Chapter 2

Hydrographs, Flood Routing and Well Hydraulics

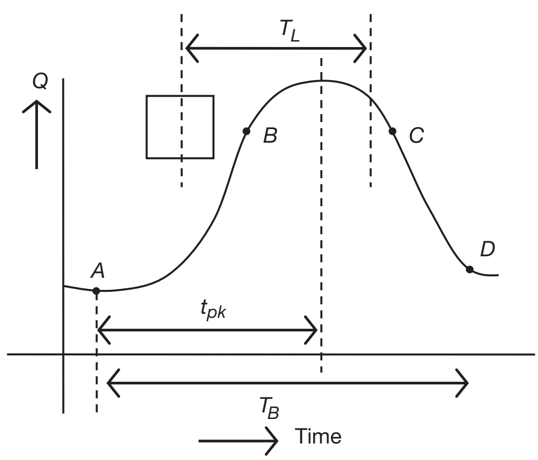
CHAPTER HIGHLIGHTS

- *Hydrographs*
- *Maximum flood estimation, flood routing, river gauging*
- *Well hydraulics*

Hydrographs

In this chapter the time distribution of run-off produced by a given precipitation on a basin is analyzed. The run-off measured at basin outlet when plotted against time gives the hydrograph.

1. **Hydrograph:** A plot between discharge in a stream and time in chronological order is known as hydrograph.



Where

T_r = Rainfall duration
T_B = Time base of hydrograph
t_{pk} = Time to peak from starting point
AB = Rising limb or concentration curve
BC = Crest segment
CD = Recession limb
T_L = Time interval from centre of mass of rainfall to centre of mass of hydrograph called 'lag time' or basin lag.

2. **Rising limb:** Basin and storm characteristics control the shape of the rising limb of a hydrograph.
3. **Crest segment:** Generally for large catchments, the peak flow occurs after the centre of mass of rainfall to the peak being essentially controlled by basin and storm characteristics.
4. **Recession limb:** The recession limb which extends from the point of inflection at the end of the crest segment to the commencement of the natural groundwater flow represents the withdrawal of water from the storage built up in the basin during the earlier phases of the hydrograph. The starting point of recession limb which is also known as point of inflection represents condition of maximum storage.

A hydrograph consists of flow in three phases:

(a) Surface run-off
(b) Interflow
(c) Base flow

Such a hydrograph is called storm hydrograph or flood hydrograph or hydrograph.

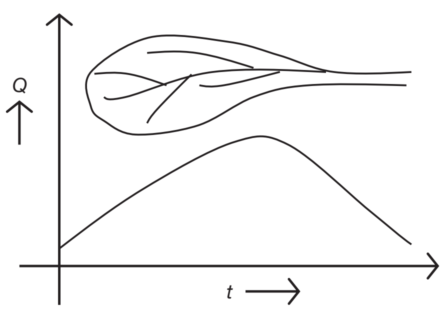
5. **Rainfall excess:** The initial loss and infiltration loss are subtracted from the total rainfall, the remaining portion of rainfall is called rainfall excess, also called supra rain.
6. **Effective rainfall:** It is the portion of rainfall which causes direct run-off.

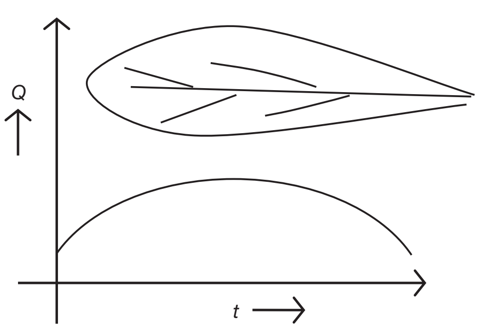
$$\therefore \text{Effective rainfall} = \frac{\text{Direct run-off volume}}{\text{Area of catchment}}$$

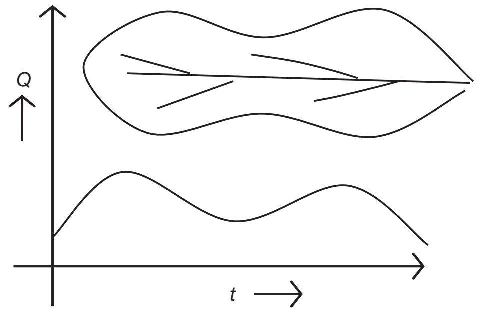
In general, effective rainfall is expressed in terms of intensity or ordinate against time as abscissa, the effective rainfall hyetograph (ERH) or rainfall excess is obtained.

A hyetograph of rainfall excess is known as supra rainfall hyetograph.

7. **Unit hydrograph theory:** A unit hydrograph is defined as the hydrograph resulting from an isolated storm of unit duration occurring uniformly over the entire catchment area and producing unit depth of direct run-off.
8. The basic propositions of unit hydrograph theory are:
   (a) Time invariance
   (b) Linearity of response
   (c) Fixed base period
   (d) Proportional ordinates
   (e) Superposition
   (f) Storm of long duration
   (g) Same distribution hydrograph
9. **Factors affecting the flood hydrograph:**
   (a) Shape of the basin: Fan shaped catchments give high peak, narrow hydrograph, while fern shaped catchments give broad and low peaked hydrograph.







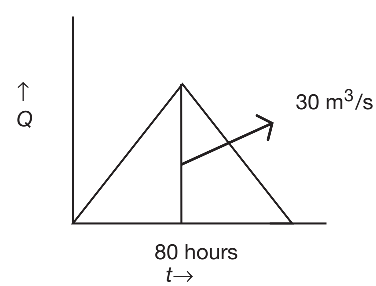
   (b) Slope: The slope of catchment is inversely proportional to the peak discharge. The steeper the catchment larger the discharge.
   (c) Drainage density: It is the ratio of total channel length to the total drainage area.
   (d) Stream density: It is the ratio of number of streams to area of basin.
   (e) Form factor: It is the ratio of basin area to square of basin length.
   (f) Land use: Vegetation and forests increases the infiltration and storage capacities of soils, thereby reducing the peak flow.
10. **Base flow separation:** Base flow is separated from the total storm hydrograph to obtain relation between surface flow hydrograph and effective rainfall.
11. **Direct run-off hydrograph (DRH):** The surface run-off hydrograph obtained after the base flow separation is called DRH.

    Total area of DRH = Time interval of ordinate × Sum of DRH ordinates = Run-off volume.

SOLVED EXAMPLES

Example 1

The direct run-off hydrograph of a storm obtained from the catchment is triangular in shape and has base period of 80 hours. The peak flow rate is 30 m^3/s and catchment area is 86.4 km^2. The rainfall excess is



(A) 5 cm
(B) 8 cm
(C) 10 cm
(D) 16 cm

Solution

Run off depth = Rainfall excess

$$= \frac{\text{Volume of run-off}}{\text{Area of catchment}}$$

$$= \frac{\frac{1}{2} \times 30 \times 80 \times 60 \times 60}{86.4 \times (100)^2} \times 100$$

= 5 cm.

12. **Unit hydrograph derivation:** The duration is an important characteristic of unit hydrograph and is used as a prefix to specific unit hydrograph.

Example: 6 hours unit hydrograph,
4 hours unit hydrograph

(a) Uniform intensity of rainfalls

$$\frac{1 \text{ cm}}{D \text{ hour}} = \frac{1}{D} \text{cm/h}$$

(b) The area of unit hydrograph is equal to volume of run-off obtained from the catchment due to rainfall excess of 1 cm, i.e.,

$$\boxed{\text{Area of UH} = \text{Catchment area} \times \text{Unit depth}}$$

(c) Initially base flow is separated from the selected hydrograph to derive DRH (direct run-off hydrograph).
(d) The area under the DRH is calculated, which will be equal to run-off volume.
(e) The run-off volume is divided by the catchment area to obtain effective rainfall.
(f) The ordinates of DRH area divided by the effective rainfall to get the ordinates of UH of *D*-hours duration.

Example 2

The peak ordinate of a flood hydrograph produced by a 4 hours storm yielding 7.7 cm of rainfall is observed to be 842 m^3/s. If the base flow and ϕ-index are 20 m^3/s and 0.8 cm/h. What is peak ordinate of 4 hours unit hydrograph?

