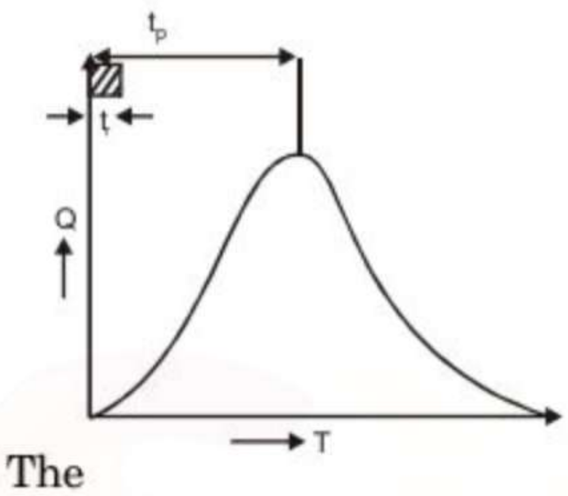
$$t_r = \frac{t_p}{5 \cdot 5}$$

Peak discharge of a unit hydrograph of standard duration $t_r h$ is given by Snyder as

$$Q_{ps} = \frac{2.78 C_p A}{t_p} \text{ (in m}^3\text{/s)}$$

where, A = catchment area in km^2

C_p = a regional constant



If a non-standard rainfall duration $t_R h$ is adopted (means not knowing experiment of value of constant of this catchment) instead of the standard value t_r to derive a unit hydrograph, value of the basin lag is affected.

Modified basin lag is given by, $t'_p = t_p + \frac{t_R - t_r}{4}$; $t'_p = \frac{21}{22} t_p + \frac{t_R}{4}$

where, t'_p = basin lag in hours for effective duration of t_R

Example. There are four raingauge stations existing in the catchment of a river. The average annual rainfall values at these stations are 800,400, and 540 mm respectively

(*i*) Determine optimum number of raingauges in the catchment, if it is desired to limit the error in the mean value of rainfall in the catchment to 10%

(*ii*) How many more gauges will then be required to be installed?

Solution :

(*i*) Mean rainfall, $\bar{P} = \frac{\sum P}{n} = \frac{800 + 620 + 400 + 540}{4} = 590$ mm

$$\Sigma P^2 = (800)^2 + (620)^2 + (400)^2 + (540)^2 = 1486000$$

$$\therefore \quad \bar{P}^2 = \frac{\Sigma P^2}{n} = \frac{14,86,000}{4} = 3,71,500$$

Standard Deviation, $\sigma = \sqrt{\frac{n}{n-1}\left[\bar{P}^2 - \left(\bar{P}^2\right)\right]} = \sqrt{\frac{4}{4-1}\left[3,71,500 - (590)^2\right]} = 176.73$

Coefficient of variation, $C_v = \frac{100\sigma}{P} = \frac{100 \times 176.63}{590} = 29.94$

Since percent allowed, E is 10%, therefore

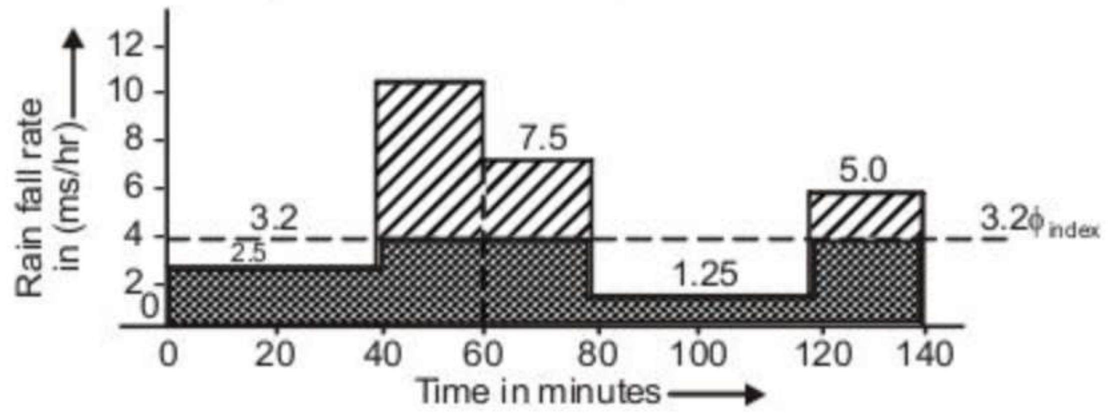
Optimum number of raingauges, $N = \left(\frac{C_v}{E}\right)^2 = \left(\frac{29.94}{10}\right)^2 = 8.96$ say 9

(*ii*) Additional gauges required to be installed = 9 – Existing gauges = 9 – 4 = 5

Example. Following are the rates of rainfall for successive 20 minutes period of a 140 minutes storm: 2.5, 2.5, 10.0, 7.5, 1.25, 1.25, 5.0 cm./hr.

Taking value of ϕ_{index} as 3.2 cm/hr, find out net run-off in cm, total rainfall, and value of W_{index}.

Solution: Rain intensity pattern can be plotten from the given rainfall rates as shown below.



ϕ_{index} curve at a height of 3.2 cm/hr is superimposed. Hatched area is calculated so as to obtain value of run-off.

$$\text{Run-off, } Q = (10-3.2)\frac{20}{60} + (7.5-3.2)\frac{20}{60} + (5-3.2) + \frac{20}{60} = 4.3 \text{ cm}$$

$$\text{Total precipitation, } P = 2.5 \times \frac{40}{60} + 10 \times \frac{20}{60} + 7.5 \times \frac{20}{60} + 1.25 \times \frac{40}{60} \times \frac{20}{60} = \mathbf{10\ cm}$$

$$\therefore \qquad W_{index} = \frac{P-Q}{T_r \text{ in hr.}} = \frac{10-4.3}{(140/60)} = \mathbf{2.44\ cm/hr}$$

Example. An intense rain assumed to be falling at a uniform rate of 5 cm/hr. for a period of 80 minutes, on a drainage basin having an area equal to 550 hectares. The average infiltration capacity during the entire rain period has been worked out to be 1.4 cm/hr. Determine the maximum run-off rate, if peak percentage based on 10 minutes interval from the distribution graph for this basin is 18%.

Solution : Rainfalls at a constant rate of 5 cm/hr, out of which infiltration takes place at a constant rate of 1.4 cm/hr. Remaining water appears as excess rain.

$$\text{Excess rainfall in cm depth} = (5.0 - 1.4) \times \frac{80}{60} = 4.8 \text{ cm}$$

$$\text{Total excess rainfall, } R_e = R_e \times \text{Area in m}^2 = \frac{4.8 \times 550 \times 10^4}{100} = 4.8 \times 550 \times 10^2 \text{ m}^3$$

Since peak percentage is based on 10 minutes interval, the volume of water (R_e) must, first of all, be converted into m³ /sec (cumccs); by dividing by the number of seconds in 10 minutes interval.

$$\therefore \qquad R_c \text{ (in cumecs)} = \frac{4.8 \times 550 \times 10^2}{10 \times 60} = 440 \text{ m}^3\text{/sec for 10 minutes}$$

But peak percentage from the distribution graph = 18% (given)

$$\therefore \qquad \text{Peak rate of run-off} = 440 \times \frac{18}{100} = \mathbf{79.2\ m^3/sec.}$$

Example. Compute mean precipitation by arithmetic average method and Thiessen polygon method for the following data :

Station Number	Precipitation mm	Area of Thiessen Polygon-km²
1	30.8	45
2	34.6	40
3	32.0	38
4	24.6	38

Solution :

(*i*) Arithmetical Method : $P_m = \frac{P_1 + P_2 + P_3 + P_4}{4} = \frac{30.8 + 34.6 + 32.0 + 24.6}{4} = 30.5 \text{ mm}$

(*ii*) By Thiessen Polygon Method : $P_m = \frac{\Sigma P_1 A_1}{\Sigma A_1} = \frac{30.8 \times 45 + 34.6 \times 40 + 32 \times 38 + 24.6 \times 38}{45 + 40 + 38 + 38} = \mathbf{30.49\ mm}$

FLOOD ESTIMATION

Flood may be defined as on overflow coming from some river or from a some other body of water. River may get flooded due to an excessive rainfall or due to melting of snow or due to some other form of obstruction in the form of jams.

Design Flood

It is the flood adopted for the design of a structure.

Spillway Design Flood

It is the design flood used for the specific purpose of designing the spillway of a storage structure.

Standard Projected Flood (SPF)

The flood that would result from a severe combination of meteorological and hydrological factors that are reasonably applicable to the region.

Probable Maximum Flood (PMF)

The extreme flood that is physically possible in a region as a result of severemost combinations, including rare combinations of meteorological and hydrological factors.

Estimating Design Flood

1. By Empirical Formula

(i) *Dicken's Formula :* High flood or peak discharge in cumecs, $Q_p = C A^{3/4}$

where, A = catchment area in sq. km.

C = constant depending upon all those fifteen to twenty factors affecting high flood discharge. It ranges from 6 to 30

(ii) *Ryve's Formula :* $Q_p = C_1 A^{2/3}$ in cumecs

(iii) *Inglis' Formula :* $Q_p = \dfrac{123A}{\sqrt{A+10.4}}$ cumecs $\approx 123\sqrt{A}$

(iv) *Jarvis Formula :* $Q_p = C\sqrt{A}$; where C varies between 1.77 to 177

2. Formula involving Drainage Area and its shape

Dredge or Burge's Formula $O_p = 19.6.B.L^{1/3}$

where B is average width of basin in km.

3. Rational Method

$$Q_v = \frac{1}{36}(K\, p_c\, A)$$

where, K = percentage of rainfall that becomes surface run-off called *run-off coefficient.*

p_c = rainfall intensity in cm/hr generally taken as average rate during time of concentration T_c and can be determined from Intensity. Duration curve for the given frequency flood.

A = catchment area in hectares.

Chance Flood If a flood of a given magnitude occurs with an average frequency of 100 years, then there exist $\frac{1}{100} \times 100 = 1$ percent chance for this flood to occur, and such a flood is generally called *1 percent chance flood.*

4. Gumbel's Method : Gumbel introduced extreme value distribution. Gumbel probability distribution functions are used widely to predict flood peaks maximum rainfall, maximum wind speed etc. He used following equation:

Peak flood discharge for any given frequency, $Q_p = \bar{Q}_p + k.\sigma$

where, $\bar{Q}_p$ = mean of observed peak discharges = $\dfrac{\Sigma Q_p}{y}$

y = total number of years or floods in record.

k = frequency factor, whose value can be obtained for a given frequency and known number of floods in the sample (y)

$$\sigma = \text{standard deviation} = 5\sqrt{\frac{y}{y-1}\left[\bar{Q}_p^2 - (\bar{Q}_p)^2\right]}$$

where, $\bar{Q}_p^2$ = Mean of squares of peak discharges = $\dfrac{\sum \bar{Q}_p^2}{y}$

5. Unit Hydrograph Method : This method requires a continuous rainfall and run-off records for 2 to 5 years to draw a number of unit hydrographs for this basin and to determine average infiltration capacity of the basin at different times during an year. In this method a graph between flood peak and its frequency is established which can be directly used to read magnitude of flood of any given frequency.

Flood-Frequency studies (Prediction of Flood Flows) : Values of the annual maximum flood from a given catchment area for large number of successive years constitute a hydrological data series called *annual series*.

Data are arranged in decreasing order of magnitude and probability P of each event being equalled to or exceeded is calculated by Weibule formula

$$P = \frac{m}{N+1}$$

where, m = order of event

N = total number of events in the data.

Recurrence Interval T (also called Return period or Frequency)

$$T = \frac{1}{P}$$

A plot of Q vs T yield the probability distribution. In frequency analysis of floods, usual problem is to predict extreme flood events. Towards this, specific extreme-value distributions are assumed and required statical parameters calculated from the available data. Using these, flood magnitude for a specific return period is estimated.

General equation of hydrologic frequency analysis : $x_T = \bar{x} + K\sigma$

where x_T = value of the variable x of a random hydrologic series with a return period T

$\bar{x}$ = mean of the variable

σ = standard deviation of the variable

K = frequency factor.

Example. From a record of 94 years of observation of a river flow at a gauging station, the probability that a flood event Q_i would be exceeded is $P(Q > Q_i) = 0.02326$. Assuming the annual flood as an independent event, compute the probability for four floods greater than Q_i to occur in the next 10 years as well as the probability that none will occur.

Solution :

As probability of occurance $p = 0.02326$

so probability of occurance $q = 1 - p = 0.97674$

so probability of flood 4 times in 10 yrs shall be given by $P = {}^nC_r . p^r . q^{n-r}$

here $n = 10, \quad r = 4$

$$\Rightarrow \quad P = {}^{10}C_4 . (0.02326)^4 \times (0.97674)^{10-4}$$

$$= \frac{10!}{4!6!} \times (0.02326)^4 \times (0.97674)^6 = 0.000053374$$

Probability of non occurance of flood once in 10 yrs

$$P = q^n = (0.97674)^{10} = 0.79029$$

Example. A 12 hour storm rainfall had the following depths in cm for each hour occurring over a basin :

1.8, 2.6, 7.8, 3.9, 10.6, 5.4, 7.8, 9.2, 6.5, 4.4, 1.8 and 1.6.

Surface run-off resulting from the above storm is found to be 24.4 cm depth over the basin.

Determine average infiltration index for the basin.

Solution : Rainfall duration, T = 12 hours,

Total surface run-off, Q = 24.4 cm.

Total precipitation, P = 1.8 + 2.6 + 7.8 + 3.9 + 10.6 + 5.4 + 7.8 + 9.2 + 6.5 + 4.4+ 1.8 + 1.6 = 63.4 cm

$$\therefore \quad \text{Average infiltration index, } W_i = \frac{P - Q}{T} = \frac{63.4 - 24.4}{12} = 3.25 \text{ cm/hr.}$$

Example 3. A storm with a 15.0 cm. precipitation produced a direct run-off of 8.7cm. Time distribution of the storm is as follows:

Time from Start (in hr.)	1	2	3	4	5	6	7	8
Incremental rainfall in each hr (in cm)	0.6	1.35	2.25	3.45	2.7	2.4	1.5	0.75

Estimate ϕ index of the storm.

Solution : Using values of incremental, rainfall, a hyetograph is prepared as shown in the figure below

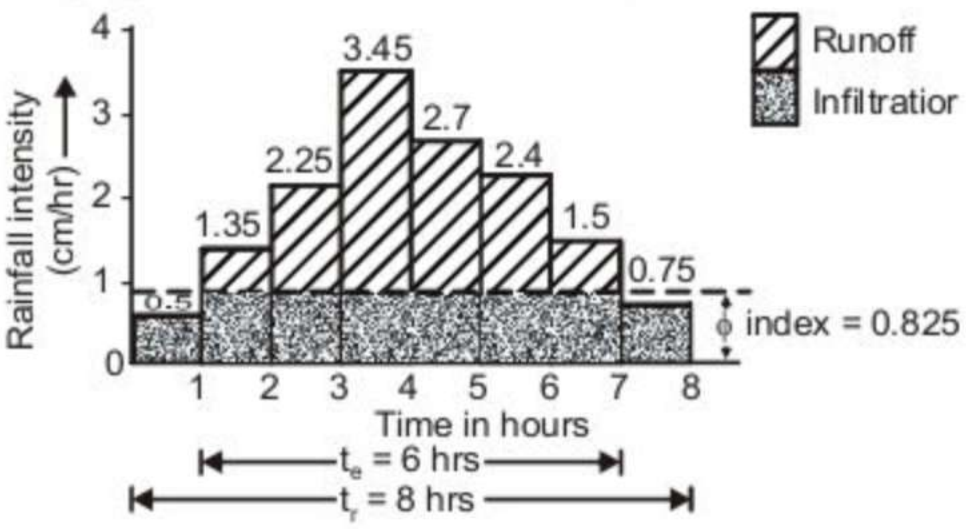
Total precipitation, P = 15.0 cm,

Total run-off, R = 8.7 cm.,

Rainfall duration, t_r = 8 hrs.

$$\therefore \quad W_{index} = \frac{P - Q}{tr}$$

$$= \frac{15 - 8.7}{8} = 0.7875 \text{ cm/hr}$$



We know, ϕ index > W index

i.e. ϕ index > 0.7875 cm/hr

It can be expected that rainfall intensity during first and eighth hour would be less than ϕ index.