Solution

Peak ordinate of 4 hours hydrograph = 842 m^3/s
Peak ordinate of 4 hours DRH = 842 – 20 = 822 m^3/s

$$\phi = \frac{P_e - R}{t_e}$$

$$0.8 = \frac{7.7 - R}{4}$$

$$R = 7.7 - 0.8 \times 4 = 4.5 \text{ cm}$$

Peak ordinate of 4 hours unit hydrograph

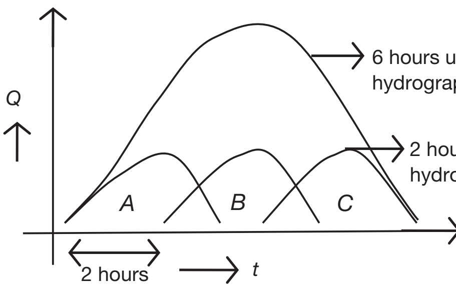
$$= \frac{\text{Peak of 4 hours DRH}}{R}$$

$$= \frac{822}{4.5} = 182.66 \text{ m}^3/\text{s}.$$

13. **Methods of developing unit hydrographs:**

(a) **Method of superposition:** This method can be used only when *n* is an integer (1, 2, 3, ..., etc.). But, when *n* is fraction (1/2, 1/3, …, etc.) this method cannot be used. *S*–curve method can be used for any value of '*n*'.

For example to derive a 6 hours UH from a given 2 hours UH, draw 3 UHs of 2 hours duration as shown in the figure with due lagging. The sum of ordinates of *A*, *B*, *C* give direct run-off hydrograph of 6 hours and due to rainfall of 3 cm. The ordinates of DRH divided by 3, gives ordinates of 6 hours UH.

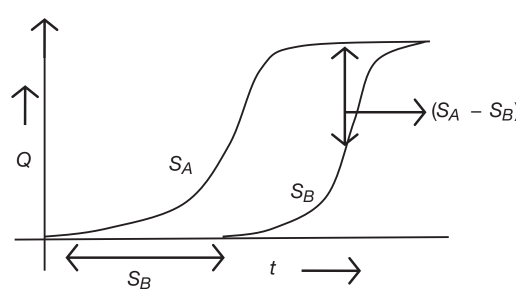


(b) ***S*-curve:** It is the hydrograph produced by a continuous effective rainfall at a constant rate for an infinite period. Each *S*-curve is specified by duration of UH from which it is derived. The average intensity of *S*-curve is $\frac{1}{D}$ cm/h. The discharge ordinate of *S*-curve gradually increases and reaches maximum value called equilibrium discharge at a time equation to 'time base' to the first UH.

$$\boxed{Q_s = 2.778 \times \frac{A}{D}}$$

Where
A = Catchment area in km^2
D = Duration of UH from which *S*-curves is derived

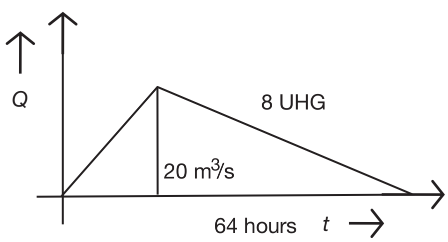
14. **Derivation of UH from *S*-curve:** Two *S*-curves are drawn *A* and *B* with lagging of T-hour. The ordinate of *B* is subtracted from *A*. These ordinates represent ordinates of direct run-off hydrograph of rainfall excess of duration *T* hour and magnitude of (*T*/*D*) cm. The ordinate differences ($S_A - S_B$) are divided by (*T*/*D*), the resulting ordinates represent a UH of *T* hour duration.



Example 3

A 8 hours unit hydrograph of catchment is triangular in shape with a base width of 64 hours and peak ordinate of 20 m^3/s. The equilibrium discharge of S-curve obtained by using this 8 hours unit hydrograph is ______.

Solution



$$\text{Area of catchment} = \frac{\text{Volume of run-off}}{\text{Depth of run-off}}$$

$$= \frac{\frac{1}{2} \times 20 \times 64 \times 60 \times 60}{\frac{1}{100} \times (100)^2}$$

$$Q_s = 2.778 \times \frac{A}{D} = 2.778 \times \frac{230.4}{8}$$

$$= 80 \text{ m}^3/\text{s}.$$

Maximum Flood Estimation, Flood Routing, River Gauging

Floods

1. **Standard project flood (SPF):** The flood which is the combination of meteorological and hydrological factors that is applicable to the basin is known as standard project flood.
2. **Maximum probable flood (MPF):** The extreme flood that is possible in a region is known as maximum probable flood. Standard project flood is 80% of maximum probable flood.
3. **Design flood:** The discharge of flood that is adopted for design of hydraulic structure.

Empirical Formula

1. **Dicken's formula:**

$$Q = CA^{3/4}$$

Where
Q = Discharge in cumecs
A = Area of basin in sq. km
The value of C is 6 for north Indian plains
The value of C is 22 to 28 for coastal Andhra Pradesh.

2. **Ryve's formula:**

$$Q = CA^{2/3}$$

The value of C = 6.8 for areas within 80 km from east coast.

= 10.2 for limited areas near hills.

3. **Inglis formula:**

$$Q = \frac{123A}{\sqrt{A + 10.4}} \approx 123A^{1/2}$$

Where, A = Area of catchment.

4. **Flood discharge by rational formula:**

The rational formula is applied for small culverts, bridges and small size catchments.

Peak flood discharge $Q_p = K \cdot P_c \cdot A$

Where,

$$K = \text{Coefficient of run-off} = \frac{\text{Run-off}}{\text{Rainfall}}$$

A = Area of catchment
P_c = Design intensity of rainfall in cm/h
t_c = Time of concentration.

5. **Isochrone:** Line joining points having equal time of travel of surface run-off in other words equal time of concentration.

6. **Flood fequency distribution functions:**

$X_T = \overline{X} + K\sigma_x$ is the general equation of hydrologic frequency analysis.

Where

X_T = Value of the variate X of a random hydrologic series with return period T

$\overline{X}$ = Mean of the variate
σ_x = Standard deviation of the variate
K = Fequency factor

The commonly used frequency distribution functions are:

(a) Gumbel's extreme value distribution
(b) Log-Pearson type III distribution and
(c) Log-normal distribution

In Gumbel's extreme value distribution,

$$X_T = \bar{X} + K\sigma_x$$

$$K = \frac{y_T - 0.577}{1.2825}$$

$$\text{where, } y_T = -\left[\ln \cdot \ln \frac{T}{T-1}\right]$$

$$= -\left[0.834 + 2.303 \log \frac{T}{T-1}\right]$$

Example 4

For a river valley project, the following results were obtained from flood frequency analysis using Gumbel's method:

Return Period (Years)	Peak Flood (m^3/s)
50	28000
70	34000

Estimate the flood magnitude with a return period of 200 years.

Solution

From Gumbel's equation:

$$X_T = \bar{X} + K_T\sigma_{x-1}$$
$$X_{70} = \bar{X} + K_{70}\sigma_{x-1}$$
$$X_{50} = \bar{X} + K_{50}\sigma_{x-1}$$

$$(K_{70} - K_{50})\sigma_{x-1} = X_{70} - X_{50}$$
$$= 34000 - 28000 = 6000$$

$$K_T = \frac{y_T - \overline{y_n}}{S_n}$$

$$\Rightarrow (y_{70} - y_{50})\frac{\sigma_n - 1}{S_n} = 6000$$

$$y_T = -\left[\ln \cdot \ln \frac{T}{T-1}\right]$$

$$y_{70} = -\left[\ln \cdot \ln\left(\frac{70}{69}\right)\right] = 4.24$$

$$y_{50} = -\left[\ln \cdot \ln\left(\frac{50}{49}\right)\right] = 3.9$$

$$\frac{\sigma_n - 1}{S_n} = \frac{6000}{4.24 - 3.9} = 17647.05$$

If $T = 200$ years,

$$y_{200} = \left[\ln \cdot \ln\left(\frac{200}{199}\right)\right] = 5.29$$

$$(y_{200} - y_{70})\frac{\sigma_n - 1}{S_n} = x_{200} - x_{70}$$

$$\Rightarrow (5.29 - 4.24)(17646.05) = x_{200} - 34000$$
$$x_{200} = 52529.4 \text{ m}^3/\text{s}.$$

6. As per CWC guidelines to select floods:

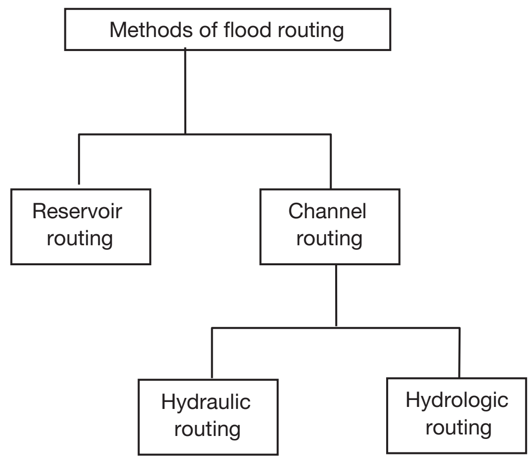
(a) For spillways for major and medium projects with storage more than 60 Mm^3 recommended design flood is either probable maximum flood or flood frequency method with return period of 1000 years.