Thus period during which rainfall is in excess could be, $t_e = 8 - 2 = 6$ hrs.

By definition, ϕ index $= \dfrac{\text{Total infiltration during period of excess rainfall}}{\text{Period of rainfall excess}}$

$$= \frac{\text{Total infiltration} - \text{Infitration during the period when no excess rainfal occured}}{t_e}$$

$$= \frac{6.3 - 0.6 - 0.75}{6} = \mathbf{0.825\ cm/hr}$$

RESERVOIRS CHANNEL ROUTING

Reservoirs

When a barrier is constructed across some river in the form of a dam, water gets stored up on the up side of the barrier forming a pool of water called *reservoirs*.

Types of Reservoirs

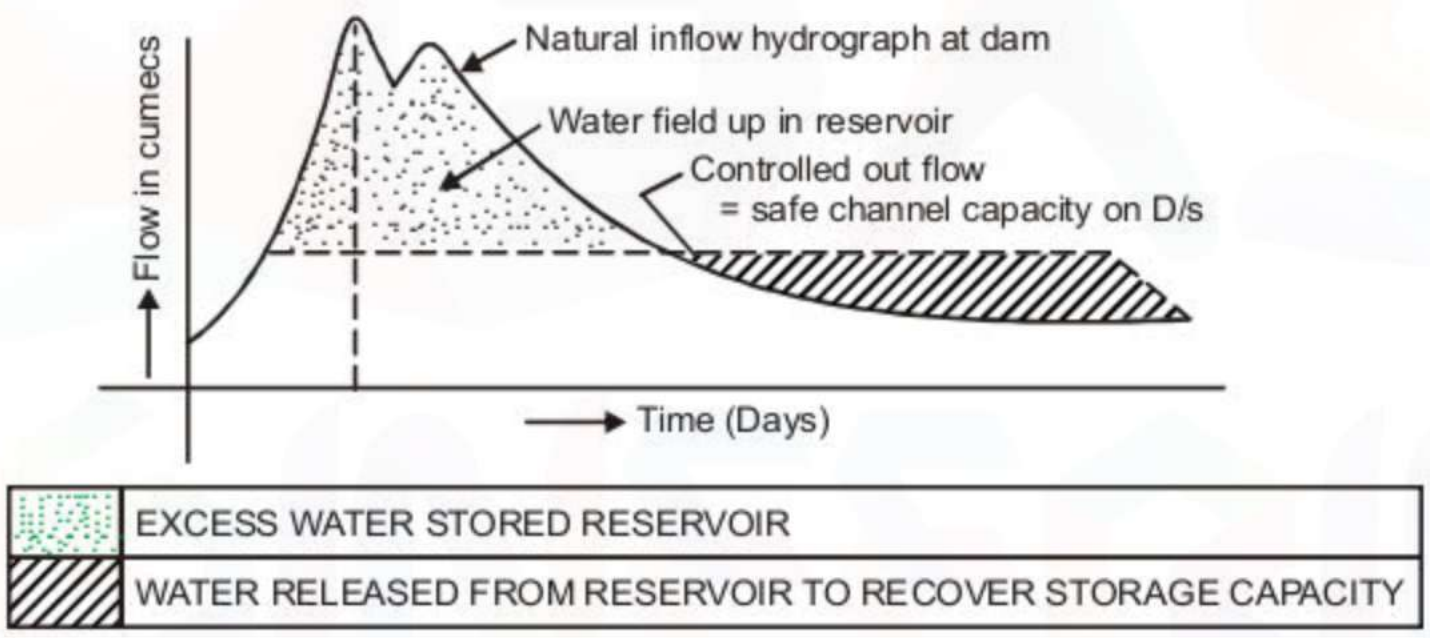
Depending upon the purposes served, reservoir can be classified as follows :

1. Storage or Conservation Reservoirs

These reservoirs can retain excess supplies during periods of peak flows and can release them gradually during low flow as and when the need arises.

2. Flood control Reservoirs

These stores a portion of the flood flows in such a way as to minimise the flood peaks at the areas to be protected downstream. For this, entire inflow entering the reservoir is discharged till outflow reaches the safe capacity of the channel downstream.



Reservoir Yield

It is the amount of water that can be drawn from a reservoir in a certain interval of time.

Now, Inflow – Outflow = Increase in storage

$\therefore$ yield (outflow) = Inflow – Increase in storage

Stream flow Routing (Flood Routing)

Flood routing is the technique of determining flood hydrograph at a section of a river by using the data of flood flow at one or more upstream sections.

Classification of Flood Routing.

1. Reservoir Routing : In this, the effect of a flood entering a reservoir is studied.

When inflow and outflow hydrographs are plotted against simultaneous outflow, the resulting curves is usually a wideloop indicating grealer storage or a given outflow during rising stages than during falling; since during advance of a wave inflow always exceeds outflow. During rising stage a considerable wedge storage exists whereas during falling stage the wedge storage volume become negative.

Routing requires a storage relation, $I = O + AS$

where, I = average Inflow during the interval

O = average outflow during the interval

AS = change in storage during the interval

The increase in storage should be taken as + ve and decrease in storage as – ve.

2. Channel Routing : In this, change in the shape of hydrograph as it travels down a channel is studied. When there is no lateral inflow into the channel reach under consideration, then unsteady flow in the channel is described by following equation :

$$\frac{\partial H}{\partial x}+\frac{V}{g}\frac{\partial V}{\partial x}+\frac{1}{g}\frac{\partial V}{\partial t}+\frac{V^2}{C^2R}=0;$$

and
$$A\frac{\partial H}{\partial x}+V\frac{\partial A}{\partial x}+B\frac{\partial H}{\partial t}=0$$

where, H = depth of water in the stream
V = average velocity of flow
A = cross-sectional area of the channel
B = surface width of flow
R = hydraulic radius
C = chezys coefficient
g = gravitational acceleration
x = distance along the flow direction
t = time variable

Routing Methods

These can be callsified into following two categories :

Hydrologic Routing. These methods employ essentially the equation of continuity.

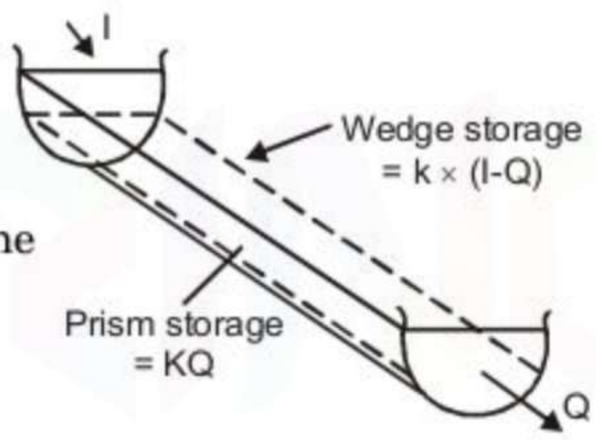
Considering a channel reach having a flood flow, total volume in storage can be considered under two categories :

(*i*) **Prism Storage :** It is volume that would exist if uniform flow occured at the d/s depth; i.e. volume formed by an imaginary plane parallel to the channel bottom drawn at the outflow section water surface.

(*ii*) **Wedge Storage :** It is the wedge like volumed formed between actual water surface profile and to surface of the prism storage.

Continuty equation for the channel reach,.

$$I-Q=\frac{dS}{dt}$$



where I, Q and S denotes, inflow rate at the upstream section, outflow rate at the downstream section and storage within the channel reach respectively.

For a routing time interval of Δt,

$$\left(\frac{I_1+I_2}{2}\right)\Delta t-\left(\frac{Q_1+Q_2}{2}\right)\Delta t=S_2-S_1$$

where I_1, Q_1, and S_1 are inflow rate, outflow rate and storage in the reach at begining of routing period I_2, Q_2, and S_2 are corresponding quantities at the end of the time interval.

Muskingham Storage Equation

It gives storage in the channel reach at any time as a function of inflow and outflow.

$\therefore$ $$S = KQ + Kx\,(I - Q)$$

$\Rightarrow$ $$S = K[I + (I - x)Q]$$

where, x = dimensionless constant (lies between 0 and 0.3) = $\dfrac{dQ/dt}{(dQ/dt)-(dt/dt)}$

K = *storage constant* having dimensions of time

By Muskingham storage equation,

Change in storage, $S_2 - S_1 = K\,[x\,(I_2 - I_1) + (I - x)\,(Q_2 - Q_1)]$

$\therefore$ $$Q_2 = C_o\,I_2 + C_1\,I_2 + C_2\,Q_1$$

where, $C_0=\dfrac{0.5\,\Delta t-K.x}{K(1-x)+0.5\Delta t}$; $C_1=\dfrac{0.5\,\Delta t+K.x}{K(1-x)+0.5\Delta t}$; $C_2=\dfrac{K(1-x)-0.5\Delta t.x}{K(1-x)+0.5\Delta t}$

C_0, C_1 and C_2 are routing constants such that, $C_0 + C_1 + C_2 = 1.0$

Example. Determine routing constants for the given flow through a channel reach. Values of K and x for the reach may be taken as 12 hrs. and 0.278 respectively

Time-(hr)	0	4	8	12	16	20	24	28	32
Inflow (m^3/s)	42	68	116	164	294	200	192	170	150
Time (hr)	–	36	40	44	48	–	66	–	–
Outflow (m^3/s)	–	128	106	88	–	62	54	–	–

Solution : With K = 12, $\Delta t = 4$ and $x = 0.278$

$$C_0 = \frac{0.5\Delta t - K.x}{K(1-x)+0.5\Delta t} = \frac{2-3.386}{8.664+2} = -0.125;$$

$$C_1 = \frac{0.5\Delta t + K.x}{K(1-x)+0.5\Delta t} = \frac{2+3.386}{8.664+2} = 0.50;$$

$$C_2 = \frac{K(1-x)-0.5\Delta t}{K(1-x)+0.5\Delta t} = \frac{8.664-2}{8.664+2} = 0.625$$

Check : $C_0 + C_1 + C_2 = -0.125 + 0.50 + 0.625 = 1.0$

Frequency Analysis

It is a direct means of estimating desired flood based on the available flood-flow data of the catchment. Results of the frequency analysis depend upon the length of data.

Frequency of storm is the time interval during which the given storm is likely to be equalled or exceeded. It is determined by simple probability method.

If Y be the total number of years of records and 'a' be the recurrence interval, then

$$Y = ab$$

where b = number of times the given rain equalled or exceeded and is called ranking of storm.

Example. Values of annual precipitation at a rain gauge station expressed in cm per year in chronological sequence from 1966 to 1977 are indicated below :

Year	1966	1967	1968	1969	1970	1972	1973	1974	1975	1976	1977
Precipitation	36.5	27.0	58.5	85.0	29.0	70.3	54.2	30.5	19.3	27.5	66.2

Estimate value of precipitation which has a recurrence interval of 5 years, using probability or statistical method.

Solution : Recurrence interval, a = 5 years.

Total number of years on record, Y = 12

From $Y = ab$, Ranking of storm, $b = \frac{Y}{a} = \frac{12}{5} = 2.4$

Hence take second severest storm, *i.e.* 70.3 cm (First most severe storm is 85 cm and second severe storm is 70.3 cm)

Use of Frequency Analysis

It is used to predict future rainfall, which is necessary to determine following :

(*i*) Maximum and minimum rainfall that can be expected within a certain period.

(*ii*) Frequency of the occurence

(*iii*) Trend of the rain fall at the end.

These are determined by laws of probability, *i.e.* **Hazen's relation,**

$$T = \frac{n}{m-0.5}$$

where, T = recurrence interval or average period within which an event will be equalled or exceeded.

n = number of years of record

m = order number of the event arranged in descending or ascending order.

Example. The value of annual, precipitation at a raingauge station expressed in cm per year in chronological sequence for 1956 to 1967 are indicated below :

Year	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
Precipitation	36.5	29.0	56.2	82.0	27.8	23.4	71.2	48.3	31.4	18.1	29.0	65.6

Estimate value of precipitation which has a recurrence interval of 5 years, using probability or statistical method.

Solution : Total number of years on record, Y = 12;

Recurrence interval, a = 5 years

$\therefore$ Ranking of the storm, $b = \frac{Y}{a} = \frac{12}{5} = 2.4$

Therefore pick up 2nd severest storm, *i.e.* 71.2 cm (First more severe storm is 82cm). Thus, value of precipitation which has a recurrence interval of five years is 71.2 cm.

Limitation of Hazen's method

Formula $\left[\frac{n}{m-0.5}\right]$ assumes recurrence interval of $2n$ to the highest event of the record. Actual frequency of occurrence of the maximum event in 'n' years is not known. It is only assumed as $2n$. No statistical device can lengthen period of record.

Example. Determine recurrence interval using Hazen 's formula for maximum and minimum rainfall for the following data for a sixteen year period :

Rainfall (mm) : 508, 613, 359, 775, 677, 489, 637, 809, 859, 704, 638, 698, 642, 549, 562

Solution : By Hazen's formula, recurrence interval for maximum rainfall of 859 mm

$$T = \frac{n}{m-0.5}$$

where, n = number of years of record = 16

m = order number of the rainfall arranged in descending order, *i.e.* first for maximum rainfall of 859 mm.

$$\therefore \quad T = \frac{16}{1-0.5} = 32 \text{ years.}$$

Recurrence interval for minimum rainfall of 359 mm, $T = \frac{16}{16-0.5} = 32$ years.

Example. Mean intensity of flood to be controlled is 4Mm^3/hour in 24 hours. Maximum possible outflow is 0.90 Mm^3/hour. Find storage capacity needed for the proposed reservoir.

Solution : Mean outflow during the filling period = $\frac{5}{6} \times 0.9 = 0.75$ Mm^3/hour

Total outflow during this period = mean outflow × duration time

= 0.75 × 24 = 18 Mm^3

$\therefore$ Storage capacity required = Total inflow – Total outflow

= (24 × 4) – 18 = 78 Mm^3

GROUND WATER FLOW

Specific Yield

It is defined as the ratio of volume of water obtained by gravity drainage to the total volume of material drained or dewatered.

$$\text{Specific yield} = \frac{\text{Volume of water obtained by gravity drainage}}{\text{Total volume of the material drained or dewatered}} \times 100$$

Specific Retention

It is de fined as the quantity of water retained by the material against the pull of gravity and is expressed as percentage of the total volume of the material drained.

$$\text{Specific Retention} = \frac{\text{Volume of water held against gravity}}{\text{Total volume of the material drained}} \times 100$$

and Porosity = Specific yield + Specific retention

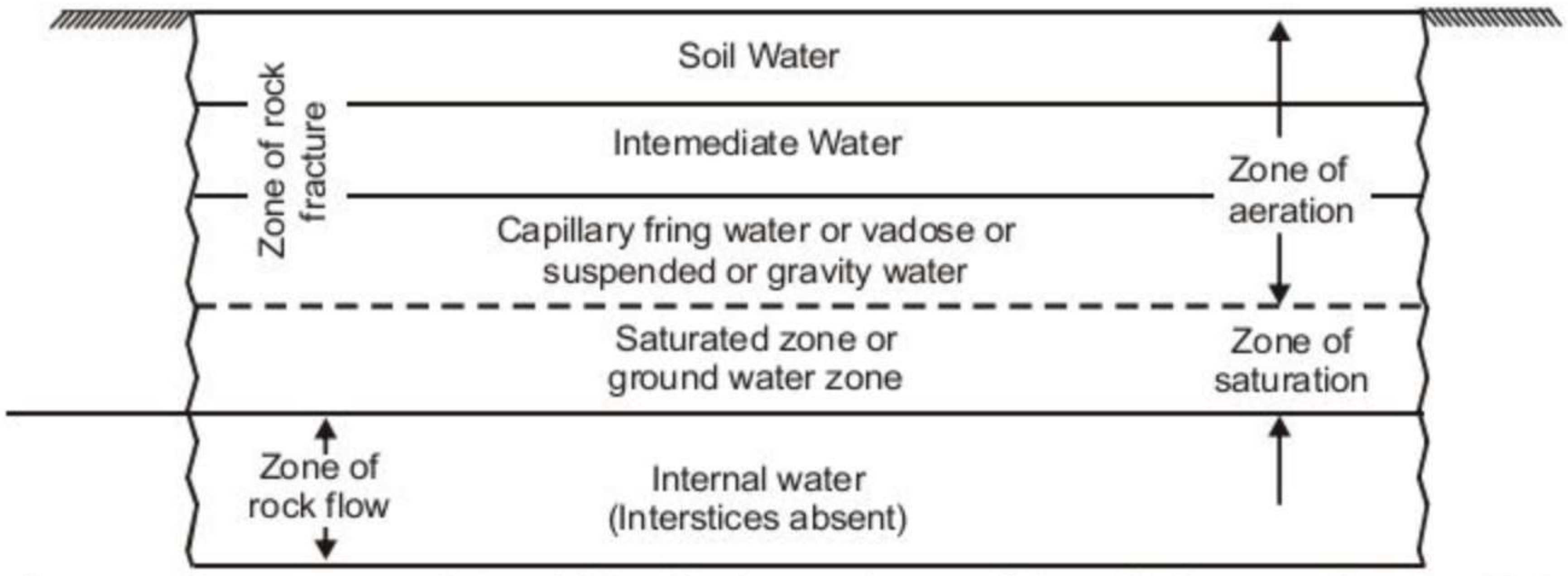
Storage Coefficient

It is defined as the volume of water that an aquifer releases or stores per unit surface area of the aquifer per unit change in the component of head normal to that surface.

Coefficient of Permeability

It is defined as average velocity of flow that will occur through total cross-sectional area of soil under unit hydraulic gradient.

Zones of Underground Water



In the zone of *saturation*, water exists within the interstices and is called *ground water.* This is the most important zone for a ground water hydrolic engineering because it has to tap out this water. Water in this zone is under hydrostatic pressure.

$$Q = kiA$$
$$V = ki$$

where, V is discharge velocity not the actual velocity (V_a) through the soil medium.

$$A_v V_a = A \times V$$

where, A_v = cross-sectional area of void

$$V = \frac{A_v}{A} V_a = nV_a; \quad \Rightarrow \quad V_a = \frac{V}{n} = \frac{ki}{n}$$

Intrinsic permeability or Specific permeability, $k_o = \frac{kv}{g} = k\left(\frac{\mu}{\gamma_w}\right)$

Coefficient of transmissibilit (T).

$$T = kd$$

where, d = depth

k = coefficient of permeability

GROUND WATER YIELD

Ground Water Specific Yield

It is the ratio of volume of water obtained by gravity-drainage to the total volume of the sub-soil.

$$\text{Specific yield} = \frac{\text{Volume of water obtained by gravity drainage}}{\text{Total volume of the sub-soil}} \times 100$$

$$\text{Specific retention} = \frac{\text{Volume of water held against gravity drainage}}{\text{Total volume of the material}} \times 100$$

$$\text{Porosity} = \text{Specific yield} + \text{specific retention}$$

Drainage of Ground Water

It means extracting water from below the water lable through well, infiltration galleries, springs, etc.

$$\text{Porosity} = \text{Specifie yield} + \text{Specific retention}$$

Ground Water Velocity

1. Slichter's formula $v = \frac{k'SD_{10}^2}{\mu}$

where, v = velocity of ground water in m/day

k' = constant (approx. 400)

s = slope of hydraulic gradient line

D = effective size of the particle in aquifer (in mm)

μ = dynamic viscosity

2. Hazen's formula $$v = \frac{k''SD_{10}^2}{60}(1.8T + 42)$$

where, k'' = constant (approx. 1000)

T = temperature (in °C)

3. Specific Yield of Well

Recuperating Test $$\frac{C'}{A} = \frac{2.3}{T}\log_{10}\frac{S_1}{S_2}$$

where, S_1 = depression head in the well immediately after the pumping was stopped.

S_2 = depression head in well at time 'T' after the pumping was stopped.

T = time after which S_2 was measured

$\frac{C'}{A}$ = specific yield.

$$\text{Discharge, } Q = \left(\frac{C'}{A}\right)\cdot AS$$

where, A = cross-sectional area of well

$$\textit{Yield of a well}, Q = \frac{\pi\rho k}{2.3}\frac{\left(H^2 - h^2\right)}{\log_{10} R/r}m^3/\text{day}$$

$$= \frac{\pi\rho k \times 1000}{2.3 \times 24 \times 60}\frac{H^2 - h^2}{\log_{10}(R/r)}\text{litres/minute}$$

$$= \frac{k_m\left(H^2 - h^2\right)}{\log_{10}(R/r)}lpm$$

where, $k_m = \frac{\pi p k \times 1000}{2.3 \times 24 \times 60}$ is called *transmission constant* of the acquifer.

This formula is called **Thiem's formula.**

Yield of tubewell when equilibrium conditions have not reached can be determined using following formula :

$$s = \frac{Q}{4\pi\mu}\left[\log e\left(\frac{4T\mu}{r^2A}\right) - 0.5772\right]$$

where, s = draw down in observation well after time T.

r = radial distance of the observation well from the main well.

Q = yield or constant discharge pumped out from the well.

A = coefficient of storage of measured drawdown.

μ = coefficient of transmissibility.

$$s_1 - s_2 = \frac{2.3Q}{4\pi\mu}\log_{10}\left(\frac{T_2}{T_1}\right)$$

AQUIFERS

Types of Aquifers

1. ***Unconfined or Non-artesian Aquifers***

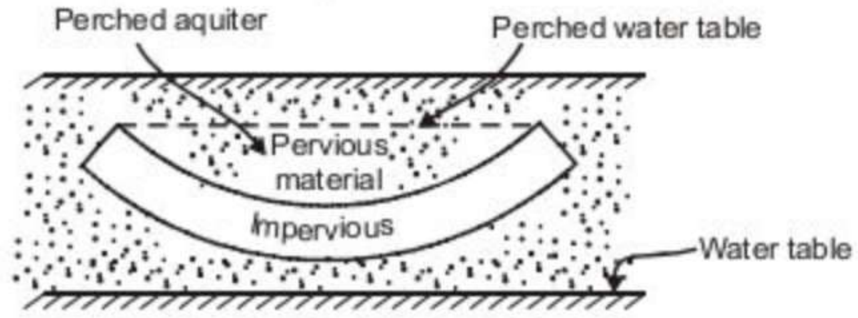
   The top most water bearing stratum having no confined impermeable overburden (*i.e.* aquiclude) lying over it, is called *unconfined aquifer or non-artesian aquifer.*

2. ***Confined or Artesian Aquifer***

   When an aquifer is confined on its upper an under surface, by impervious rock formation (*i.e.* aquiclude), and is also broadly inclined so as to expose the aquifer for somewhere to the catchment area at higher level for the creation of sufficient hydraulic head, it is called *confined aquifer or artesion aquifer.*

Perched aquifer

If within zone of saturation, an impervious diposit below a pervious deposit is found to support a body of saturated material, then this is called perched aquifer. Yield from a perched aquifer is very limited.



AQUIFUSE, AQUITARD AND AQUICLUDE

Aquifuse

It is that geological formation which is, neither porous nor permeable. *e.g.* granite rock

Aquitard

It is that geological formation, which does not yield water to wells due to its lesser permeability. The yield from such a formation is, thus insignificant. *e.g.,* sandy clay.

Aquiclude

It is highly porous, containing large quantities of water, but essentially impervious. *e.g.* clay layer.

Storage coefficient (A)

It is defined as the volume of water that an aquifer release or storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. Storage co-efficient for an artesian aquifer is equal to volume of water released from the aquifer of full height and unit area when piezometric surface declines by unity.

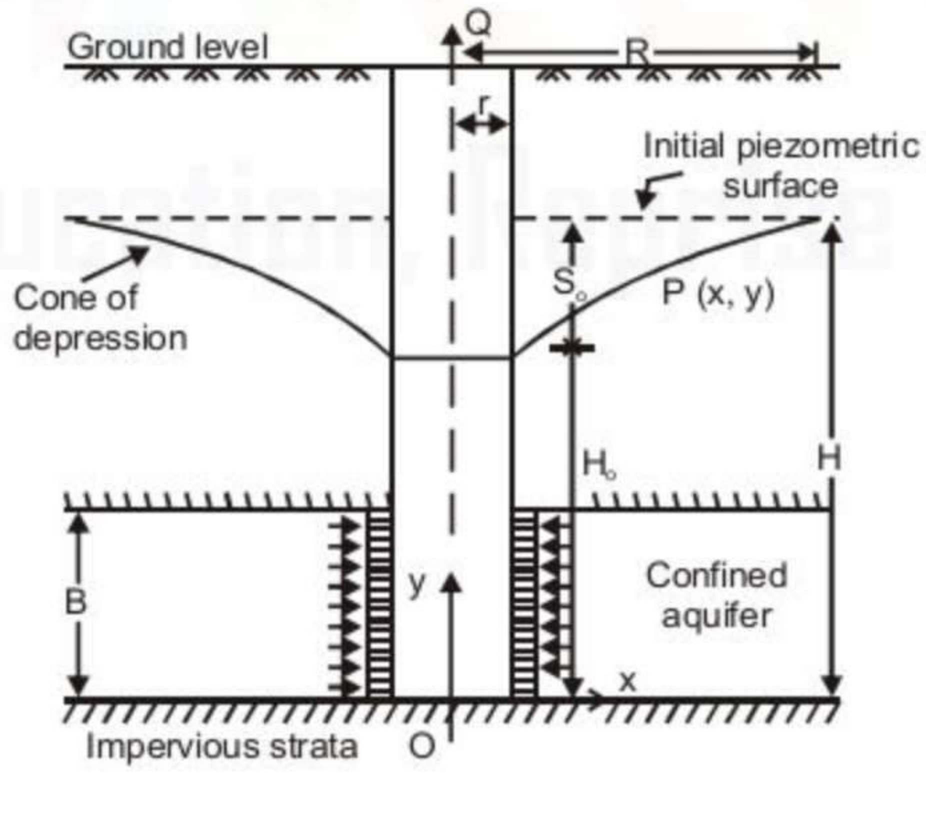
WELL HYDRAULICS

Yield of a well

When water is pumped from a well at high rate, its water level is lowered and hydraulic gradient assumes a slope towards the well. The line of depressed water table is called *inverted cone of depression*. Base of the cone which lies over the original water table is called *circle of influence* and the inclined side of it is called *draw down curve*.

Types of Aquifer

1. Confined (Artesian) Aquifer : Radial flow through (towards) a well.



Assumptions

(*i*) Darcy's law is valid

(*ii*) Soil is homogeneous and isotropic

(*iii*) Well is fully penetrating the aquifer.

$$Q = \frac{2\pi k\left(h_2^2 - h_1^2\right)}{2.303\log_{10}\left(r_2/r_1\right)}$$

where, A_x = cross-sectional area of flow measured at $P = 2\,px$B

B = thickness of confined aquifer

i_x = hydraulic gradient at $P = \dfrac{dy}{dx}$

T = coefficient of transmissibility = kB

k = permebility

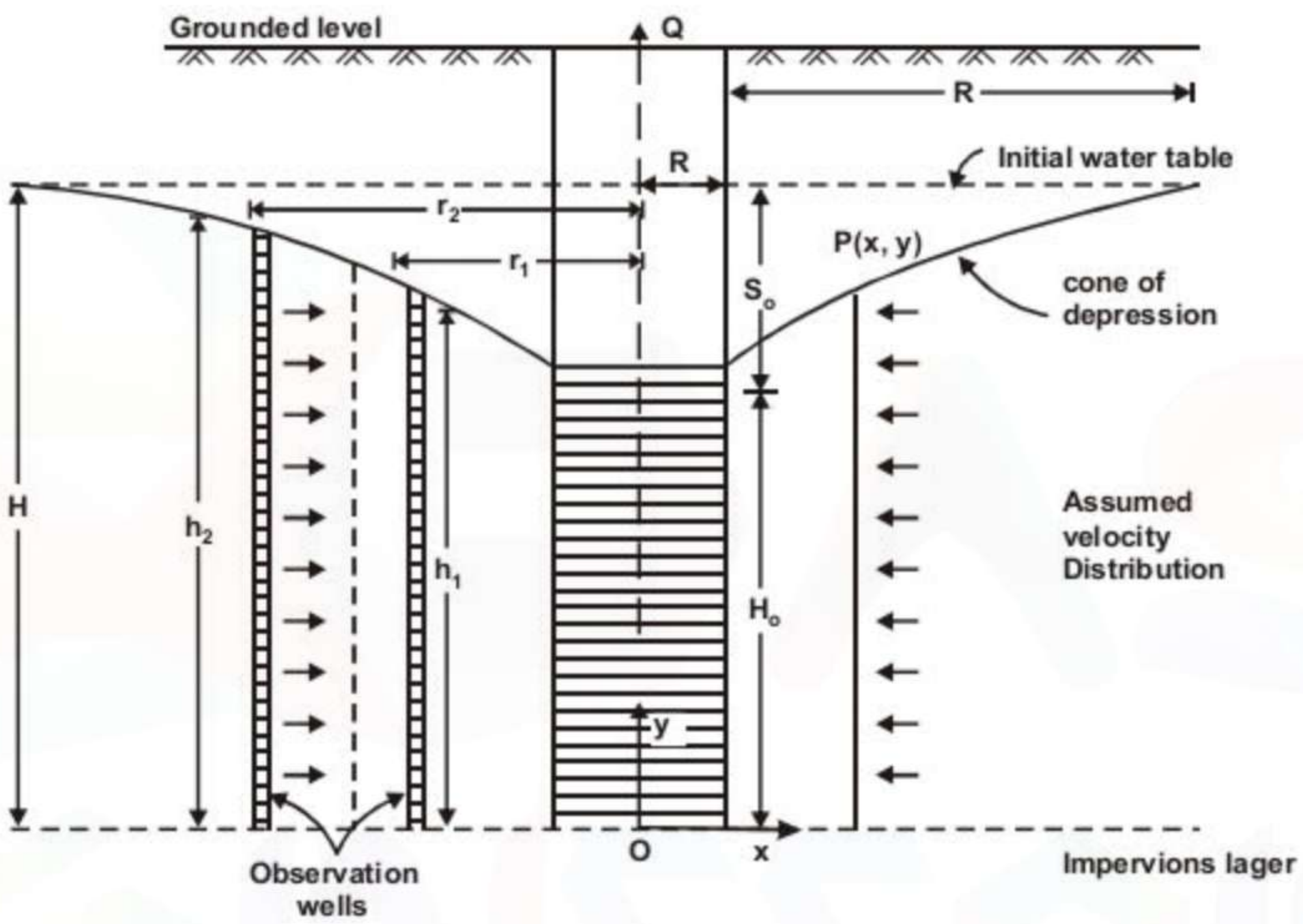
S_o = drawdown at the well surface

R = radius of zero drawdown (influence)

$R = 3000\ S_o \sqrt{k}$ (m/sec.)

R = varies from 100 to 300 m normally.

2. Unconfined Aquifer : Radial flow towards a well.



Dupuit's Assumptions :

(*i*) Flow is horizontal and uniform in vertical cross-section ($A_x = 2\pi xy$)

(*ii*) Velocity of flow is proportional to the tangent of hydraulic gradient. $\left(i_x = \dfrac{dy}{dx}\right)$

(*iii*) Aquifer is homogeneous, isotropic and of infinite aerial extent.

(*iv*) Well is fully penetrating the aquifer.

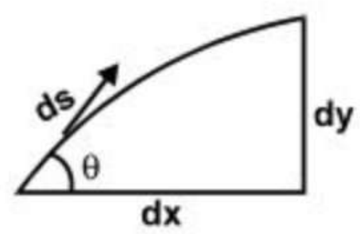
(*v*) Flow is laminar and Darcy's law is valid.

(*vi*) Co-efficient of transmissibility is constant (T = kB) at all places and at all times.