(b) For permanent barrages and minor dams with capacity less than 60 Mm^3 recommended design flood is standard probable flood (or) flood with time period of 100 years whichever is higher.

(c) Aqueducts is recommended for a design flood for time period of 50 years.

7. Flood routing: The process of calculating water levels in a reservoir, storage quantities and out flow rates corresponding to particular inflow hydrograph at various instants is known as flood routing.

Methods of food routing:



(a) Reservoir routing: Reservoir routing is done to predict the variation in reservoir elevation and outflow discharge with time.

(b) Channel routing: It is done to find the changes in shape of the hydrograph as it travels down the channel.

(c) Hydrologic routing: This type of routing employs equation of continuity.

(d) Hydraulic routing: This type of routing employs equation of continuity, equation of motion of unsteady flow and St Venant equations.

Basic equation of flood routing:

$$\boxed{I - Q = \frac{ds}{dt}}$$

Where

I = Inflow rate

Q = Outflow rate

S = Storage

$\frac{ds}{dt}$ = Change of storage with time

Hydrologic channel routing (Muskingum equation):

$$\boxed{S = k[x \cdot I + (1-x)Q]}$$

Where

S = Storage

K = Storage time constant

x = Weighing factor

For natural channels, x lies between 0 to 0.3.
In other words,

$$\boxed{Q_2 = C_0 I_2 + C_1 I_1 + C_2 Q_1}$$

Where,

I_1, I_2 = Inflow rates before and after time interval Δt
Q_1, Q_2 = Outflow rates before and after time interval Δt
C_0, C_1, C_2 = Routing coefficients

$$C_0 = \frac{-Kx + 0.5\Delta t}{K - Kx + 0.5\Delta t}$$

$$C_1 = \frac{Kx + 0.5\Delta t}{K - Kx + 0.5\Delta t}.$$

Example 5

At a time 3rd hour and 4th hour, the inflow values into a channel are 18 m^3/s and 42 m^3/s respectively. The C_0 and C_1 in the Muskingum equation are 0.042 and 0.538 respectively.

If the outflow at 3rd hour were 15 m^3/s, then what will be the corresponding outflow at 4th hour?

Solution

$Q_2 = C_0 I_2 + C_1 I_1 + C_2 Q_1$

Here

$C_0 = 0.042$	$I_1 = 18$ m^3/s
$C_1 = 0.538$	$I_2 = 42$ m^3/s
$C_0 + C_1 + C_2 = 1$	$Q_1 = 15$ m^3/s
$C_2 = 1 - (C_0 + C_1)$	$Q_2 = ?$

$= 1 - (0.042 + 0.538) = 0.42$

$Q_2 = (0.042 \times 42) + (0.538 \times 18) + (0.42 \times 15)$

$= 17.748$ m^3/s.

8. Important definitions:

(a) Lag: The time difference between the peaks of inflow and outflow hydrographs is known as lag.

(b) Attenuation: In the process of routing the peak of outflow hydrograph becomes smaller than that of the inflow hydrograph. This reduction in the peak value is 'attenuation'. This attenuation occurs due to the friction of the river and when the flood wave passes through the reservoir.

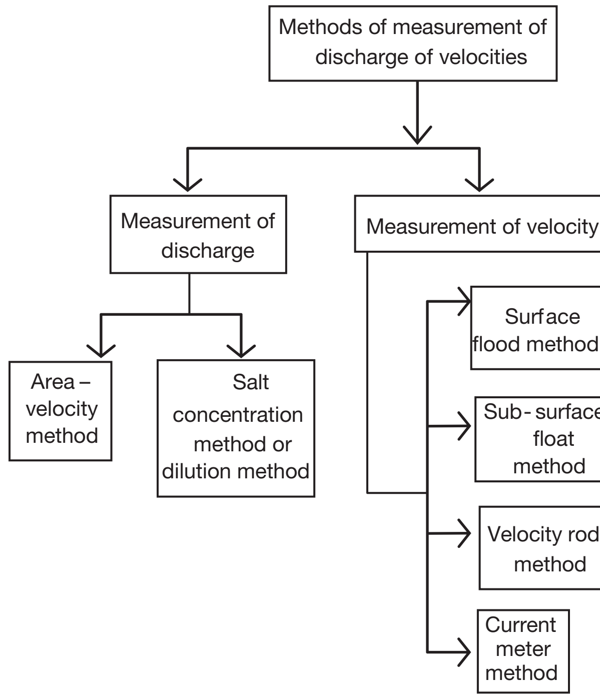
(c) Linear channel: The channel in which time required to translate the discharge through given reach. There is no attenuation of peak.

(d) Linear reservoir: The reservoir in which storage is directly proportional to the outflow rate i.e., $S \propto Q$.

(e) Prism storage: Volume formed by an imaginary line parallel to the channel bottom drawn at the outflow section water surface.

(f) Wedge storage: A wedge like volume formed between the actual water surface profile and the surface of prism storage. It is +ve for advancing flood and –ve for receding flood.

9. River gauging: River gauging is the measure of discharge of river.



(a) Measurement of discharge by area-velocity method: The area of the river are calculated by measuring the depth of water by sounding rod and the velocity of flow is measured by floats, sub-floats, etc.

$\therefore Q = A \times V$

(b) Measurement of velocity by surface float method: A cork is allowed to flow on the surface of the river for a known distance. The time taken to travel the known distance is noted. Thus the velocity of the river is calculated by the formula.

$V = d \times t$ = Distance travelled × Time taken.

The velocity obtained here is multiplied by a constant 0.85.

(c) Measurement of velocity by current meter method: The velocity of the river is calculated by Price current meter and Gurley current meter.

(d) Measurement of velocity by sub-surface float method: The velocity calculated by this method is similar to surface float method. The only difference is that the cork is allowed to flow just below the surface of the river.

(e) Measurement of velocity by velocity rod method: The velocity rod is introduced into the river and a weight is hanged at the end of the rod. The velocity of the rod gives the velocity of river directly.

(f) Measurement of discharge by salt concentration method: Depending of the equation of continuity the equation can be written as,

$$QC_0 + qC_1 = (Q + q_1)C_2$$

$$\Rightarrow Q = q_1\left[\frac{C_1 - C_2}{C_2 - C_0}\right]$$

Where

C_1 = Concentration injected into the stream

C_2 = Concentration of tracer at downstream section

C_0 = Concentration of the stream

q_1 = Discharge of the tracer

Q = Discharge of the stream.

Example 6

A 600 gm/lit solution of tracer is used in measurement of discharge of stream. It was dozed at a constant rate of 4 lit/s and at a *D*/s, the equilibrium concentration was measured as 4 ppm. The discharge of stream is

Solution

$Q = C_0 + q_1C_1 = (Q + q_1)C_2$

$Q = ?$

$C_2 = 4$ ppm $= 4$ gm/lit

$C_1 = 600$ gm/lit

$C_0 = 0$

$q_1 = 4$ lit/s

$$Q = q_1\left[\frac{C_1 - C_2}{C_2 - C_0}\right] = 4\left[\frac{600 - 4}{4 - 0}\right]$$

$$= 596 \text{ m}^3/\text{s} \sim 600 \text{ m}^3/\text{s}$$

(g) Velocity of flow can also be calculated by the equation,

$V = a{\cdot}N_s + b$

Where

a, b = Constants of the meter

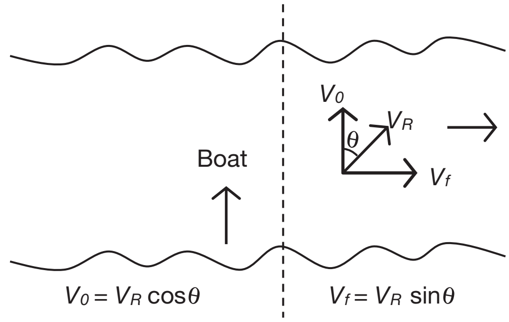
N_s = Revolutions per second of the meter

V = Stream velocity of the instrument location in m/s.