Note : Actual hydraulic gradient = $\dfrac{dy}{ds}$ = sin q and not $\dfrac{dy}{dx}$ = tan q

H.G. = (drop in height/path travelled by water)

Applying Darcy's law at $P\,(x, y)$



$$Q = k\, i_x A_x$$

$$\Rightarrow \quad Q = k\,\frac{dy}{dx}(2\pi xy)$$

$$\Rightarrow \quad Q\int_r^R \frac{dx}{x} = k2\pi\int_{H_o}^{H} y\,dy$$

$$\Rightarrow \quad Q = \frac{\pi k(H^2 - H_0^2)}{\log_e (R/r)} = \frac{1.36k(H^2 - H_0^2)}{\log_{10} (R/r)}$$

Also,

$$Q = \frac{\pi k(h_2^2 - h_1^2)}{\log_e (r_2/r_1)} = \frac{1.36k(h_2^2 - h_1^2)}{\log_{10} (r_2/r_1)}$$

where, r = radius of well

H = thickness of aquifer

S = drawdown at the well

h = depth of water in the well

A_x = cross-sectional area of flow

This formula is called *Thiem's formula*.

Example. Following observations were made on a 30 cm diameter tube well :
Rate of pumping = 1500 litre/minute; Draw down in a test well 30 m away = 1.5 m.
Draw down in another test well 60 m away = 0.6 m; Depth of water in the well before pumping = 40 m.
Determine radius of the circle of influence, and transmission constant of the acquifer.

Solution : While pumping, as the water level in the neighbouring wells gets depressed, they lie on the circle of influence and depressed levels of water in them lie on the drawdown curve.

By formula, $$Q = k_m \left[\frac{h_2^2 - h_1^2}{\log_{10}(R/r)}\right] \text{liters/min}$$

$$\Rightarrow \quad k_m \left[\frac{40^2 - 38.5^2}{\log_{10}(R/30)}\right] = k_m \left[\frac{40^2 - 39.4^2}{\log_{10}(R/60)}\right]$$

Solving for R by trial and error, we get $R \approx 94$ m

Now solving for K_m, $$1500 = k_m \left[\frac{40^2 - 38.5^2}{\log_{10}(94/30)}\right]$$

$$\Rightarrow \quad k_m = \frac{1500 \times \log_{10} 3.133}{(40^2 - 38.5)^2} = \mathbf{6.31}$$

Yield of a Tube well

$$S = \frac{Q}{4\pi\mu}\left(\log_e \frac{4T\mu}{r^2 A} - 0.5772\right)$$

where, μ = coefficient of transmissibility

Q = yield or constant discharge pumped out from the well

r = radial distance of the point of observation well from the main well.

If in the above formula, while doing observations in the observation well at distance r, draw down are respectively S_1 and S_2 at time interval of T_1 and T_2, under after converting to common log,

$$S_2 - S_1 = \frac{2.30}{4\pi\mu} \log_{10} \frac{T_2}{T_1}$$

Consider the acquifer of uniform thickness, following reelation can be derived :

For unconfined aquifer : $$Q = \frac{1.36\, k\left[h_2^2 - h_1^2\right]}{\log_{10}(R/r)}$$

where, r = radius of tube well in metres

R = radius of circle of influence

h_2 = height of static water table above impervious layer in meters

h_1 = height of water table in the tube well in metres after depression

Q = total discharge of the tube well

k = permeability of the soil

For confined aquifer : $$Q = \frac{2\pi.k.m\left[h_2 - h_1\right]}{2.303.\log_{10}\left(\dfrac{R}{r}\right)}$$

where, m = thickness of confined aquifer

Example. A tube well is 0.46 m in diameter. The unconftncd aquifer is 18 m deep. After drawdown depth of water is 12 m in the well. Soil permeability is 24.5 m/day. Radius of circle of influence is 275m. Calculate discharge of the tube well.

Solution : *Given :* k = 24.50; R = 275 m; r = 0.23 m; h_2 = 18 m; h_1 = 12 m.

Discharge of tube well, $Q = \dfrac{\pi k(h_2 - h_1)}{2.303\log_{10}\left(\dfrac{R}{r}\right)} = \dfrac{\pi \times 24.5(18^2 - 12^2)}{2.303\log_{10}\left(\dfrac{2.75}{0.23}\right)}$ = **1954.46 m³/day**

Example. A tube well is driven in a confined aquifer of 24 m thickness. The aquifer is met 25 m below ground level. The static water table is 15 m below ground level. Discharge of tube well is found to be 600 in /day when depression head is 12.23 m Permeability is 24.50 m/day. Radius of circle of influence is 300 m. Compute diameter of the tube well.

Solution : Given : k = 24.50; m = 24m; $(h_2 - h_1)$ = 12.25m; R = 300 m; Q = 600 m^3 day;

From
$$Q = \frac{2\pi\, k\,.m.(h_2 - h_1)}{2.303\log_{10}\left(\dfrac{R}{r}\right)}$$

$$600 = \frac{2\pi \times 24.5 \times 24 \times 12.25}{2.303\log_{10}\left(\dfrac{300}{r}\right)}$$

$$\Rightarrow \quad \log_{10}\left(\frac{300}{r}\right) = \frac{2\pi \times 24.5 \times 24 \times 12.25}{2.303 \times 6000} = 3.275$$

$$\Rightarrow \quad \log_{10} 300 - \log_{10} r = 3.275$$

$$\Rightarrow \quad \log_{10} r = -0.79788 \text{ or } 1,20212$$

$$\Rightarrow \quad r = 0.16 \text{ m.}$$

Therefore diameter of tubel well is 0.32 metre.

Example. A tube well 0.6 in in diameter is driven in a sub-soil. Formation of the sub soil layers is as shown in the figure. The strainer is provided only for an aquifer of maximum depth. Permeability of soil is 24.50 m/day. Radius of circle of influence is 300 m. Drawdown in the well is 10m. Calculate discharge of the tube well.

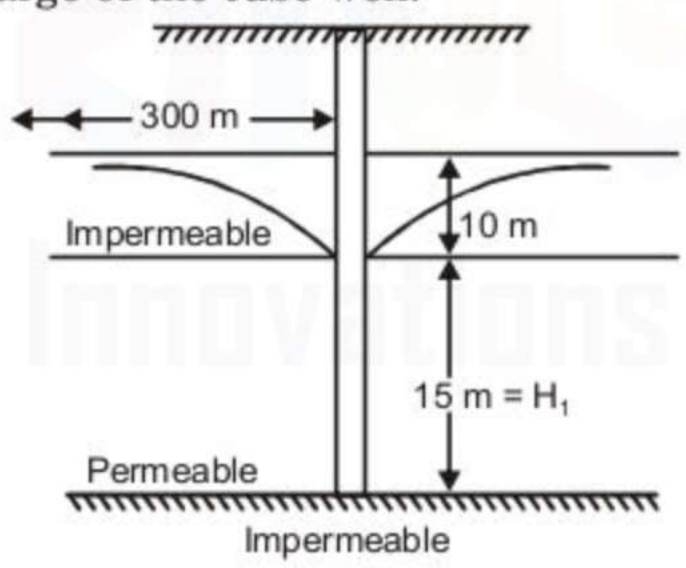
Solution : *Given :* k = 24.50 m/day; $(h_2 - h_1)$ = 10 m

m = 15m; R = 300 m; r = 0.30m

$\therefore$ Discharge of the tube well, $Q = \dfrac{2\pi k.m.(H_1 - H_2)}{2.303\log_{10}\left(\dfrac{R}{r}\right)}$

$$= \frac{2\pi \times 24.5 \times 15 \times 10}{2.303 \times \log_{10}\left(\dfrac{300}{0.30}\right)}$$

$$= 3342 \text{ m}^3\text{/day.}$$



EXERCISE – I

MCQ TYPE QUESTIONS

1. If mean daily flow at a gauging station for a period of 7 days are 7, 27, 58, 41, 31, 20 and 13 m³/s respectively, then total volume of stream flow at the site in ha-m will be

(*a*) 1505.2 ha-m (*b*) 1662.4 ha-m

(*c*) 1702.08 ha-m (*d*) 1805.02 ha-m

2. What volume is represented by 57 mm of run-off depth from a basin of area 3300 km² in cumec-days?

(*a*) 2177.08 (*b*) 2275.09

(*c*) 2378.5 (*d*) 2425.5

3. A drainage basin has an area of 210 km². Average depth of rainfall received by it during a monsoon period is computed as 65 cm, while run-off measured at its outlet during the same period is estimated to be 5.68×10^7 m³. What percentage of rainfall has become runoff ?

(*a*) 50.5% (*b*) 41.62%

(*c*) 61.42% (*d*) 38%

4. What is the evaporation, if 4.75 litre of water is removed from an evaporation pan of diameter 1.22m and simultaneous rainfall measurement is 8.8 mm ?

(*a*) 8.64 mm (*b*) 7.24 mm

(*c*) 5.34 mm (*d*) 4.74 mm

5. If pan evaporation is denoted by E_p and actual evaporation by E, then

(*a*) $E_p > E$ (*b*) $E > E_p$

(*c*) $E = E_p$ (*d*) $E \lessgtr E_p$

6. Average daily evaporation loss from a reservior with an average water spread area of 15 km² in a month having lake evaporation of 20 cm, will be

(*a*) 20×10^4 m³

(*b*) 30×10^4 m³

(*c*) 10×10^4 m³

(*d*) 15×10^4 m³

7. In India, which of the following is adopted as standard recording raingauge ?

(*a*) Symon's raingauge

(*b*) Tipping bucket type

(*c*) Natural syphon type

(*d*) Weighing bucket type

8. Maximum average depth due to one day storm over an area of 100 km² is 10 cm. Depth-Area-Duration (DAD) curves indicate that for the same area of 100 km², maximum average depth for a 3 hour storm will be

(*a*) 10 cm (*b*) more than 10 cm

(*c*) less than 10 cm (*d*) none of these

9. If intensity of rainfall is more than the infiltration capacity of soil, then infiltration rate will be

(*a*) equal to the rate of rainfall

(*b*) equal to infiltration capacity

(*c*) more than rate of rainfall

(*d*) more than infiltration capacity

10. ϕ is defined as

(*a*) difference between maximum and minimum infilteration capacities.

(*b*) difference between total rainfall and the total runoff divided by duration of the storm

(*c*) rainfall intensity above which the rainfall volume equals the observed runoff volume

(*d*) minimum infilteration rate during the storm

11. A 6 hr storm of uniform intensity and a total rainfall of 8 cm produced a runoff of 5 cm. What is the runoff produced by a 12 hr storm of uniform intensity and a total rainfall of 11 cm assuming ϕ index to be same during both the storms ?

(*a*) 5 cm (*b*) 8 cm

(*c*) 11 cm (*d*) 9 cm

12. Under identical conditions if infilteration capacity measured by double ring infilterometer is f_d and that measured by a rainfall simulator is f_s, then

(*a*) $f_s < f_d$ (*b*) $f_s > f_d$

(*c*) $f_s = f_d$ (*d*) difficult to tell

13. A well of 0.5 m diameter penetrates fully into a confined aquifer of thickness 20 m and hydraulic conductivity 8.2×10^{-4} m/s. What is the maximum yield expected from this well if drawdown in the well is not to exceed 3 m? Radius of influence may be taken as 260 m

(*a*) 50.5 lit/sec (*b*) 48.43 lit/s

(*c*) 60.23 lit/s (*d*) 65.5 lit/sec.

14. What should be the diameter of an open well to give a safe yield of 4.8 lit/s ? Assume working head as 3.75 m and subsoil consists of fine sand of C = 0.5 h⁻¹

(*a*) 2.5 m (*b*) 1.4 m

(*c*) 3.4 m (*d*) 4.6 m

15. If a tangent drawn parallel to the demand line from a ridge point of a flow mass curve does not intersect the mass curve again, it represents that

(*a*) runoff inflow into the reservoir cannot meet the demand as reservoir will not be full again

(*b*) reservoir is overflowing resulting in wastage

(*c*) there is enough stream flow to meet a higher demand rate

(*d*) none of these

16. If peak discharges in 4 and 8 hr unit hydrographs of a basin occurs at t_1 and t_2, then

(*a*) $t_1 = t_2$ (*b*) $t_1 > t_2$

(*c*) $t_1 < t_2$ (*d*) difficult to guess

17. The direct runoff hydrograph was found to have a peak ordinate at 20 h after commencement of the effective rainfall and a base period of 100 h. The duration of the storm was

(*a*) less than 20 h (*b*) between 20 and 100 h

(*c*) more than 100 h (*d*) 100 h

18. The statement "ordinate of the direct run-off hydrographs of a common base period are directly proportional to the volumes of runoff represented by the respective hydrograph" is

(*a*) principle of linearity

(*b*) principle of time invariance

(*c*) principle of uniformity

(*d*) none of these

19. Muskingham method of flood routing assumes that storage is related to inflow rate I and outflow rate Q of reach as S is equal to

(*a*) $k\,[x\mathrm{I} - (1-x)\,\mathrm{Q}]$ (*b*) $k\,[x\mathrm{I} + (1-x)\,\mathrm{Q}]$

(*c*) $k\,[(1-x)\,\mathrm{I} + x\mathrm{Q}]$ (*d*) $k\,[(1+x)\,\mathrm{Q} + x\mathrm{I}]$

20. In Gambel's distribution, relation between the reduced variate y and return period T_r is given by

(*a*) $e^{-e^{-y}} = 1 - \dfrac{1}{\mathrm{T}_r}$ (*b*) $e^{-e^{-y}} = \dfrac{1}{\mathrm{T}_r}$

(*c*) $e^{-e^{-y}} = 1 + \dfrac{1}{\mathrm{T}_r}$ (*d*) $e^{-e^{-y}} = \dfrac{1}{\mathrm{T}_r} - 1$

21. If maximum rainfall depth of 300 mm in 24 hours has a return period of 100 years, then probability of 24 hours rainfall equal to or greater than 300 mm occuring at least once in 10 years is given by

(*a*) $(0.99)^{10}$ (*b*) $1-(0.99)^{10}$

(*c*) $(0.9)^{100}$ (*d*) $1-(0.9)^{100}$

22. If risk of a flood occuring in the next 10 years is accepted to 10%, then return period for design should be

(*a*) $1+(0.9)^{0.10}$ (*b*) $1-(0.9)^{0.10}$

(*c*) $\dfrac{1}{(1-0.9)^{0.10}}$ (*d*) $\dfrac{1}{(1+0.9)^{0.10}}$

23. If in a mass curve, a demand line drawn tangent to lowest point in a valley of the curve doese not intersect the mass curve at an earlier time period, it represents that

(*a*) storage is inadequate

(*b*) reservoir will not be full at the start of dry period

(*c*) reservoir is full at the beginning of dry period

(*d*) reservoir is wasting water by spill.

24. Total rainfall in a catchment area of 1200 km^2 during a 6 hour storm is 16 cm while surface run off due to the storm is 1.2×10^8 m^3. The ϕ index is

(*a*) 0.1 cm/h

(*b*) 1.0 cm/h

(*c*) 0.2 cm/h

(*d*) cannot be estimated with given data

25. In India meterological sub-division is considered to be affected by moderate drought if it receives a total seasonal rainfall which is

(*a*) less than 25% of normal value

(*b*) between 25% to 49% of normal value

(*c*) between 50% to 74% of normal value

(*d*) between 75% to 99% of normal value

26. A direct run-off hydrograph due to storm was found to be triangular in shape with a peak of 150 m^3/s time from start of effective storm to peak of 24 h and a total time base of 72 h. Duration of the storm in this case was

(*a*) < 24 hour

(*b*) between 24 to 72 hours

(*c*) 72 hours

(*d*) > 72 hours

27. Ordinate of instantaneous unit Hydrograph of a catchment at any time t is

(*a*) difference in the slope of S curve and 1 hour unit hydrograph

(*b*) slope of S curve of intensity 1 cm/h

(*c*) slope of ERH at that time

(*d*) slope of 1 hour unit hydrograph at that time

28. The peak of flood hydrograph due to 3 hour duration isolated storm in a catchment area is 270 m^3/s. Total depth of rainfall 6.0 cm. Assuming an average infiltration loss of 0.3 cm/h and a constant base flow of 20 m^3/s, which of the following will be the peak of 3h unit hydrogroup of the given catchment?

(*a*) 60 m^3/s (*b*) 75 m^3/s

(*c*) 50 m^3/s (*d*) 30 m^3/s

29. If area of catchment is 567 km^2, then what will be the base width of 3h unit hydrograph, assuming it to be of triangular shape ?

(*a*) 78 hrs (*b*) 63 hrs

(*c*) 82 hrs (*d*) 58 hrs

30. If a 4-h unit hydrograph of a catchment has a peak ordinate 60 m^3/s, then peak ordinate of an 8 hour unit hydrograph for the same catchment will be

(*a*) 60 m^3/s (*b*) 60 m^3/s

(*c*) < 60 m^3/s (*d*) data inadequate

31. When a 2 hour unit hydrograph is available, other unit hydrograph of following duration may be easily prepared except

(*a*) 4 hours (*b*) 5 hours

(*c*) 1 hours (*d*) 8 hours

32. In order to prepare 2 hour unit hydrograph from a 6 hour unit hydrograph which of the following method will be applied ?

(*a*) Synthetic unit hydrograph

(*b*) S-curved method

(*c*) Instantaneous unit hydrograph

(*d*) Simple unit hydrograph

33. Which of the following is a non-recording rain gauge ?

(*a*) Tipping bucket type rain gauge

(*b*) Simon's rain gauge

(*c*) Steven's weighing type rain gauge

(*d*) Floating type rain gauge

34. If allowable percentage error in the estimate of basic rainfall is E and co-efficient of variation of rainfall is C_v, then optimum number of raingauges is given by

(*a*) $\frac{C_V}{E}$ (*b*) $\sqrt{\frac{C_V}{E}}$

(*c*) $\left(\frac{C_v}{E}\right)^2$ (*d*) $\left(\frac{C_V}{E}\right)^{3/2}$

35. S-hydrograph is used to obtain unit hydro-graph of

(*a*) shorter duration from longer duration

(*b*) longer duration from shorter duration

(*c*) both (*a*) and (*b*)

(*d*) none of these

36. If two 4 hour unit hydrographs are stagered by 4 hours and added graphically, then resulting hydrograph will be

(*a*) 4-hour unit hydrograph

(*b*) 4-hour hydrograph with 20 mm run-off

(*c*) 8-hour unit hydrograph

(*d*) 8-hour hydrograph with 20 mm run-off

37. Under same conditions, which of the following shapes of water surface will give highest rate of evaporations ?

(*a*) Flat water surface

(*b*) Convex water surface

(*c*) Concave water surface

(*d*) Independent of shape of water surface

38. Prism storage in a river reach during the passage of a flood wave is a function of

(*a*) inflow (*b*) outflow

(*c*) constant (*d*) both (*a*) and (*b*)

39. Wedge storage in a river reach during passage of a flood wave in the rising phase is

(*a*) positive (*b*) negative

(*c*) constant (*d*) not necessary

40. Muskingham method of flood - routing is a

(*a*) hydraulic channel - routing method

(*b*) hydrologic channel - rounting method

(*c*) hydrologic reservoir - routing method

(*d*) none of these

41. Which source of water among the following is not a surface source ?

(*a*) Rivers (*b*) Wells

(*c*) Lakes (*d*) Oceans

42. A dam reservoir, not provided with gate controls on its spillway and other sluices, is called

(*a*) retention basin

(*b*) barrage

(*c*) retarding basin

(*d*) weir

43. A dam reservoir, catering to flood control, irrigation, and water supply, although basically designed for irrigation alone, is

(*a*) multipurpose reservoir

(*b*) single purpose reservoir

(*c*) distribution reservoir

(*d*) none of these

44. A hydel power project has been envisaged to serve the water supply and irrigation needs of the area at its inception stage. The dam reservoir, so constructed, will be called

(*a*) a multipurpose reservoir

(*b*) a single purpose reservoir

(*c*) both (*a*) and (*b*)

(*d*) none of these

45. '*Surcharge storage*' in a dam reservoir is volume of water stored between
(*a*) minimum and maximum reservoir levels
(*b*) minimum and normal reservoir levels
(*c*) normal and maximum reservoir levels
(*d*) none of these

46. '*Useful storage*' in a dam reservoir is volume of water stored between
(*a*) minimum and maximum reservoir levels
(*b*) minimum and normal reservoir levels
(*c*) normal and maximum reservoir levels
(*d*) none of these

47. '*Dead storage*' in a dam reservoir is available volume for collection of silt and sediment between
(*a*) bed level of the reservoir and minimum reservoir level
(*b*) bed level of the reservoir and maximum conservation level in the reservoir
(*c*) bed level of the reservoir and normal reservoir level
(*d*) none of these

48. '*Bank storage*' in a dam reservoir
(*a*) increases computed reservoir capacity
(*b*) decreases computed reservoir capacity
(*c*) sometimes increases and sometimes decreases computed reservoir capacity
(*d*) has no effect on the computed reservoir capacity.

49. Water stored in a reservoir below the minimum pool level is called
(*a*) valley storage
(*b*) bank storage
(*c*) surcharge storage
(*d*) dead storage

50. For a flood control reservoir, effective storage is equal to
(*a*) useful storage + valley storage
(*b*) useful storage + surcharge storage – valley storage
(*c*) useful storage + surcharge storage + valley storage
(*d*) useful storage – valley storage

51. Yield of a given reservoir is dependent upon
(*a*) catchment yield
(*b*) reservoir evaporation
(*c*) reservoir leakage
(*d*) all of these

52. Capacity of a storage reservoir can be decided by using
(*a*) mass curve of inflow
(*b*) mass curve of outflow
(*c*) both (*a*) and (*b*)
(*d*) none of these

53. Design yield (outflow demand) of a proposed storage reservoir is usually equal to
(*a*) safe yield of its constant
(*b*) safe yield of its catchment minus the reservoir losses
(*c*) dependable yield of its catchment
(*d*) dependable yield of its catchment minus the reservoir losses.

54. The amount of water stored in a river channel without any artificial storage is called
(*a*) bank storage (*b*) river storage
(*c*) valley storage (*d*) dead storage

55. With reduction in the reservoir capacity over passage of time, trap efficiency
(*a*) increases
(*b*) remains unaffected
(*c*) decreases
(*d*) may increase or decrease, depending upon reservoir characteristics

56. Trap efficiency of a storage reservoir is defined as
(*a*) $\dfrac{\text{Total annual sediment inflow}}{\text{Reservoir capacity}}$
(*b*) $\dfrac{\text{Total sediment deposited in a given period}}{\text{Total sediment inflow in that period}}$
(*c*) $\dfrac{\text{Total annual sediment deposited in the reservoir}}{\text{Dead storage capacity of the reservoir}}$
(*d*) None of these

57. Capacity-inflow ratio for a storage reservoir is defined as
(*a*) $\dfrac{\text{reservoir capacity}}{\text{average annual flood inflow}}$
(*b*) $\dfrac{\text{reservoir capacity}}{\text{average annual sediment inflow}}$
(*c*) $\dfrac{\text{dead storage capacity of the reservoir}}{\text{average annual sediment deposited}}$
(*d*) none of these

58. With the increase in its capacity-inflow ratio, trap efficiency of a reservoir
(*a*) increases
(*b*) remains unchanged
(*c*) decreases
(*d*) may increase or decrease depending on the reservoir characteristics.

59. Capacity-inflow ratio for a reservoir
(*a*) is a constant factor overtime
(*b*) increases with time
(*c*) decreases with time
(*d*) may increases or decrease with time

60. Dead storage zone in a reservoir is provided for the storage of
(*a*) water for firm power
(*b*) sand and silt
(*c*) water for water supplies
(*d*) none of these

61. Trap efficiency of a storage reservoir indicates sediment volume
(*a*) trapped in the reservoir
(*b*) let out from the reservoir
(*c*) trapped in relation to the sediment volume entering the reservoir
(*d*) none of these

62. Percentage of total sediment flow depositing in the reservoir, is called its
(*a*) capacity-inflow ratio
(*b*) sediment co-efficient
(*c*) trap efficiency
(*d*) displacement efficiency

63. With reduction in the reservoir capacity, quantum of the sediment trapped by it
(*a*) increases (*b*) decreases
(*c*) remains same (*d*) does not get affected

64. As height of a proposed dam is increased, cost per unit of storage
(*a*) increases
(*b*) decreases
(*c*) initially increases and then decreases
(*d*) initially decreases and then increases

65. "*Economical height of a dam*" is that height, for which
(*a*) cost per unit of storage is minimum
(*b*) benefit cost ratio is maximum
(*c*) net benefits are maximum
(*d*) none of these

66. Appropriate value of the estimated average life of a dam reservoir is
(*a*) 10 years (*b*) 25 years
(*c*) 75 years (*d*) none of these

67. Evaporation losses from surface of a reservoir can be reduced by sprinkling
(*a*) DDT
(*b*) acetylalcohol
(*c*) potassium permanganate
(*d*) none of these

68. For unconfined aquifers, storage co-efficient is same as
(*a*) porosity
(*b*) specific retention
(*c*) specific yield
(*d*) none of these

69. For a free flowing well, piezometric surface is
(*a*) above the G.L. (*b*) below the G.L.
(*c*) at the G.L. (*d*) none of these

70. Safe yield of an aquifer is the rate at which ground water can be withdrawn without causing
(*a*) sand entering the well
(*b*) overload of the pumping machine
(*c*) long-term decline of the piezometric surface
(*d*) all of these

71. An acquifer is
(*a*) permeable geological stratum in which there is a storage of ground water
(*b*) geological stratum which does not have underground water upto 100 feet
(*c*) both (*a*) and (*b*)
(*d*) none of these

72. Specific yield of an acquifer is
(*a*) proportional to soil porosity
(*b*) volume of the water which drains freely
(*c*) depends on soil conditions
(*d*) none of these

73. A geological formation which can absorb water but cannot transmit signficant amount is called
(*a*) acquifer (*b*) acquiclude
(*c*) sand hole (*d*) none of these

74. An acquifer, confined at the bottom but open at top, is called
(*a*) acquiclude
(*b*) unconfined acquifer
(*c*) semiconfined acquifer
(*d*) none of these

75. An artesian acquifer is one where

(*a*) water surface under the ground is at atmospheric pressure

(*b*) water table serves as upper surface of zone of saturation

(*c*) water is under pressure between two impervious strata

(*d*) none of these

76. Specific capacity of a well

(*a*) decreases with diameter

(*b*) decreases with time from the start of pumping

(*c*) increases with discharge rate

(*d*) none of these

77. Dimensions of storage coefficient are

(*a*) $M^0 L^0 T^0$ (*b*) $M^0 L T^{-2}$

(*c*) $M^0 L^{-1} T$ (*d*) $M^0 L T$

78. A deep well

(*a*) is always deeper than a shallow well

(*b*) is weaker structurally than a shallow well

(*c*) has more discharge than a shallow well

(*d*) all of these

79. A shallow well is

(*a*) always deeper than a deep well

(*b*) always shallower than a deep well

(*c*) can be deeper than a deep well

(*d*) none of these

80. Discharge per unit of drawdown of a well is called its

(*a*) specific capacity (*b*) efficiency

(*c*) well loss (*d*) yield

81. In wells, specific capacity

(*a*) increases with time from the start of pumping

(*b*) decreases with time from the start of pumping

(*c*) is always constant

(*d*) none of these

82. Energy is necessarily required in the utilisation of

(*a*) ground water (*b*) lake water

(*c*) reservoir water (*d*) none of these

83. In an underground profile, zone of aeration does not include

(*a*) soil water

(*b*) capillary water

(*c*) ground water

(*d*) none of these

84. Ground water is found to occur in the geological formation, which is

(*a*) porous (*b*) permeable

(*c*) both (*a*) and (*b*) (*d*) none of these

85. Property of a geological formation, which represents its water storage capacity, is

(*a*) permeability (*b*) porosity

(*c*) both (*a*) and (*b*) (*d*) none of these

86. Zone of aeration in a ground profile consists of

(*a*) capillary fringe (*b*) soil water zone

(*c*) intermediate zone (*d*) all of these

87. Zone of aeration in a ground profile does not include

(*a*) capillary zone (*b*) soil water zone

(*c*) intermediate zone (*d*) saturation zone

88. Relation between transmissibility (T) and permeability (K) for an aquifer of depth d, is

(*a*) K = Td (*b*) T = K.d

(*c*) T = K log d (*d*) T = ln (Kd)

89. Geological formation, which yields only insingnificant quantity of ground water, is

(*a*) aquifer (*b*) aquifuse

(*c*) aquiclude (*d*) aquitard

90. Zeological formation which may contain water, but does yield any, is

(*a*) aquifer (*b*) aquifuse

(*c*) aquiclude (*d*) aquitard

91. Geological formation, which contains and readily yields water to our tubewells, is

(*a*) aquifuse (*b*) aquitard

(*c*) aquiclude (*d*) aquifer

92. Field capacity of a ground aquifer is equal to the

(*a*) specific yield (*b*) 100 — specific yield

(*c*) $\dfrac{100}{\text{specific yield}}$ (*d*) none of these

93. Water wells excavated through unconfined aquifers are called

(*a*) gravity wells (*b*) watertable wells

(*c*) non-artesian wells (*d*) all of these

94. Water wells excavated through confined aquifers are called

(*a*) artesian wells

(*b*) pressure wells

(*c*) both (*a*) and (*b*)

(*d*) none of these

95. In case of a flowing well, piezometric surface is always

(*a*) below the ground level

(*b*) above the ground level

(*c*) at the ground level

(*d*) none of these

96. Line joining static water levels in several wells, excavated wells, excavated through a confined aquifer, is called

(*a*) cone of depression (*b*) piezometric surface

(*c*) perched watertable (*d*) hypsometric curve

97. If piezpmetric surface along an unconfined aquifer declines to a level below the top of the aquifer, then aquifer at this point is called

(*a*) perched aquifer (*b*) leaky aquifer

(*c*) flowing aquifer (*d*) unconfined aquifer

98. Permeability of an aquifer (m/day) will

(*a*) increase with increase in temperature of water flowing through the aquifer

(*b*) decrease with increase in temperature of water flowing through the aquifer

(*c*) not get effected by change in the temperature of water flowing through the aquifer

(*d*) increase upto 20°C and then decrease, with increase in the temperature of water flowing through the aquifer.