(i) For shallow streams of depth 3 m, the velocity measured at 0.6 times the depth of flow, is taken as average velocity.

(ii) For moderately deep streams the velocity is observed at two points one at 0.2 times the depth of flow and other at 0.8 times the depth of flow.

(h) Moving boat method:



The flow velocity is V_f and the resultant velocity is V_R which makes an angle θ with the direction of boat. The resultant direction is registered by the current meter.

Well Hydraulics

The movement of water below the surface of the earth is known as ground water hydrology.

1. **Aquifer:** Aquifer is the geological formation which allow the water to penetrate inside and outside. It has high porosity and permeability.

   Example: Sand and gravel.

2. **Aquiclude:** It is the geological formation which allows the water to enter inside but does not transmit or supply water easily. It is highly porous but impermeable.

   Example: Clays

3. **Aquifuge:** It is an impermeable and non-porous geological formation which does not allow the water to enter inside and does not transmit any water.

   Example: Unconsolidated rocks

4. **Aquitard:** It is the geological formation which transmits the water easily but does not allow the water to enter inside. It is highly permeable but non-porous.

5. **Porosity:** It is defined as the ratio of the volume of openings or pores V_v in the material to its total volume V and is expressed as percentage.

$$n = \frac{V_v}{V} \times 100$$

6. **Specific yield:** It is the ratio of volume of water which after being saturated can be drained by gravity to its own volume expressed as percentage (S_y).

$$S_y = \frac{W_s}{V} \times 100$$

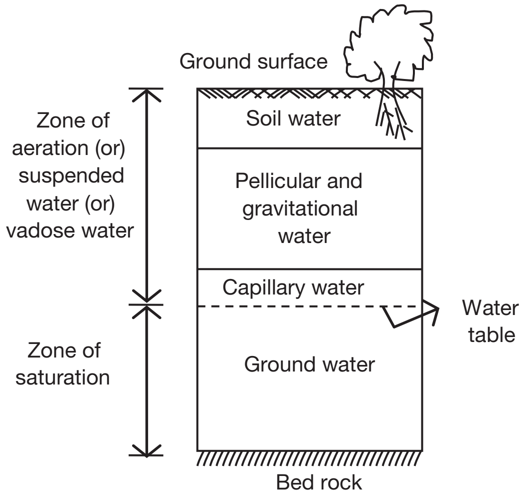
7. **Specific retention:** It is the ratio of volume of water it will retain after saturation against the force of gravity to its own volume expressed as percentage (S_r).

$$S_r = \frac{W_r}{V} \times 100$$

Porosity = Specific yield + Specific retention

$n = S_y + S_r$.

8. Divisions of surface water:

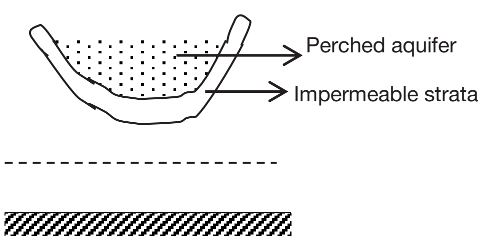


9. Types of aquifers:

(a) Unconfined aquifer: It is the zone in which the water table serves as upper surface of zone of saturation.

(b) Confined aquifer: It is one in which ground water is confined under pressure by relatively impermeable strata.

(c) Perched aquifer: It is an aquifer in which the ground water is separated from the main ground water by an impermeable stratum.



10. Storage coefficient: The water yielding capacity of a confined aquifer can be expressed in term of storage coefficient. The volume of water that an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in component of head normal to the surface is known as storage coefficient. In general storage coefficient ranges between 0.00005 to 0.005.

11. Coefficient of permeability: It is the velocity of flow which will occur through the total cross-sectional area of soil under a unit hydraulic gradient.

Coefficient of transmissibility is product of coefficient of permeability and aquifer thickness

$$\boxed{T = bK}$$

12. Darcy's law:

$$Q = KiA$$

$$\Rightarrow \frac{Q}{A} = Ki = V$$

Where

Q = Rate of flow

i = Hydraulic gradient

K = Darcy's coefficient of permeability

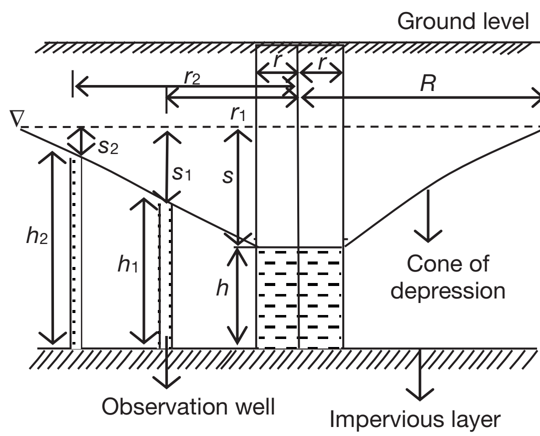
A = Total cross-section of soil mass perpendicular to direction of flow

V = Flow velocity

Assumptions of Darcy's law:

1. Law is valid only for laminar flow:
2. Law is valid when the Reynold's number is less than 1.

Steady Radial Flow in a Well for Unconfined Aquifer (Dupit's Theory)



Steady radial flow for unconfined aquifer

$$Q = KAi$$

Where

$$A = (2\pi x) \times (y) = 2\pi xy$$

$$i = \frac{dy}{dx}$$

$$Q = K(2\pi xy)\frac{dy}{dx}$$

$$Q\frac{dx}{x} = 2\pi Kydy$$

$$Q\int_r^R \frac{dx}{x} = 2\pi K\int_h^H ydy$$

$$Q[\log_e x]_r^R = 2\pi K\left[\frac{y^2}{2}\right]_h^H$$

$$Q\log_e\frac{R}{r} = 2\pi K\left[\frac{H^2 - h^2}{2}\right];$$

$$Q = \frac{2\pi K\left[\frac{H^2 - h^2}{2}\right]}{\log_e \frac{R}{r}}$$

If the two observation wells at radial distance r_1 and r_2, and the depths of water in them are h_1 and h_2 respectively, then

$$Q = \frac{\pi K\left(h_2^2 - h_1^2\right)}{\log_e \frac{r_2}{r_1}}$$

If drawdown(s) is measured then

$$s = H - h$$

$$\Rightarrow H = s + h$$

$$H + h = s + 2h$$

$$\therefore Q = \frac{\pi K(H-h)(H+h)}{\log_e \frac{R}{r}} = \frac{\pi Ks(s+2h)}{\log_e \frac{R}{3r}}.$$

Steady Radial Flow in a Well for Confined Aquifer (Dupit's Theory)

$$Q = KiA$$

Where,

$A = 2\pi xb$

$b =$ Thickness of confined aquifer

$$i = \frac{dy}{dx}$$

$$Q = K\left(\frac{dy}{dx}\right)(2\pi xb)$$

$$Q\frac{dx}{x} = 2\pi Kbdy$$

$$Q\int_r^R \frac{dx}{x} = 2\pi Kb\int_h^H dy$$

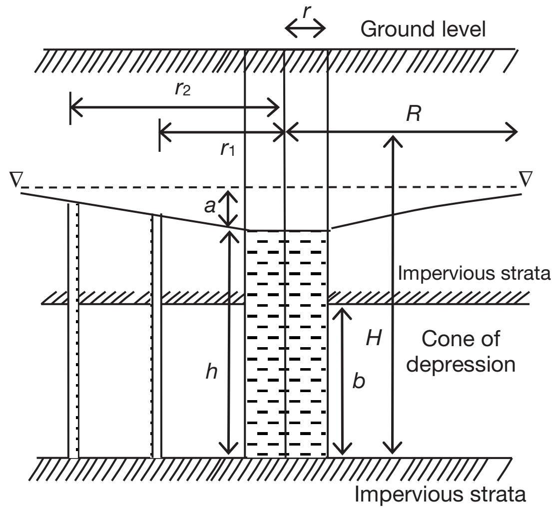
$$Q[\log x]_r^R = 2\pi Kb[y]_h^H$$

$$Q = \frac{2\pi Kb(H-h)}{\log_e \frac{R}{r}}$$

$$= \frac{2\pi Kbs}{\log_e \frac{R}{r}} = \frac{2\pi Ts}{\log_e \frac{R}{r}} (T = bK).$$

If h_1 and h_2 are the measured depth of water in two observation wells situated at distances r_1 and r_2, then

$$Q = \frac{2\pi Kb(h_2 - h_1)}{\log_e \frac{r_2}{r_1}}$$



Steady radial flow for confined aquifer

Example 7

A well penetrates fully of diameter 20 cm into confined aquifer. After a long period of pumping at a rate of 2720 lit/min, the observations of drawdown taken at 10 m and 100 m distances from the center of the well are found to be 3 m and 0.5 m respectively. The transmissibility of aquifer is

Solution

Radius of well $r = \frac{20}{2} = 10 \text{ cm} = 0.1 \text{ m}$

Discharge $Q = 2.72 \text{ m}^3\text{/min}$

$= 2.72 \times 60 \times 24$

$= 3916.8 \text{ m}^3\text{/day}$

At $r_1 = 10$ m, drawdown $S_1 = 3$ m

At $r_2 = 100$ m, drawdown $S_2 = 0.5$ m

$$Q = \frac{2\pi Kb(s_1 - s_2)}{\log_e\left(\frac{r_2}{r_1}\right)}$$

$$= \frac{2\pi T(s_1 - s_2)}{\log_e\left(\frac{r_2}{r_1}\right)}$$

$$3916.8 = \frac{2\pi T(3 - 0.5)}{\log_e\left(\frac{100}{10}\right)}$$

$T = 574.4 \text{ m}^2\text{/day}.$

Example 8

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 0.4 and the specific retention is 0.15, what is the change in the ground water storage of aquifer?

Solution

$S_y + S_R = n$

$S_y = 0.4 - 0.15$

$S_y = 0.25$

Specific yield,

$$S_y = \frac{\text{Volume of water extracted by force of gravity}}{\text{Total volume of aquifer}}$$

∴ Change in ground water storage = Volume of water extracted.

$= S_y \times \text{Total volume of aquifer}$

$= 0.25 \times 150(23 - 20)$

$= 112.5$ ha-m.

13. **Specific capacity:** It is the yield of well per unit drawdown. It is also called as storativity.

    Specific capacity $= \dfrac{Q}{s}$.

14. **Assumptions of Dupits theory:**
    (a) Velocity of flow is proportional to tangent of hydraulic gradient.
    (b) Flow is horizontal and uniform.
    (c) Aquifer is homogeneous, isotropic, the well penetrates and receives water from the entire thickness of aquifer.
    (d) Coefficient of transmissibility is constant.
    (e) Flow is laminar and Darcy's law is valid.

15. **Open well—Recuperation test:** Discharge from the bottom of the well is,

$$Q = \left(\frac{K}{A}\right) \times A \times H$$

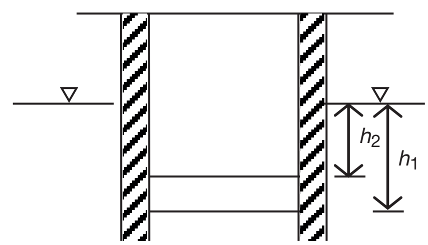
Where,

$$\frac{K}{A} = \frac{1}{T}\log_e\left(\frac{h_1}{h_2}\right)$$

h_1 = Depression head when pumping topped

h_2 = Depression head at a time T after pumping stopped.

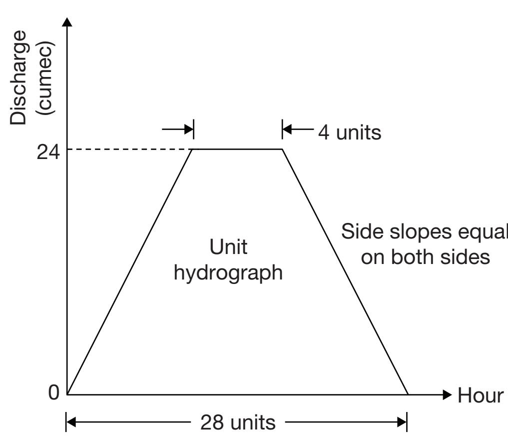
K = Constant



EXERCISES

1. The peak discharge of the instantaneous unit hydrograph of a basin, when compared to the peak discharge of a 4 hours unit hydrograph of that basin, would be
   (A) greater (B) equal
   (C) equal or lesser (D) lesser

2. A 2 hours unit hydrograph can be approximated as trapezoidal as shown in the figure. The unit hydrograph refers to the catchment of area



   (A) 138.24 km^2 (B) 0.0384 km^2
   (C) 384 m^2 (D) 3840 m^2

3. Match List I with List II and select the correct answer using the codes given below the lists:

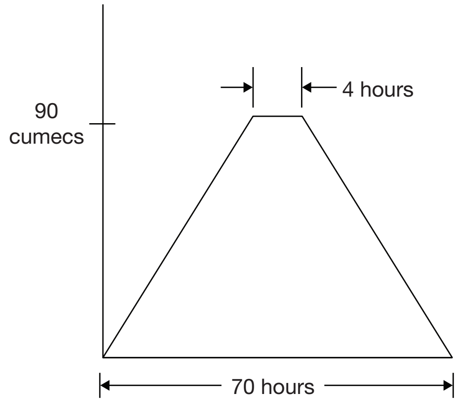
	List I		List II
a.	Rising limb of a hydrograph	1.	Depends on intensity of rainfall
b.	Falling limb of a hydrograph	2.	Function of total channel length
c.	Peak rate of flow	3.	Function of catchment slope
d.	Drainage density	4.	Function of storage characteristics

Codes:

	a	b	c	d		a	b	c	d
(A)	3	4	1	2	(B)	1	4	3	2
(C)	3	2	1	4	(D)	1	2	3	4

4. The ordinate of the Instantaneous Unit Hydrograph (IUH) of a catchment at any time t, is
   (A) the slope of the 1 hour unit hydrograph at that time.
   (B) the slope of the direct run-off unit hydrograph at that time.
   (C) difference in the slope of the S-curve and 1 hour unit hydrograph.
   (D) the slope of the S-curve with effective rainfall intensity of 1 cm/h.

5. A direct run-off hydrograph due to an isolated storm with an effective rainfall of 2 cm was trapezoidal in shape as shown in the figure. The hydrograph corresponds to a catchment area (in sq. km) of



(A) 790.2 (B) 599.4
(C) 689.5 (D) 435.3

6. A two hours storm hydrograph has 5 units of direct run-off. The two hours unit hydrograph for this storm can be obtained by dividing the ordinates of the storm hydrograph by
(A) 2 (B) 2/5
(C) 5 (D) 5/2

7. The number of revolutions of a current meter in 50 seconds were found to be 12 and 30 corresponding to the velocities of 0.25 and 0.46 m/s respectively. What velocity (in m/s) would be indicated by 50 revolutions of that current meter in one minute?
(A) 0.42 (B) 0.50
(C) 0.60 (D) 0.73

8. In a river, discharge is 173 m^3/s; water surface slope in 1 in 6000; and stage at the gauge station 10.0 m. If during a flood, the stage at the gauge station is same and the water surface slope is 1 in 2000, the flood discharge in m^3/s, is approximately
(A) 371 (B) 100
(C) 519 (D) 300

9. The parametes in Horton's infiltration equation [$f(t) = f_c + (f_0 - f_c)e^{-kt}$] are given as, $f_0 = 7.62$ cm/h, $f_c = 1.34$ cm/h and $k = 4.182$/h. For assumed continuous ponding the cumulative infiltration at the end of 2 hours is
(A) 2.68 cm (B) 1.50 cm
(C) 1.34 cm (D) 4.18 cm

10. The direct run-off hydrograph of a storm obtained from a catchment is triangular in shape and has a base period of 80 hours. The peak flow rate is 30 m^3/s and catchment area is 86.4 km^2. The rainfall excess that has resulted the above hydrograph is
(A) 5 cm (B) 8 cm
(C) 10 cm (D) 16 cm