99. Component of permeability of a porous medium, which is usually expressed in units of darcy or m^2, is called

(*a*) specific permeability

(*b*) intrinsic permeability

(*c*) both (*a*) and (*b*)

(*d*) none of these

100. Discharge per unit drawdown of a well is called

(*a*) specific yield (*b*) specific retention

(*c*) specific capacity (*d*) specific storage

101. Storage coefficient (A) divided by aquifer depth (d) is called

(*a*) specific storage

(*b*) specific capacity per unit depth of aquifer

(*c*) specific yield

(*d*) specific retention

102. Coefficient of storage (A) has the dimensions of

(*a*) L^3

(*b*) L^2

(*c*) L

(*d*) dimensionless

103. Units of specific capacity of a well are

(*a*) m^3/sec (*b*) m^2/sec

(*c*) m/sec (*d*) no units

104. Specific capacity of a well is

(*a*) constant over time after commissioning of the well

(*b*) increases with time after start of pumping

(*c*) decreases with time after start of pumping

(*d*) may increase or decrease, depending upon a particular aquifer

105. Standard specific capacity of a well is the well discharge per unit of drawdown. This value of discharge should be obtained at

(*a*) any drawdown

(*b*) a particular drawdown of 3 m

(*c*) first 1 m of drawdown

(*d*) none of these

106. Performance of a well is measured by its

(*a*) specific capacity (*b*) specific yield

(*c*) storage co-efficient (*d*) all of these

107. Water level in confined well

(*a*) increases with increase in the atmospheric pressure

(*b*) decreases with increase in the atmospheric pressure

(*c*) does not undergo any change with change in the atmospheric pressure

(*d*) all of these

108. Water in an unconfined well

(*a*) increases with increase in the atmosheric pressure

(*b*) decreases with increase in the atmospheric pressure

(*c*) does not undergo any change with change in the atmospheric pressure

(*d*) all of these

109. *Specific yield* for an unconfined aquifer is

(*a*) greater than porosity

(*b*) less than porosity

(*c*) equal to porosity

(*d*) unrelated to porosity

110. A perched aquifer is essentially found within

(*a*) an unconfined aquifer

(*b*) a confined aquifer

(*c*) an aquiclude

(*d*) none of these

111. Most widely used type of a deep state tubewell in India is
(*a*) cavity tubewell
(*b*) strainer tubewell
(*c*) slotted pipe-gravel packed tubewell
(*d*) none of these

112. Average yield from standard tubewells is of the order of
(*a*) 5 L/s (*b*) 50 L/s
(*c*) 500 L/s (*d*) 5000 L/s

113. Types of pumps used in tubewells are
(*a*) submergible pumps
(*b*) jet pumps
(*c*) turbine pumps
(*d*) all of these

NUMERICAL TYPE QUESTIONS

1. A basin area is served by four rain gauges with Theissen weights of 0.1, 0.4, 0.4 and 0.1 respectively. If rainfall recorded at these stations is 4, 2, 2 and 4 cm respectively, then average depth of rainfall over the basin will be _____cm

2. Theissen weights of 4 raingauges A, B, C and D covering a river basin are 0.15, 0.25, 0.30 and 0.30 respectively. If average depth of rainfall for the basin is 5 cm and rainfalls recorded at B, C and D are 5 cm, 4 cm and 5 cm respectively, then rainfall at A will be _____cm

3. Rainguage station X did not function for a part of a month during which a storm occured. The storm produced rainfalls of 84, 70, and 76 mm at three surrounding stations A, B, and C respectively. If normal annual rainfalls at the stations X, A, B and C are respectively 770, 882, 736 and 944 mm, then missing storm rainfall at station X will be _____mm

4. In a water-shed, four raingauges I, II, III and IV are installed. The depths of normal annual rainfall at these stations are 60, 75, 80 and 100 cm respectively. The raingauges at station III went out of order during a particular year. The annual rainfall for that year recorded at the remaining three stations was 90, 60 and 70 cm. The rainfall at station III can be considered as _____m

5. Average annual rainfalls in cm at 4 existing raingauges stations in a basin are 105, 79, 70 and 66. If average depth of rainfall over the basin is to be estimated within 10% error, then additional number of gauges needed will be _____

6. If run-off from a drainage basin of area 4320 km^2 is estimated as 10,000 cumec-days, then depth of runoff will be _____cm

7. During a daily routine observation, 10.8 litre of water is added to bring the water surface in the evaporation pan to the stipulated level and nearby raingauge measured 3.6 mm of rainfall. The evaporation recorded for the day if diameter of the pan is 122 cm is _____mm

8. If wind velocity at a height of 2m above the ground is 15 km/h, then velocity at a height of 10 m above the ground will be _____km/h

9. If co-efficient of variation of rainfall values at 4 raingauge stations is 30% and permissible error in the estimation of mean rainfall is 10%, then additional number of raingauge stations required in the catchment is _____

10. The rainfall in four successive 12 hours period on catchment are 4, 8, 9 and 3 cm. If infilteration index ϕ for the storm is 0.5 cm/hour, then total surface runoff will be _____cm

11. Total observed run-off volume during a 6 hr storm with a uniform intensity of 1.5 cm/h is 21.6×10^6 m^3. If area of the basin is 300 km^2, then average infilteration rate for the basin will be _____mm/h

12. A 6 hr storm produced rainfall intensities of 7, 18, 25, 12, 10 and 3 mm/h in successive one hour intervals over a basin of 800 km^2. If resulting runoff is observed to be 2640 hect-metre, then ϕ-index for the basin will be _____mm/h

13. A 6 hr storm with a uniform intensity of 1.5 cm/h produced a runoff depth of 72 mm. The average infilteration rate during this storm is _____mm/h

14. An undisturbed rock sample has an oven dry weight of 0.655 kg. After saturation with kerosene its weight is 0.732 kg. It is then immersed in kerosene and found to displace 0.301 kg. Porosity of the sample will be _____%

15. When 3.68 million m^3 of water was pumped out from an unconfined aquifer of 6.2 km^2 arial extent, the water table was observed to go down by 2.6 m. The specific yield of the aquifer will be _____%

16. The water table levels in two observation wells 350 m apart are + 210.5 m and 206.25 m respectively. If hydraulic conductivity and porosity of the aquifer are 12.5 m/day and 15 percent, then actual velocity of flow in the aquifer will be _____m/day

17. An unconfined aquifer has a thickness of 30 m. A fully penetrating 20 cm diameter well in this aquifer is pumped at a rate of 35 lit/s. If drawdown measured in two observation wells located at distances of 10 m and 100 m from the wells are 7.5 m and 0.5 m respectively, then average hydraulic conductivity of the aquifer will be _____m/day

18. A well with a radius of 0.5 m, completely penetrates an unconfined aquifer of thickness 50 m and k = 30 m/day. The well is pumped so that water level in the well remains at 40 m above the bottom. Assuming that pumping has essentially no effect on water table at r = 500 m, the steady-state discharge will be _____lit/s

19. In an artesian aquifer of 8 m thick, a 10 cm diameter well is pumped at a constant rate of 100 lit/minute. If steady state drawdown observed in two wells located at 10 m and 50 m distances from the centre of the well are 3 m and 0.05 m respectively, then transmissibility of the aquifer will be _____m^2/day

20. During a recuperation test conducted on an open well in a region, water level in the well was depressed by 3 m and it was observed to size by 2.75 m in 75 minutes. The yield from a well of 5 m diameter under a depression head of 2.5 m will be _____m^3/h

21. If observed annual runoff from a basin of area 500 km^2 is 150 M m^3 and corresponding annual rainfall over the basin during the same year in 750 mm, then runoff co-efficient will be _____

22. A storm occuring over a basin for a period of 6 h with uniform intensity produced an effective rainfall of 15 cm and peak flow of 930 m^3/s. Over the same basin, if another storm of same duration but with an effective rainfall of 7.5 cm occurs, then corresponding peak flow will be _____m^3/s

23. If 4 hr unit hydrograph of a basin can be approximated as a triangle with a base period 48 h and a peak ordinate of 200 m^3/s, then area of basin is _____km^2

24. Direct runoff hydrograph of a basin can be approximated as a triangle with a base period of 80 h and a peak flow of 200 m^3/s occuring at 16th hour. If area of the basin is 1440 km^2, then depth of runoff indicated by the hydrographwill be _____cm

25. 12 hr unit hydrograph of a basin of area 4320 km^2 can be approximated as a triangle with base period of 5 days. The peak flow in the direct run-off hydrograph of this basin produced by an effective rainfall of 5 cm in 12 h will be _____m^3/s

26. If S-curve hydrograph is desired for a basin of 540 km^2 from a 6 h unit hydrograph, then equilibrium discharge in the S-curve is _____m^3/s

27. In the channel routing by Muskingum method, value of the routing co-efficients C_0 and C_1 are estimated as –0.2 and 0.5 respectively. The value of third co-efficient C_2 would be _____

28. A mean annual run-off (1 m^3/s) from a catchment area of 31.54 km^2 represents an effective rainfall of _____cm

29. A basin area is served by four rain gauges with Thiessen weight of 0.1, 0.4, 0.4 and 0.1 respectively. If rainfall recorded at these stations are 4, 2, 2 and 4 cm respectively, then average depth of rainfall over the basin will be _____cm

30. Recorded number of 3 cm/hr storm in three difference rain gauge stations were 3, 1 and for period of record which were 25, 30 and 35 years respectively, using station year method, the recurrence interval of the storm at any given point in the area is _____years

31. Normal annual precipitation at stations X, A, B and C are 700 mm, 1000mm, 900 mm and 800 mm respectively. If storm precipitation at three station A, B and C were 100 mm, 90 mm and 80 mm respectively, then storm precipitation for station X will be _____mm

32. Rainfall on five successive days were measured as 100 mm, 80 mm, 60 mm, 40 mm, and 20 mm respectively. If infiltration index or storm loss rate for the catchement area is earlier estimated as 50 mm/day, then total surface run off will be _____mm

33. Area between isohyets 45 cm and 55 cm is 100 square km and between 55 cm and 65 cm is 150 square km. The average depth of annual precipitation over the above basin of 250 square km will be _____cm

34. When recurrence interval or frequency is 5 years and total number of years for which records are available are 40 years, then ranking of the required storm will be _____

35. For open wells, ratio of the safe depression head to critical deperession head is equal to _____

EXERCISE – II

(QUESTIONS FROM PREVIOUS GATE EXAMS)

MCQ TYPE QUESTIONS

2015

1. The average surface area of a reservoir in the month of June is 20 km^2. In the same month, the average rate of inflow is 10 m^3/s, outflow rate is 15 m^3/s, monthly rainfall is 10 cm, monthly seepage loss is 1.8 cm and the storage change is 16 million m^3. The evaporation (in cm) in that month is

(*a*) 46.8 (*b*) 136.6

(*c*) 13.6 (*d*) 23.4

2014

2. A conventional flow duration curve is a plot between

(*a*) Flow and percentage time flow is exceeded

(*b*) Duration of flooding and ground level elevation

(*c*) Duration of water supply in a city and proportion of area receiving supply exceeding this duration

(*d*) Flow rate and duration of time taken to empty a reservoir at that flow rate

3. In reservoirs with an uncontrolled spillway, the peak of the plotted outflow hydrograph

(*a*) lies outside the plotted inflow hydrograph

(*b*) lies on the recession limb of the plotted inflow hydrograph

(*c*) lies on the peak of the inflow hydrograph

(*d*) is higher than the peak of the plotted inflow hydrograph

4. An isolated 3-h rainfall event on a small catchment produces a hydrograph peak and point of inflection on the falling limb of the hydrograph at 7 hours and 8.5 hours respectively, after the start of the rainfall. Assuming, no losses and no base flow contribution, the time of concentration (in hours) for this catchment is approximately

(*a*) 8.5 (*b*) 7.0

(*c*) 6.5 (*d*) 5.5

5. The Muskingum model of routing a flood through a stream reach is expressed as $O_2 = K_0I_2 + K_1I_1 + K_2O_1$, where K_0, K_1 and K_2 are the routing coefficients for the concerned reach, I_1 and I_2 are the inflows to the reach, and O_1 and O_2 are the outflows from the reach corresponding to time steps 1 and 2 respectively. The sum of K_0, K_1 and K_2 of the model is

(*a*) – 1

(*b*) – 0.5

(*c*) 0.5

(*d*) 1

2013

6. A 1-h rainfall of 10 cm magnitude at a station has a return period of 50 years. The probability that a 1-h rainfall of magnitude 10 cm or more will occur in each of two successive years is

(*a*) 0.04 (*b*) 0.2

(*c*) 0.02 (*d*) 0.0004

7. An isohyet is a line joining points of

(*a*) equal temperature

(*b*) equal humidity

(*c*) equal rainfall depth

(*d*) equal evaporation

8. The normal depth in a wide rectangular channel is increased by 10%. The percentage increase in the discharge in the channel is

(*a*) 20.1 (*b*) 15.4

(*c*) 10.5 (*d*) 17.2

2012

9. The ratio of actual evapo-transpiration to potential evapo-transpiration is in the range

(*a*) 0.0 to 0.4 (*b*) 0.6 to 0.9

(*c*) 0.0 to 1.0 (*d*) 1.0 to 2.0

2011

10. A watershed got transformed from rural to urban over a period of time. The effect of urbanization on storm runoff hydrograph from the watershed is to

(*a*) decrease the volume of runoff

(*b*) increase the time to peak discharge

(*c*) decrease the time base

(*d*) decrease the peak discharge

11. For a given discharge, the critical flow depth in an open channel depends on

(*a*) channel geometry only

(*b*) channel geometry and bed slope

(*c*) channel geometry, bed slope and roughness

(*d*) channel geometry, bed slope, roughness and Reynolds number

12. The flow in a horizontal, frictionless rectangular open channel is supercritical. A smooth hump is built on the channel floor. As the height of hump is increased, choked condition is attained. With further increase in the height of the hump, the water surface will

(*a*) rise at a section upstream of the hump

(*b*) drop at a section upstream of the hump

(*c*) drop at the hump

(*d*) rise at the hump

13. A single pipe of length 1500 m and diameter 60 cm connects two reservoirs having a difference of 20 m in their water levels. The pipe is to be replaced by two pipes of the same length and equal diameter d to convey 25% more discharge under the same head loss. If the friction factor is assumed to be the same for all the pipes, the value of d is approximately equal to which of the following options?

(*a*) 37.5 cm (*b*) 40.0 cm

(*c*) 45.0 cm (*d*) 50.0 cm

14. A spillway discharges flood at a rate of 9 m^3/s per metre width. If the depth of flow on the horizontal apron at the toe of the spillway is 46 cm, the tail water depth needed to form a hydraulic jump is approximately given by which of the following options?

(*a*) 2.54 m (*b*) 4.90 m

(*c*) 5.77 m (*d*) 6.23 m

15. In an aquifer extending over 150 hectare, the water table was 20 m below ground level. Over a period of time the water table dropped to 23 m below the ground level. If the porosity of aquifer is 0.40 and the specific retention is 0.15, what is the change in ground water storage of the aquifer?

(*a*) 67.5 ha-m (*b*) 112.5 ha-m

(*c*) 180.0 ha-m (*d*) 450.0 ha-m

2010

16. The correct match of Group -I Group-II is

Group-I	**Group-II**
P. Evapotranspiration	1. Penman method
Q. Infiltration	2. Snyder's method
R. Synthetic unit hydrography	3. Muskingum method
S. Channel Routing	4. Horton's method

Codes :

	P	Q	R	S
(*a*)	1	3	4	2
(*b*)	1	4	2	3
(*c*)	3	4	1	2
(*d*)	4	2	1	3

2009

17. Direct step method of computation for gradually varied flow is

(*a*) applicable to non-prismatic channels

(*b*) applicable to prismatic channels

(*c*) applicable to both prismatic and non-prismatic channels

(*d*) not applicable to both prismatic and non-prismatic channels

18. The relationship among specific yield (S_y), specific ratention (S_r) and porosity (η) of an aquifer is

(*a*) $S_y = S_r + \eta$ (*b*) $S_y = S_r - \eta$

(*c*) $S_y = \eta - S_r$ (*d*) $S_y = S_r + 2\eta$

2008

19. A flood wave with a known inflow hydrograph is routed through a large reservoir. The outflow hydrograph will have

(*a*) attenuated peak with reduced time-base

(*b*) attenuated peak with increased time-base

(*c*) increased peak with increased time-base

(*d*) increased peak with reduced time-base

20. A stable channel is to be designed for a discharge of Q m^3/s with silt factor f as per Lacey's method.The mean flow velocity (m/s) in the channel is obtained by

(*a*) $(Q f^2/140)^{1/6}$

(*b*) $(Qf/140)^{1/3}$

(*c*) $(Q^2 f^2/140)^{1/6}$

(*d*) $0.48\ (Q/f)^{1/3}$

21. Water emerges from an ogee spillway with velocity = 13.72 m/s and depth = 0.3 m at its toe. The tail water depth required to form a hydraulic jump at the toe is

(*a*) 6.48 m

(*b*) 5.24 m

(*c*) 3.24 m

(*d*) 2.24 m

22. A river reach of 2.0 km long with maximum flood discharge of 10000 m^3/s is to be physically modeled in the laboratory where maximum available discharge is 0.20 m^3/s. For a geometrically similar model based on equality of Froude number, length of the river reach (m) in the model is

(*a*) 26.4 (*b*) 25.0
(*c*) 20.5 (*d*) 18.0

2007

23. There is a free overfall at the end of a long open channel. For a given flow rate, the critical depth is less than the normal depth. What gradually varied flow profile will occur in the channel for this flow rate ?