11. A 6 hours unit hydrograph (UH) of a catchment is triangular in shape with a total time base of 36 hours and a peak discharge of 18 m^3/s. The area of the catchment (in sq. km) is
(A) 233
(B) 117
(C) 1.2
(D) Sufficient information not available

12. A 3 hours unit hydrograph U_1 of a catchment of area 235 km^2 is in the form of a triangle with peak discharge 30 m^3/s. Another 3 hours unit hydrograph U_2 is also triangular in shape and has the same base width as U_1, but has a peak flow of 90 m^3/s. What is the catchment area of U_2?
(A) 117.5 km^2 (B) 235 km^2
(B) 470 km^2 (D) 705 km^2

13. During a 6 hours storm, the rainfall intensity was 0.8 cm/h on a catchment of area 8.6 km^2. The measured run-off volume during this period was 256000 m^3. The total rainfall that was lost due to infiltration, evaporation and transpiration (in cm/h) is
(A) 0.80
(B) 0.304
(C) 0.496
(D) Sufficient information not available

14. The rainfall on five successive days in a catchment were measured as 3, 8, 12, 6 and 2 cms. If the total run-off at the outlet from the catchment was 15 cm, the value of the ϕ-index (in mm/h) is
(A) 0.0
(B) 1.04
(C) 1.33
(D) Sufficient information not available

15. The vertical hydraulic conductivity of the top soil at certain stage is 0.2 cm/h. A storm of intensity 0.5 cm/h occurs over the soil for an indefinite period. Assuming the surface drainage to be adequate, the infiltration rate after the storm has lasted for a very long time, shall be
(A) smaller than 0.2 cm/h
(B) 0.2 cm/h
(C) between 0.2 and 0.5 cm/h
(D) 0.5 cm/h

16. While applying the rational formula for computing the closing discharge, the rainfall duration is stipulated as the time of concentration because
(A) this leads to the largest possible rainfall intensity.
(B) this leads to the smallest possible rainfall intensity.
(C) the time of concentration is the smallest rainfall duration for which the rational formula is applicable.
(D) the time of concentration is the largest rainfall duration for which the rational formula is applicable.

Direction for questions 17 and 18:

An average rainfall of 16 cm occurs over a catchment during a period of 12 hours with a uniform intensity. The unit hydrograph (unit depth = 1 cm, duration = 6 hours) of the catchment rises linearly from 0 to 30 cumecs in six hours and then falls linearly from 30 to 0 cumecs in the next 12 hours. ϕ-index of the catchment is known to be 0.5 cm/h. Base flow in the river is known to be 5 cumecs.

17. Peak discharge of the resulting direct run-off hydrograph shall be
(A) 150 cumecs (B) 225 cumecs
(C) 230 cumecs (D) 360 cumecs

18. Area of the catchment in hectares is
(A) 97.20 (B) 270
(C) 9720 (D) 27000

19. The average rainfall for a 3 hours duration storm is 2.7 cm and the loss rate is 0.3 cm/h. The flood hydrograph has a base flow of 20 m^3/s and produces a peak flow of 210 m^3/s. The peak of a 3 hours unit hydrograph is
(A) 125.50 m^3/s (B) 105.50 m^3/s
(C) 77.77 m^3/s (D) 70.37 m^3/s

20. The rainfall during three successive 2 hours periods are 0.5, 2.8 and 1.6 cm. The surface run-off resulting from this storm is 3.2 cm. The ϕ-index value of this storm is
(A) 0.20 cm/h (B) 0.28 cm/h
(C) 0.30 cm/h (D) 0.80 cm/h

Direction for questions 21 and 22:

A 4 hours unit hydrograph of a catchment is triangular in shape with base of 80 hours. The area of the catchment is 720 km^2. The base flow and ϕ-index are 30 m^3/s and 1 mm/h, respectively. A storm of 4 cm occurs uniformly in 4 hours over the catchment.

21. The peak discharge of 4 hours unit hydrograph is
(A) 40 m^3/s (B) 50 m^3/s
(C) 60 m^3/s (D) 70 m^3/s

22. The peak flood discharge due to the storm is
(A) 210 m^3/s (B) 230 m^3/s
(C) 260 m^3/s (D) 720 m^3/s

23. During a 3 hours 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/h, 20 mm/h and 10 mm/h respectively and the infiltration was idealized as a Horton curve, $f = 6.8 + 8.7 \exp(-t)$ (f in mm/h and t in hour). What is the effective rainfall?
(A) 10.00 mm (B) 11.33 mm
(C) 12.43 mm (D) 13.63 mm

Direction for questions 24 and 25:

For a catchment, the S-curve (or S-hydrograph) due to a rainfall of intensity 1 cm/h is given by $Q = 1 - (1 + t) \exp(-t)$ (t in hour and Q in m^3/s).

24. What is the area of the catchment?
(A) 0.01 km^2 (B) 0.36 km^2
(C) 1.00 km^2 (D) 1.28 km^2

25. What will be the ordinate of a 2 hours unit hydrograph for this catchment at $t = 3$ hours?
(A) 0.13 m^3/s (B) 0.20 m^3/s
(C) 0.27 m^3/s (D) 0.54 m^3/s

26. The standard project flood is
(A) same as the probable maximum flood.
(B) same as the design flood.
(C) smaller than the probable maximum flood.
(D) larger than the probable maximum flood by a factor implying safety factor.

27. Dickens formula predicts maximum flood discharge Q, in terms of the area A, and the coefficient c, as $Q = cA^n$. The value of n is
(A) 0.25 (B) 0.50
(C) 0.67 (D) 0.75

28. Match the following:

a.	Coriolis coefficient	**1.**	Perched quifer
b.	Khosla's curves	**2.**	Prediction of flood peaks
c.	Gumbel's method	**3.**	Weirs and barrages
d.	Manning's coefficient	**4.**	Velocity distribution
		5.	Open channel flow

29. The design flood for a culvert should be preferably
(A) the probable maximum flood.
(B) obtained from statistical considerations.
(C) the highest observed flood.
(D) obtained from a flood formula.

30. Match the following

a.	Coriolis coefficient	**i.**	Weirs and barrages
b.	Khosla's curves	**ii.**	Open channel flow
c.	Gumbel's method	**iii.**	River meandering
d.	Manning's coefficient	**iv.**	Estimation of flood peaks

31. Muskingham method for routing of flood
(A) is used for routing floods through reservoirs.
(B) is a method of routing that uses continuity and momentum equations.
(C) is a hydrologic method of routing floods through streams.
(D) is one in which only energy equation is used.

32. Storage coefficient of a compressible confined aquifer is a function of
(A) specific weight of water, thickness of the aquifer, compressibility of the aquifer and that of water.
(B) permeability, thickness and compressibility of aquifer and compressibility of water.
(C) transmissibility of the aquifer and compressibility of water.
(D) transmissibility of aquifer and specific yield of aquifer.

33. Match List I (Well hydraulics parameters) with List II (Definition) and select the correct answer using the codes given below the lists:

	List I		List II
a.	Specific yield	**1.**	Discharge per unit drawdown of well
b.	Safe yield	**2.**	Same as specific retention
c.	Specific capacity	**3.**	Measure of water that can be removed by pumping
d.	Field capacity	**4.**	Limit of withdrawal from well without depletion of the aquifer
		5.	Water-bearing capacity of aquifer

Codes:

	a	b	c	d		a	b	c	d
(A)	4	3	2	5	(B)	3	4	1	2
(C)	4	3	1	2	(D)	3	4	2	5

34. The return period for the annual maximum flood at a given magnitude is 8 years. The probability that this flood magnitude will be exceeded once during the next 5 years is

(A) 0.625 (B) 0.966
(C) 0.487 (D) 0.3664

35. The stage-discharge relation in a river during the passage of flood is measured. If q_f is the discharge at the stage when water surface is falling and q_t is the discharge at the same stage when water surface is rising, then

(A) $q_f = q_t$
(B) $q_f < q_t$
(C) $q_f < q_t$
(D) $\frac{q_f}{q_t}$ = Constant for all stages

36. A linear reservoir is one in which

(A) storage varies linearly with time.
(B) storage varies linearly with outflow rate.
(C) storage varies linearly with inflow rate.
(D) storage varies linearly with elevation.