(*a*) M_1 (*b*) M_2
(*c*) M_3 (*d*) S_1

24. As per the Lacey's method for design of alluvail channels, identify the true statement from the following.

(*a*) Wetted perimeter increases with an increase in design discharge
(*b*) Hydraulic radius increases with an increase in silt factor.
(*c*) Wetted perimeter decreases with an increase in design discharge
(*d*) Wetted perimeter increases with an increase in silt factor

25. The culturable command area for a distributary channel is 20,000 hectares. Wheat is grown in the entire area and the intensity of irrigation is 50%. The *kor* period for wheat is 30 days and the *kor* water depth is 120 mm. The outlet discharge for the distributary should be

(*a*) 2.85 m^3/s (*b*) 3.21 m^3/s
(*c*) 4.63 m^3/s (*d*) 5.23 m^3/s

26. An isolated 4-hour storm occurred over a catchment as follows

Time	1st hour	2nd hour	3rd hour	4th hour
Rainfall (mm)	9	28	12	7

The ϕ index for the catchment is 10 mm/h. The estimated runoff depth from the catchment due to the above storm is

(*a*) 10 mm (*b*) 16 mm
(*c*) 20 mm (*d*) 23 mm

2006

27. During a 3 hour storm event, it was observed that all abstractions other than infiltration are negligible. The rainfall was idealized as 3 one hour storms of intensity 10 mm/hr, 20 mm/hr and 10 mm/hr respectively and the infiltration was idealized as a Horton curve, $f = 6.8 + 8.7 \exp(-t)$ (f in mm/hr and t in hr).

What is the effective rainfall?

(*a*) 10.00 mm
(*b*) 11.33 mm
(*c*) 12.43 mm
(*d*) 13.63 mm

NUMERICAL TYPE QUESTIONS

2015

1. The 4-hr unit hydrograph for a catchment is given in the table below. What would be the maximum ordinate of the S-curve (in m^3/s) derived from this hydrograph?

Time (hr)	0	2	4	6	8	10	12	14	16	18	20	22	24
Unit hydrograph ordinate (m^3/s)	0	0.6	3.1	10	13	9	5	2	0.7	0.3	0.2	0.1	0

2. In a catchment, there are four rain-gauge stations, P, Q, R and S. Normal annual precipitation values at these stations are 780 mm, 850 mm, 920 mm and 980 mm respectively. In the year 2013, stations Q, R and S, were operative but P was not. Using the normal ratio method, the precipitation at station P for the year 2013 has been estimated as 860 mm. If the observed precipitation at stations Q and R for the year 2013 were 930 mm and 1010 mm, respectively, what was the observed precipitation (in mm) at station S for that year?

3. A field channel has cultivable commanded area of 2000 hectares. The intensities of irrigation for gram and wheat are 30% and 50% respectively. Gram has a kor period of 18 days, kor depth of 12 cm, while wheat has a kor period of 18 days and a kor depth of 15 cm. The discharge (in m^3/s) required in the field channel to supply water to the commanded area during the kor period is _____.

ANSWERS

EXERCISE – I

MCQ Type Questions

1. (c)	**2.** (a)	**3.** (b)	**4.** (d)	**5.** (a)	**6.** (c)	**7.** (c)	**8.** (b)	**9.** (b)	**10.** (c)
11. (a)	**12.** (a)	**13.** (b)	**14.** (c)	**15.** (a)	**16.** (c)	**17.** (a)	**18.** (a)	**19.** (b)	**20.** (a)
21. (b)	**22.** (c)	**23.** (b)	**24.** (b)	**25.** (b)	**26.** (a)	**27.** (b)	**28.** (c)	**29.** (b)	**30.** (c)
31. (b)	**32.** (b)	**33.** (b)	**34.** (c)	**35.** (c)	**36.** (d)	**37.** (b)	**38.** (b)	**39.** (a)	**40.** (b)
41. (b)	**42.** (c)	**43.** (a)	**44.** (a)	**45.** (c)	**46.** (b)	**47.** (a)	**48.** (a)	**49.** (d)	**50.** (b)
51. (d)	**52.** (c)	**53.** (d)	**54.** (c)	**55.** (c)	**56.** (b)	**57.** (a)	**58.** (a)	**59.** (c)	**60.** (b)
61. (c)	**62.** (c)	**63.** (b)	**64.** (d)	**65.** (a)	**66.** (c)	**67.** (b)	**68.** (c)	**69.** (a)	**70.** (c)
71. (a)	**72.** (d)	**73.** (b)	**74.** (b)	**75.** (c)	**76.** (b)	**77.** (a)	**78.** (c)	**79.** (c)	**80.** (a)
81. (b)	**82.** (a)	**83.** (c)	**84.** (c)	**85.** (b)	**86.** (d)	**87.** (d)	**88.** (b)	**89.** (d)	**90.** (c)
91. (d)	**92.** (b)	**93.** (d)	**94.** (c)	**95.** (b)	**96.** (b)	**97.** (d)	**98.** (a)	**99.** (c)	**100.** (c)
101. (a)	**102.** (d)	**103.** (b)	**104.** (c)	**105.** (c)	**106.** (a)	**107.** (b)	**108.** (c)	**109.** (b)	**110.** (a)
111. (b)	**112.** (b)	**113.** (d)							

Numerical Type Questions

1. (2.4)	**2.** (7)	**3.** (70)	**4.** (80)	**5.** (1)	**6.** (20)	**7.** (12.84)
8. (19)	**9.** (5)	**10.** (5)	**11.** (3)	**12.** (8)	**13.** (3)	**14.** (25.58)
15. (22.8)	**16.** (1.012)	**17.** (6.089)	**18.** (142.12)	**19.** (12.5)	**20.** (34.36)	**21.** (0.4)
22. (465)	**23.** (1728)	**24.** (2)	**25.** (1000)	**26.** (250)	**27.** (0.7)	**28.** (100)
29. (3.66)	**30.** (14)	**31.** (70)	**32.** (90)	**33.** (56)	**34.** (8)	**35.** ($\frac{1}{3}$)

EXERCISE – II

MCQ Type Questions

1. (d)	**2.** (a)	**3.** (b)	**4.** (d)	**5.** (d)	**6.** (d)	**7.** (c)	**8.** (d)	**9.** (c)	**10.** (c)
11. (a)	**12.** (b)	**13.** (d)	**14.** (c)	**15.** (b)	**16.** (b)	**17.** (b)	**18.** (c)	**19.** (*)	**20.** (a)
21. (c)	**22.** (*)	**23.** (b)	**24.** (a)	**25.** (c)	**26.** (c)	**27.** (d)			

Numerical Type Questions

1. (22)	**2.** (1094)	**3.** 1.4275

EXPLANATIONS

EXERCISE – I

MCQ TYPE QUESTIONS

1. Total volume of flow

$$= (7 + 27 + 58 + ... + 13) \times \frac{86400}{10^4}$$

2. Volume of run-off $= \frac{3300 \times 10^6 \times 57 \times 10^{-3}}{86400}$

$= 2177.08$

3. % of rainfall that become run-off

$$= \frac{5.68 \times 10^7 \times 100 \times 100}{210 \times 10^6 \times 65}$$

$= 41.62\%$

4. Evaporation = Rainfall – Depth of water removed

$$= 8.8 - \frac{4.75 \times 10^6}{\frac{\pi}{4} \times 1220^2} = 4.74 \text{ mm}$$

6. $\frac{15 \times 10^6 \times 0.20 \times 10^{-2}}{30} = 10 \times 10^4 \text{ m}^3$

8. For a given area, maximum depth increases with duration.

11. $$\frac{8-5}{6} = \frac{11-R}{12} = \phi$$

$\therefore$ $R = 11 - 6 = 5$ cm

14. $$Q = \frac{2\pi T S_w}{\log_e \frac{R}{r_w}}$$

$$= \frac{2\pi \times (8.2 \times 10^{-4}) \times 20 \times 3}{\log_e \frac{260}{0.25}} \times 1000$$

$= 48.43$ lit/sec

15. $Q = CAH$

where, $A = \frac{\pi d^2}{4} = \frac{Q}{C H}$

Here Q is in m^3/h.

21. $P = 1 - (1 - P)^n$

$$= 1 - \left(1 - \frac{1}{100}\right)^{10}$$

$= 1 - (0.99)^{10}$

22. $p = \frac{1}{T}$

$\Rightarrow$ $T = \frac{1}{p} = \frac{1}{(1-0.9)^{0.10}}$

24. Surface run-off $= 1.2 \times 10^8 \text{ m}^3$

$$= \frac{1.2 \times 10^8}{A} = \frac{1.2 \times 10^8}{1200 \times 10^6} = \frac{1}{10} = 10 \text{ cm}$$

Given : Total run-off = 16 cm

$$\phi \text{ index} = \frac{16-10}{6} = 1 \text{ cm/hr}$$

25. *Moderate* if defficiency is between 25% to 50%

Severe if deficiency is above 50%

If drought occurs in the area with probability $0.2 < P \leq 0.4$, then area is classified as drought prone area.

Aridity index $= \left[\frac{PET - AET}{PET}\right] \times 100$

AI anamoly	Severity class
1 – 25	mild arid
26 – 50	moderate arid
> 50	severe arid

28. Duration of rainfall excess = 3 h

Total depth of rainfall = 5.9 cm

Loss 3 cm/h for 3 h = 0.9 cm

Rainfall excess = 5.9 – 0.9 = 5.0 cm

Peak flow peak of flood hydrograph = 270 m^3/s

Base flow = 20 m^3/s

Peak DRH = 250 m^3/s

Peak 3 h unit hydrograph $= \frac{\text{Peak of DRH}}{\text{Rainfall excess}}$

$$= \frac{250}{5} = 50 \text{ m}^3/\text{s}$$

29. Let B = base width 3h UH

Volume of unit hydrograph

= Volume of 1 cm depth on catchment

Area of unit hydrograph = (Area of catchment) × 1cm

$$\therefore \quad \frac{1}{2} \times B \times 60 \times 60 \times 5 = 567 \times 10^6 \times \frac{1}{100}$$

$$\Rightarrow \quad B = \left[\frac{567 \times 10^4}{9 \times 10^4}\right] = 63 \text{ hours}$$

31. Five not being multiple of 2; hence its difficult to prepare a 5 hour unit hydrograph

35. S hydrograph is used to obtain hydrograph of shorter duration as well as longer duration from the given hydrograph.

37. Convex water surface will give highest rate of evaporation.

NUMERICAL TYPE QUESTIONS

1. $P_{av} = \dfrac{P_1A_1 + P_2A_2 + P_3A_3 + P_4A_4}{A_1 + A_2 + A_3 + A_4}$

2. $5 \text{ cm} = \dfrac{P \times 0.15 + 5 \times 0.25 + 4 \times 0.30 + 5 \times 0.30}{1}$

3. $\dfrac{P_x}{N_x} = \dfrac{1}{3}\left[\dfrac{P_a}{N_a} + \dfrac{P_b}{N_b} + \dfrac{P_c}{N_c}\right]$

5. Additional rain gauge

$$= N - 4 = \left(\frac{C_v}{\epsilon}\right)^2 - 4$$

where, $\epsilon = 10\ \%$.

$$C_v = \frac{\sigma_{n-1}}{\bar{x}} \times 100$$

6. Depth of run-off $= \dfrac{10{,}000}{4320 \times 10^6} \times 86400 \times 100$

$$= 20 \text{ cm}$$

7. Evaporation = Depth of water added + Rainfall

$$= \frac{10.8 \times 10^6}{\frac{\pi}{4} \times 1220^2} + 3.6$$

$$= 12.84 \text{ mm}$$

8. $\dfrac{v_1}{v_2} = \left(\dfrac{Z_1}{Z_2}\right)^{\frac{1}{7}} \quad v \propto (Z)^{1/7}$

9. $n = \left(\dfrac{C_v}{\epsilon}\right)^2 = \left(\dfrac{30}{10}\right)^2 = 9$

$\therefore \quad N = 9 - 4 = 5$

10. $R = (4 - 12 \times 0.5) + (8 - 12 \times 0.5) + (9 - 12 \times 0.5) + (3 - 12 \times 0.5)$

$= 0 + 2 + 3 + 0 = 5$ cm

First and last rainfall will have zero excess rainfall as infiltration losses exceed rainfall.

11. Infilteration rate

$$= \frac{\text{Total rainfall} - \text{Total run-off}}{\text{duration}}$$

$$= \frac{1.5 \times 10 \times 6 - \dfrac{21.6 \times 10^6}{300 \times 10^6} \times 10}{6}$$

$$= 3 \text{ mm/h}$$

12. $0 + (18 - \phi) + (25 - \phi) + (12 - \phi) + (10 - \phi) + 0$

$$= \frac{264 \times 10^5}{800 \times 10^6}$$

$$= 33 \text{ mm}$$

13. $f = \dfrac{1.5 \times 10 \times 6 - 72}{6}$

$$= \frac{90 - 72}{6} = \frac{18}{6} = 3 \text{ mm/hr}$$

14. $n = \dfrac{\text{weight of kerosene required to saturate sample}}{\text{weight of kerosene displaced by saturated sample}}$

$$= \frac{W_2 - W_1}{W_3}$$

$$= \frac{0.732 - 0.655}{0.301} \times 100$$

$$= 25.58\%$$

15. Water released from aquifer = Water pumped out

$\therefore \quad [(6.2 \times 10^6) \times 2.6 \times S_y] = 3.68 \times 10^6 \text{ m}^3$

$\Rightarrow \quad S_y = \dfrac{3.68}{6.2 \times 2.6} \times 100 = \mathbf{22.83\%}$

16. $V_a = \dfrac{V}{h}$

$$= \frac{k\left(-\dfrac{dh}{dl}\right)}{h}$$

$$= \frac{12.5\left[-\dfrac{(206.25 - 210.5)}{350}\right]}{0.15}$$

17. $k = \dfrac{Q.\log_e\left(\dfrac{r_1}{r_2}\right)}{\pi\left(h_1^2 - h_2^2\right)}$

$$= \frac{0.035 \log \dfrac{100}{10}}{\pi\left[(30 - 0.5)^2 - (30 - 7.5)^2\right]} = 6.089 \text{ m/day}$$

18. $Q = \dfrac{\pi K (H^2 - h_w^2)}{\log_e\left(\dfrac{R}{r_w}\right)}$

$$= \frac{\pi \times 30\,(50^2 - 40^2) \times 1000}{\log_e\left(\dfrac{500}{0.5}\right)} = 142.12 \text{ lit/sec.}$$

19. $Q = \dfrac{2\pi T(S_2 - S_1)}{\log_e \dfrac{r_1}{r_2}}$

$\therefore \quad 100 \text{ lit/min} = \dfrac{2\pi \times T(3 - 0.05)}{\log_e \dfrac{50}{10}}$

$\Rightarrow \quad T = 12.5 \text{ m}^2\text{/day}$

20. $$Q = CAH = \frac{K}{A} \cdot AH$$

$$Q = \frac{2.303}{T} \log\left(\frac{h_1}{h_2}\right) \cdot AH$$

Here, $h_1 = 3\ m$, $h_2 = (3 - 1.75)$ m

21. Run-off coefficient $= \dfrac{150 \times 10^6}{500 \times 10^6 \times 750 \times 10^{-3}} = 0.4$

22. Since area is same

$$\therefore \quad \frac{1}{2} \times \frac{930 \times 6 \times 3600}{15} = \frac{1}{2} \times \frac{x \times 6 \times 3600}{7.5}$$

$\Rightarrow \quad x = 465\ m^3/s$

23. Area of basin $= \dfrac{1}{2} \times 48 \times 3600 \times 200 = 1728\ km^2$

24. Depth of run-off $= \dfrac{1}{2} \times \dfrac{80 \times 3600 \times 200}{1440 \times 10^6}$

$= 0.02$ m $= 2$ cms

25. $\dfrac{1}{2} \times 5 \times 24 \times 3600 \times x = 4320 \times 10^6 \times \dfrac{5}{100}$

$\therefore$ Peak flow $= 1000 m^3/s$

26. $q_e = 2.778 \dfrac{A}{D} = \dfrac{2.778 \times 540}{6} = 250\ m^3/s$

27. $$C_0 + C_1 + C_2 = 1$$

$\therefore \quad -0.2 + 0.5 + C_2 = 1$

$\Rightarrow \quad C_2 = 0.7$

28. Mean annual rainfall of $= 1\ m^3/sec$

Annual rainfall $= 1 \times 365 \times 24 \times 60 \times 60\ m^3$

$= 31536000$

$A = 31.54\ km^2 = 31.54 \times 10^6$

$\therefore$ Effective rainfall $= \left[\dfrac{31546000}{31.54 \times 10^6}\right] = 1$ cm

29. Average rainfall

$$= \frac{0.1 \times 4 + 0.4 \times 2 + 0.4 \times 2 + 0.1 \times 4}{0.1 + 0.4 + 0.4 + 0.1} = 2.4 \text{ cm}$$