37. Consider the following statements. In case of flood routing in a river channel by Muskingum method, the coefficient x represents:

I. A dimensionless constant indicating the relative importance of inflow an outflow in determining storage.
II. A storage constant having the dimension of time.
III. In natural channels, x usually varies between 0.1 and 0.3.
IV. When the values of x equals 0.5, there exists the influence of both inflow and outflow on storage.

Which of these statements are correct?

(A) I, II, III and IV (B) I, III and IV only
(C) I, II and III only (D) I, III and IV only

38. By using Gumbel's method, the flood discharge with a return period of 500 years at a particular township neighbourhood was estimated as 18000 m^3/s with a probable error of 2000 m^3/s. What are the 95% confidence probability limits of the 500 year flood at the location?

(A) 16100 m^3/s to 19900 m^3/s
(B) 17050 m^3/s to 18950 m^3/s
(C) 14080 m^3/s to 21920 m^3/s
(D) 13600 m^3/s to 22400 m^3/s

39. Which of the following is not a continuous random variable?

(A) Annual peak flood
(B) Annual run-off
(C) Number of cyclones in a year
(D) Wind velocity

40. Storage in the channel is equal to

(A) prism storage (B) wedge storage
(C) largest of A and B (D) $(A + B)$

41. Which of the following formations does not contain any ground water?

(A) Aquifer (B) Acquifuge
(C) Aquitard (D) Aquiclude

42. Sodium dichromate solution with a concentration of 30 mg/cc is introduced into a stream at a rate of 1.7 lit/minute. The samples collected at a downstream section sufficiently far away indicated on equilibrium concentration of 0.001 ppm. Determine the discharge in the stream. (Assume no initial concentration of sodium dichromate in the stream)

(A) 424.5 m^3/s (B) 380.6 m^3/s
(C) 298.3 m^3/s (D) 484.1 m^3/s

Direction for questions 43 and 44:

Ordinates of 1 hour UGH at 1 hour intervals are 6, 8, 11, 14, 12, 2, 1 m^3/s.

43. Calculate the equilibrium discharge of S-curve in m^3/s.

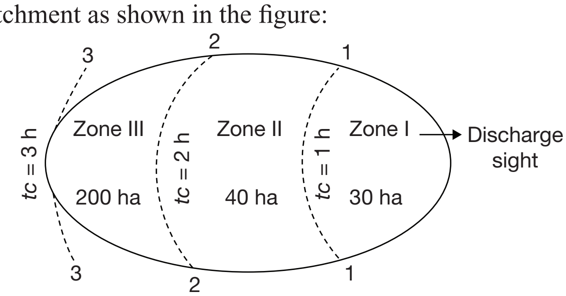
(A) 53 (B) 54
(C) 55 (D) 56

44. Calculate the maximum ordinate of 3 hours UHG in m^3/s.

(A) 9.33 (B) 8.33
(C) 12.33 (D) 13.33

Direction for questions 45 and 46:

A 4 hours rain of average intensity 1.6 cm/h falls over the catchment as shown in the figure:



The time of concentration from the lines 11, 22, 33 are 1 hour, 2 hours, and 3 hours respectively to the discharge measuring site. The values of run-coefficients are 0.4, 0.5, and 0.6 for 1st, 2nd, 3rd hours of rainfall respectively and there after attains a constant value of 0.65.

45. The discharge at the end of 3 hours period, at the measuring site is
(A) 1.03 m^3/s (B) 1.51 m^3/s
(C) 1.77 m^3/s (D) 2.04 m^3/s

46. The discharge at the end of 5 hours period, at the measuring site, is
(A) 0.58 m^3/s (B) 0.93 m^3/s
(C) 1.21 m^3/s (D) 1.53 m^3/s

47. Water present in artesian aquifer is usually
(A) at sub-surface atmospheric pressure.
(B) at atmospheric pressure.
(C) at 0.5 times the atmospheric pressure.
(D) above atmospheric pressure.

48. A double mass curve analysis is useful in
(A) consistency analysis.
(B) frequency analysis.
(C) storage computation analysis.
(D) guessing missing data in cases of non-homogenous terrain.

49. The land use of an area and the corresponding run-off coefficients are

Land use	Area (ha)	Run-off coefficient
Roads	10	0.7
lawn	20	0.1
Residential area	50	0.3
Industrial area	20	0.8

The equivalence run-off coefficient is?
(A) 0.15 (B) 0.36
(C) 0.4 (D) 0.51

50.

	List I		List II
a.	Unit hydrograph	1.	Design flood
b.	Synthetic unit hydrograph	2.	Permeability
c.	Darcy's law	3.	Ungauged basin
d.	Rational method	4.	1 cm run-off

Codes:

	a	b	c	d		a	b	c	d
(A)	2	3	4	1	(B)	2	1	4	3
(C)	4	3	2	1	(D)	4	1	2	3

51. A ground water basin consists of 10 km^2 area of plains. The maximum groundwater table fluctuations has been observed to be 1.5 m, consider specific yield of basin as 10%. What is the available ground water storage in million cubic metres?
(A) 1.0 (B) 1.5
(C) 2.5 (D) 2.0

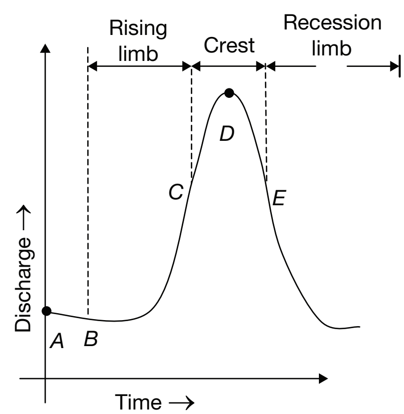
52. When 3.5 million m^3 of water was pumped out from an unconfined aquifer of 6.3 km^2 areal extent, the water table was observed to go down by 2.5 m. The specific yield of the aquifer is best approximated as
(A) 32% (B) 28%
(C) 25% (D) 22%

53. An *S*-curve hydrograph has been obtained for catchments of 270 km^2 from a 3 hours unit hydrograph. The equilibrium discharge for the *S*-curve is
(A) 750 m^3/s
(B) 277.8 m^3/s
(C) 250 m^3/s
(D) 187 m^3/s

54. Generally to estimate PMP, $P_m = 42.16\ D^{0.475}$ is used. (P_m is maximum depth of precipitation, D = Duration). What are the units of P_m and D in the equation?
(A) mm, second (B) cm, second
(C) mm, hour (D) cm, hour

55. The working head for open wells is generally taken to be ______ of the critical depression head.
(A) 1/3 (B) 1/2
(C) 2/3 (D) 3/2

56. Statement I and II are related to the hydrograph below.



Statement I: The recession curve after the point *E* represents the withdrawal of water from storage within the channel system.

Statement II: The discharge in the recession limb is independent of variations in rainfall and infiltration.
(A) I is true, II is false
(B) I is false, II is true
(C) Both I and II are true
(D) Both I and II are false

57. The saint venant equation in hydraulic routing represent
(A) continuity and momentum equations.
(B) continuity equation in two different forms.
(C) momentum equation in two different forms.
(D) momentum and energy equations.

58. The statements below are related to infiltration indices

I. Lowest value of ω-index under very wet initial conditions tend to be equal to ϕ-index.

II. The area below ω-index in rainfall hyetograph excludes depression storage and interception losses.

III. $\omega = \frac{\text{Total infiltration in time 't'}}{(t)\text{time}}$

t = time during which rainfall exceeds infiltration capacity rate.

(A) Only I is correct
(B) Both I and II are correct
(C) Both II and III are correct
(D) All I, II, III are correct

59. The formation length of 5.8 km between two streams A and B is made up of two layers. The bottom layer is pervious with a thickness of 7 m and hydraulic conductivity of 36 m /day. The upper layer is impervious. Find the discharge from stream A to stream B if the depths of water in them are 15 m and 12.5 m respectively

(A) 0.108 m^3/day (B) 0.23 m^3/day
(C) 0.38 m^3/day (D) 0.44 m^3/day

60. Observed annual peak flood of river Ganga in m^3/s for a period of 9 years are given. 100, 140, 80, 75, 40, 115, 62, 54, 95. Find the probability that annual peak flood flow of 115 m^3/s will not occur in river Ganga during next 20 years. (Use Weibulls equation.)