31. Average rainfall

$$= 3\left[\frac{700}{1000} \times 100 + \frac{700}{900} \times 90 + \frac{700}{800} \times 80\right]$$

$= 70$ mm

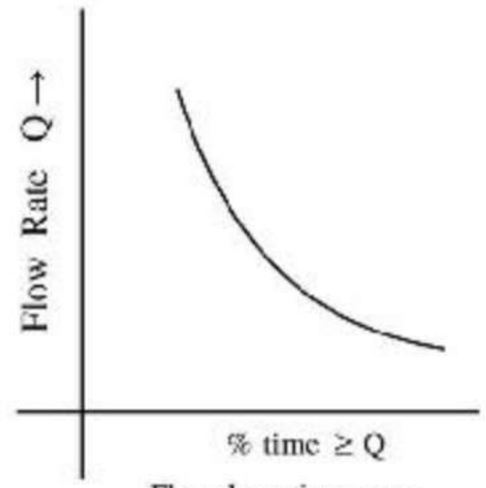
33. Average depth of annual ppt of basin

$$= \frac{100 \times 50 + 150 \times 60}{250} = 56 \text{ cm}$$

EXERCISE – II

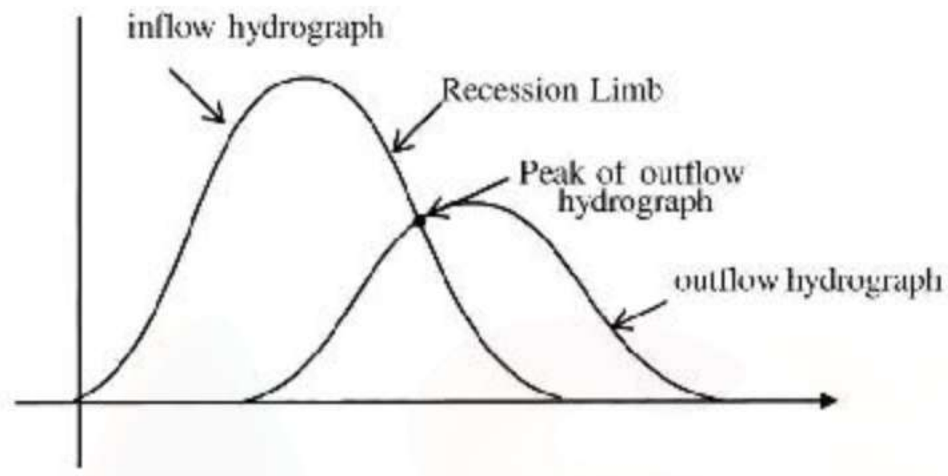
MCQ TYPE QUESTIONS

2.

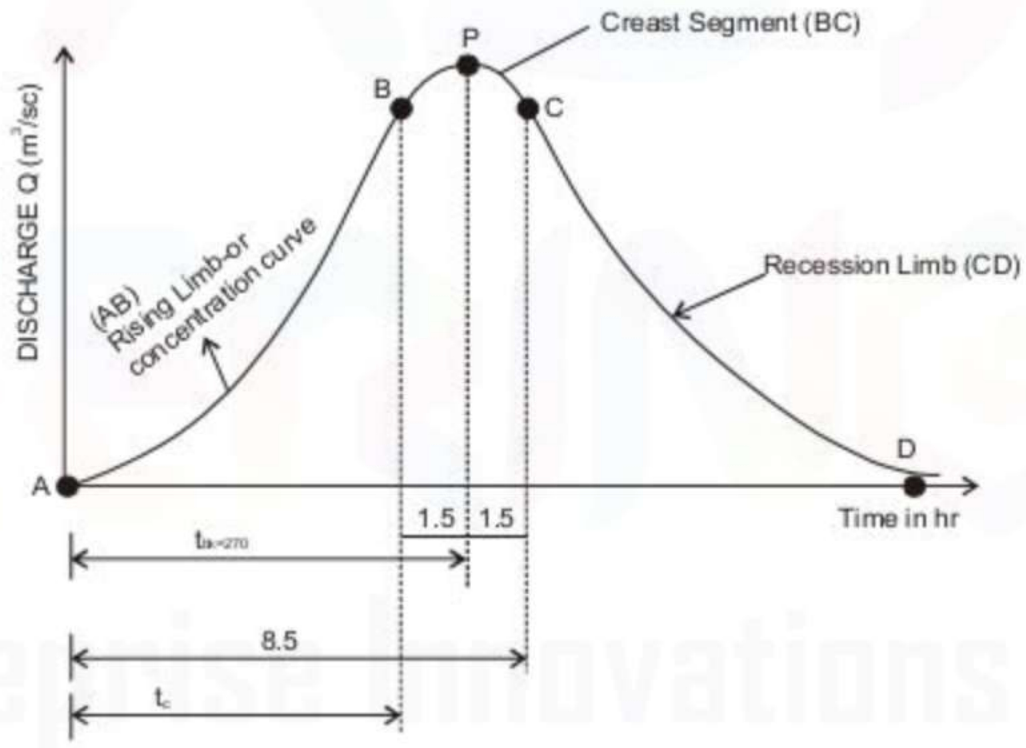


Flow duaration curve

3.



4.



Peak make in between B & C. So distance between P to C is 1.5 hr.

So the distance between P to B is also 1.5 hr.

$\because \ t_c = 7.0 - 1.5 = 5.5$ hr

So correct choice is (*d*)

5. Using the Muskingum equation, the change in storage is:

$S_2 - S_1 = K[x(I_2 - I_1) + (1 - x)(Q_2 - Q_1)]$

$x \Rightarrow$ Weighting factor (0 to 0.5)

Where, suffix 1 & 2 represent conditions before & after the time interval Δt.

[$K \Rightarrow$ storage – time constant].

From continuity equation.

$$S_2 - S_1 = \left[\frac{I_2 + I_1}{2}\right]\Delta t - \left[\frac{Q_2 + Q_1}{2}\right]\Delta t$$

Q_2 is evaluated as:

$$\boxed{Q_2 = C_o I_2 + C_1 I_1 + C_2 Q_1}$$

Note that the sum of $\boxed{C_0 + C_1 + C_2 = 1.0}$

So that in given question the sum of

$$K_0 + K_1 + K_2 = 1.0$$

6. Given

$1 - h$ rainfall of 10 cm magnitude

Return period $T = 50$ years

Successive year $n = 2$

find the probability of $1 - h$ rainfall of magnitude 10 cm or more will occur in each of two successive year, i.e.

$\because \quad r = 2$

$$P_{2,n} = \frac{\lfloor n}{\lfloor(n-2)\lfloor 2} p^2 \cdot q^{n-2}$$

$$q = 1 - P$$

$$P = \frac{1}{T} = \frac{1}{50} = 0.02$$

$$q = 1 - 0.02 = 0.98$$

$$P_{2,n} = \frac{2!}{(2-2)!2!}(0.02)^2 \times (0.98)^{2-2}$$

$$P_{2,n} = 1 \times (0.02)^2 \times 10 = 0.0004$$

$$\Sigma X = 0$$

$$F_{RS} + F_{ST} \cos 45° = 15$$

$$F_{RS} + 31.819 \times \cos 45° = 15$$

$$F_{RS} = 15 - 22.5$$

$$= -7.5 \text{ (comp.)}$$

$\because$ Force in member RS = 7.5 (comp.)

7. An isohyet is a line joining point of equal rainfall magnitude.

$\because$ (*c*) is correct Answer. i.e. equal rainfall depth.

8. Assume the depth of rectangular channel = Y

the width of rectangular channel = B

$\because$ Hydraullic mean depth of rectangular channel

$$R = \frac{Y}{2}$$

Discharge Q before increasing the depth

$$Q = A \times V = Y \times B \times \frac{1}{n}(R)^{\frac{2}{3}}(S)^{\frac{1}{2}}$$

$$Q = Y \times B \times \frac{1}{n}\left(\frac{Y}{2}\right)^{\frac{2}{3}}(S)^{\frac{1}{2}}$$

Discharge Q after increasing the depth = 10%

$$\because \quad Q_1 = 1.1Y \times B \times \frac{1}{n}\left(\frac{1.1Y}{2}\right)^{\frac{2}{3}} \cdot (S)^{\frac{1}{2}}$$

Ratio of Q and Q_1

$$\frac{Q}{Q_1} = \frac{Y \times B \times \frac{1}{n}\left(\frac{Y}{2}\right)^{\frac{2}{3}}(S)^{\frac{1}{2}}}{1.1Y \times B \times \frac{1}{n}\left(\frac{1.1Y}{2}\right)^{\frac{2}{3}}(S)^{\frac{1}{2}}}$$

$$\frac{Q}{Q_1} = \frac{1}{(1.1)^{\frac{5}{3}}}$$

$$Q = 1.172\, Q_1$$

$\because$ Discharge will increase 17.2%

10. Vegetation and forests increase infiltration and storage capacity of the soils. Further, they cause considerable retardance to the overland flow. Thus, vegetal cover reduces peak flow and increases the time loss with the change of land use from rural to ruban, there will be increase of discharge and reduction of time loss.

13. Let D be the diameter of the single large pipe which is to be replaced by 2 parallel pipes of equal diameter d to increase discharge by 25%. Let all the pipes be of equal length L.

$\therefore$ Heat loss, $h_f = \dfrac{fL}{D} \cdot \dfrac{V^2}{2g}$

$\therefore$ Velocity in large pipe,

$$V = \sqrt{\frac{h_f \times 2g}{f}}\sqrt{\frac{D}{L}}$$

Discharge in large pipe,

$$Q = \frac{\pi D^2}{4} . V$$

$$= \frac{\pi D^2}{4} \times \sqrt{\frac{h_f \times 2g}{f}} \times \sqrt{\frac{D}{L}}$$

$$= \frac{\pi}{4}\sqrt{\frac{2gh_f}{f}}\left(\frac{D^{5/2}}{L^{1/2}}\right)$$

Frictional head loss in each of the parallel pipes

= Frictional head less in large pipe = h_f

Similarly, discharge in each of parallel pipes

$$q = \frac{\pi}{4}\sqrt{\frac{2gh_f}{f}} \cdot \left(\frac{d^{5/2}}{L^{1/2}}\right)$$

But $2q = 1.25\,\alpha$

$$\therefore \quad 2 \times \frac{\pi}{4}\sqrt{\frac{2gh_f}{f}}\left(\frac{d^{5/2}}{L^{1/2}}\right)$$

$$= 1.25 \times \frac{\pi}{4}\sqrt{\frac{2gh_f}{f}}\left(\frac{D^{5/2}}{L^{1/2}}\right)$$

$\Rightarrow \quad 2(d^{5/2}) = 1.25\ D^{5/2}$

$\Rightarrow \quad d^{5/2} = 0.625\ (60)^{5/2}$

$\Rightarrow \quad d = 49.7 \approx 50$ cm.

14. In hydraulic jump formation

$$y_2 = \frac{y_1}{2}\ [-1 + \sqrt{\frac{1+8q^2}{gy_1^3}}\ ]$$

$$= \frac{0.46}{2}\ [-1 + \sqrt{\frac{1+8\times 9^2}{9.81\times 0.46^3}}\ ]$$

$$= 5.677$$

$$\approx 5.77$$

15. Porosity, n = specific yield (S_y) + specific retention S_r

$0.40 = S_y + 0.15$

$\Rightarrow \quad S_y = 0.25$

Volume pumped out

= Area × drop in water table × specific yield (S_y)

= 150 × 3 × 0.25 = 112.5 ha. m

Specific yield.

The actual volume of water that can be extracted by the force of gravity from a unit volume of aquifer is called *specific yield*.

18. We know, $S_y = \frac{V_w}{V}$

$$S_r = \frac{V_r}{V}$$

and $\quad V_w + V_r = V_{void}$

$$\therefore \quad S_y + S_r = \frac{V_w + V_r}{V}$$

$$= \frac{V_v}{V}$$

$$S_y + S_r = n$$

where, n = porosity

$$S_y = n - S_r$$

20. According to Lacey, the relation between cross sectional area A, mean velocity V and silt factor f is given by

$$A\ .\ f^2 = 140\ V^5$$

$\Rightarrow \quad V.\ A.\ f^2 = 140\ V^5$

$\Rightarrow \quad Q\ f^2 = 140\ V^6$

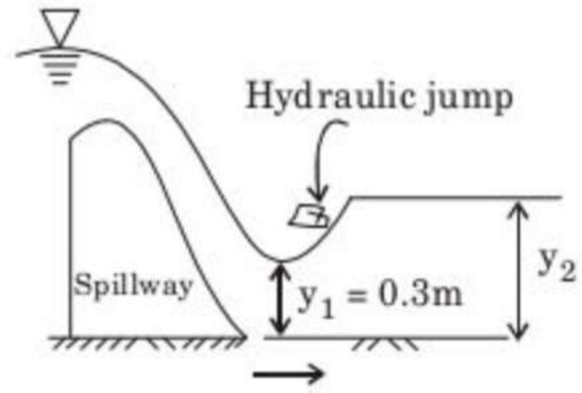
$$\Rightarrow \quad \left(\frac{Qf^2}{140}\right)^{1/6} = V$$

which is the required expression.

21. Here, $V_1 = 13.72$ m/s

y_1 = pre jump depth

y_2 = post jump depth



Froude number, $F_1 = \frac{v_1}{\sqrt{gy_1}}$

$$= \frac{13.72}{\sqrt{9.8\times 0.3}} = 8$$

We know, $\frac{y_2}{y_1} = \frac{1}{2}\left(-1+\sqrt{1+8F_1^2}\right)$

$$\Rightarrow \quad y_2 = 0.3\times\frac{1}{2}\left(-1+\sqrt{1+8\times 8^2}\right) = 3.24\ \text{m}$$

23. For a given flow rate, if crifical depth (y_c) is less than normal depth (y_n)

i.e. if $\quad y_c < y_n$

then flow profile will be M_2.

24. According to Lacey's method for design of alluvial channels, watted perimeter increases with an increase in design discharge

25. Total command area, A = 20,000 heat

Intensity of irrigation, i = 50% = 0.5

Kor period, t = 30 days

Kor water depth, d = 120 mm

Outlet discharge factor,

$$F = \frac{8.64\times t}{d}$$

$$= \frac{8.64\times 30}{120\times 10^{-3}} = 2160\ \text{hect/cumec}$$

$\therefore$ Outlet discharge, $Q = \frac{Ai}{F}$

$$= \frac{0.5\times 20{,}000}{2160} = \mathbf{4.63\ m^3/sec}$$

26.

Time	1	2	3	4
Rainfall	9	28	12	7
ϕ– index	10	10	10	10
Rainfall excess	–1	18	2	–3

$\therefore$ Runoff depth = 18 + 2 = 20 mm

NUMERICAL TYPE QUESTIONS

1.

Time	Ordinate	Lagging by 4-hrs & adding	S-curve
0	0	—	0
2	0.6	—	0.6
4	3.1	0	3.1
6	10	0.6	10.6
8	13	3.1	16.1
10	9	10.6	19.6
12	5	16.1	21.1
14	2	19.6	21.6
16	0.7	21.1	21.8
18	0.3	21.6	21.9
20	0.2	21.8	22
22	0.1	21.9	22
24	0	22	22

2. $$\frac{P_S}{N_S} = \frac{1}{3}\left[\frac{P_P}{N_P} + \frac{P_Q}{N_Q} + \frac{P_R}{N_R}\right]$$

$$\Rightarrow \quad \frac{P_S}{980} = \frac{1}{3}\left[\frac{860}{780} + \frac{930}{850} + \frac{1010}{920}\right]$$

$$\Rightarrow \quad P_S = 1094 \text{ mm}$$

3. Cultivable command area = 2000 hectares

Irrigation intensities ⇒ 30% for Gram

50% for Wheat

Kor period ⇒ 18 days for both

Kor depth ⇒ 12 cm for Gram

15 cm for Wheat

$$\text{Discharge} = \frac{\left[0.3 \times (2000 \times 10^4) \times 0.12\right] + \left[0.5 \times (2000 \times 10^4) \times 0.15\right]}{18 \times 24 \times 60 \times 60}$$

$$= 1.4275$$