(A) 0.358 (B) 0.459
(C) 0.0226 (D) 0.0115

61. A 24 hours storm occurred over a catchment of 2 km^2 area and the total rainfall observed was 12 cm. An infiltration capacity curve prepared has the initial infiltration capacity of 1 cm/h and attained a constant value of 0.3 cm/h after 15 hours of rainfall with a Horton's constant k = 5/years. An IMB pan installed in the catchment indicated a decrease of 0.5 cm in the water level (after allowing for rainfall) during 24 hours of its operation. Other losses were found to be negligible. Determine the run-off volume from the catchment. Assume a pan coefficient of 0.7

(A) 40320 m^3 (B) 52860 m^3
(C) 63500 m^3 (D) 86200 m^3

62. A 2 hours UH of a catchment is in the form of a triangle with base of 10 hours and peak of 10 m^3/s occurring at 4th hour. If two rainfalls of 2 hours duration each with magnitudes of 3.6 cm and 4.6 cm occur in succession. Calculate the peak discharge of resulting DRH. Assume ϕ-index as 0.6 cm/h

(A) 20 m^3/s (B) 50 m^3/s
(C) 80 m^3/s (D) 100 m^3/s

63. While calibrating current meter the following observations were made. For 10 revolutions in 20 second, the velocity is found to be 0.13 m/s. For 21 revolutions in 35 seconds, the velocity is found to be 0.21 m/s. What will be the velocity of flow when the current meter records 26 revolutions in 40 seconds.

(A) 0.18 m/s (B) 0.25 m/s
(C) 0.28 m/s (D) 0.3 m/s

Previous Years' Questions

1. An isolated 4 hours storm occurred over a catchments as follows:

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

The ϕ-index for the catchment is 10 mm/h. The estimated run-off depth from the catchment due to the above storm is **[GATE, 2007]**

(A) 10 mm (B) 16 mm
(C) 20 mm (D) 23 mm

2. Ordinates of a 1 hour unit hydrograph at 1 hour intervals, starting from time t = 0 are 0, 2, 6, 4, 2, 1 and 0 m^3/s.

Catchment area represented by this unit hydrograph is **[GATE, 2007]**

(A) 1.0 km^2 (B) 2.0 km^2
(C) 3.2 km^2 (D) 5.4 km^2

3. A flood wave with a known inflow hydrograph is routed through a large reservoir. The outflow hydrograph will have **[GATE, 2008]**

(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.

Direction for questions 4 and 5:

The drainage area of a watershed is 50 km^2. The ϕ-index is 0.5 cm/h and the base flow at the outlet is 10 m^3/s. One hour unit hydrograph (unit depth = 1 cm) of the watershed is triangular in shape with a time base of 15 hours. The peak ordinate occurs at 5 hours.

4. The peak ordinate (in m^3/s/cm) of the unit hydrograph is **[GATE, 2012]**

(A) 10.00 (B) 18.52
(C) 37.03 (D) 185.20

5. For a storm of depth of 5.5 cm and duration of 1 hour, the peak ordinate (in m^3/s) of the hydrograph is **[GATE, 2012]**

(A) 55.00 (B) 82.60
(C) 92.60 (D) 102.60

Direction for questions 6 and 7:
Storm I of duration 5 hours, gives a direct run-off of 4 cm and has an average intensity of 2 cm/h.
Storm II of 8 hours, duration gives a run-off of 8.4 cm. (Assume ϕ-index is same for both the storms.)

6. The value of ϕ-index is (in cm/h) **[GATE, 2013]**
(A) 1.2 (B) 1.6
(C) 1 (D) 1.4

7. Intensity of Storm II in cm/h is **[GATE, 2013]**
(A) 2 (B) 1.5
(C) 1.75 (D) 2.25

8. A 1 hour rainfall of 10 cm has return period of 50 year. The 1 hour rainfall of 10 cm or more will occur in each of two successive year is **[GATE, 2013]**
(A) 0.04 (B) 0.2
(C) 0.02 (D) 0.0004

9. In reservoirs with an uncontrolled spillway, the peak of the plotted outflow hydrograph **[GATE, 2014]**
(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.

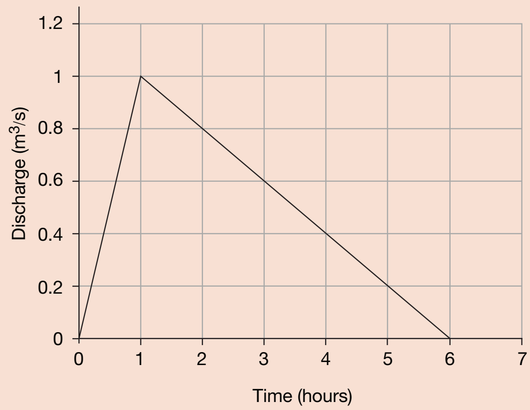
10. An isolated 3 hours rainfall event on a small catchment produces a hydrograph peak and point of inflection on the falling limb of the hydrograph at 7 hours and 8.5 hours respectively, after the start of the rainfall. Assuming, no losses and no base flow contribution, the time of concentration (in hours) for this catchment is approximately _______. **[GATE, 2014]**
(A) 8.5 (B) 7.0
(C) 6.5 (D) 5.5

11. The Muskingum model of routing a flood through a stream reach is expressed as $O_2 = K_0 I_2 + K_1 I_1 + K_2 O_1$, 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 _______. **[GATE, 2014]**
(A) −1 (B) −0.5
(C) 0.5 (D) 1

12. The 4 hours 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? **[GATE, 2015]**

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

13. The direct runoff hydrograph in response to 5 cm rainfall excess in a catchment is shown in the figure. The area of the catchment (expressed in hectares) is _________. **[GATE, 2016]**



14. The type of flood routing (List I) and the equation(s) used for the purpose (List II) are as follows: **[GATE, 2016]**

List I	List II
P Hydrologic flood routing	1. Continuity equation
Q Hydraulic flood routing	2. Momentum equation
	3. Energy equation

The correct match is
(A) P-1; Q-1, 2 and 3
(B) P-1; Q-1 and 2
(C) P-1 and 2; Q-1
(D) P-1 and 2; Q-1 and 2

15. Water table of an aquifer drops by 100 cm over an area of 1000 km^2. The porosity and specific retention of the aquifer material are 25% and 5%, respectively. The amount of water (expressed in km^3) drained out from the area is ______. **[GATE, 2016]**

16. The ordinates of a one-hour unit hydrograph at sixty minute interval are 0, 3, 12, 8, 6, 3 and 0 m^3/s. A two-hour storm of 4 cm excess rainfall occurred in the basin from 10 am. Considering constant base flow of 20 m^3/s, the flow of the river (expressed in m^3/s) at 1 pm is ______. **[GATE, 2016]**

17. A tracer takes 100 days to travel from Well 1 to Well 2 which are 100 m apart. The elevation of water surface in Well 2 is 3 m below that in Well 1. Assuming porosity equal to 15%, the coefficient of permeability (expressed in m/day) is **[GATE, 2016]**
(A) 0.30
(B) 0.45
(C) 1.00
(D) 5.00

Answer Keys

Exercises

1. A **2.** A **3.** A **4.** D **5.** B **6.** C **7.** C **8.** D **9.** D **10.** A
11. B **12.** D **13.** B **14.** C **15.** C **16.** C **17.** B **18.** C **19.** B **20.** C
21. B **22.** A **23.** D **24.** B **25.** C **26.** C **27.** D **28.** a-4, b-3, c-2, d-5 **29.** B
30. a-iii, b-i, c-iv, d-ii **31.** C **32.** A **33.** B **34.** D **35.** B **36.** B **37.** B **38.** C
39. C **40.** D **41.** B **42.** A **43.** B **44.** C **45.** D **46.** A **47.** D **48.** A
49. C **50.** C **51.** B **52.** D **53.** C **54.** C **55.** A **56.** C **57.** A **58.** B
59. A **60.** D **61.** D **62.** B **63.** B

Previous Years' Questions

1. C **2.** D **3.** A **4.** B **5.** D **6.** A **7.** D **8.** D **9.** B **10.** D
11. D **12.** 22 **13.** 21.6 **14.** B **15.** 0.2 **16.** 60 **17.** D