HYDROLOGY

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Hydrologic Cycle

— Balance between precipitation and evaporation is maintained.
— Total water resource on Earth is always constant.
— Sun is main energy source for hydrological cycle.

Rainfall or Precipitation

Mass inflow – Mass outflow = Change in storage (Δs)
Mass inflow is by precipitation (P)
Mass outflow is by surface runoff (R), ground water net outflow (G), evaporation (E) and transpiration (T)

$$P - (R + G + E + T) = \Delta s$$

Rain Gauge Density

It is the average area served by a rain gauge, i.e.

$$\text{Rain gauge density} = \frac{\text{Total area}}{\text{Total number of rain gauges}}$$

Optimum Number of Rain Gauges

$$\text{Optimum no. of rain gauges, } n = \left(\frac{C_V}{e}\right)^2$$

e – allowable degree of error (in %) of mean rainfall measurement.
C_V – coefficient of variation.

$$C_V = \left(\frac{\sigma}{P_a}\right) \times 100$$

where,
σ = standard deviation

$P_a = \dfrac{\Sigma P}{m}$, i.e. average rainfall.

$$\sigma = \sqrt{\left(\Sigma P^2 - \frac{(\Sigma P)^2}{m}\right)\left(\frac{1}{m-1}\right)} = \sqrt{\frac{\Sigma\left(P_i - \overline{P}\right)^2}{m-1}}$$

m – number of stations.
P_i – precipitation at i^{th} station.

Finding Out Missing Rainfall Data

To find annual precipitation of station x, P_x, having normal annual precipitation N_x.

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

$P_1, P_2, P_3, ..., P_m$ – precipitations of 'm' nearby stations.
$N_1, N_2, N_3, ..., N_m$ – normal annual precipitations of these stations.

Index of Wetness

$$\text{Index of wetness} = \frac{\text{Actual rainfall at a place in 1 year}}{\text{Normal annual rainfall at that place}}$$

If wetness index = 70%, it means there is rainfall deficiency of 30%.

Methods to Find Mean Precipitation

1. Arithmetic Mean Method:—

$$\overline{P} = \frac{P_1 + P_2 + P_3 + ... + P_m}{m} = \frac{\sum_{i=1}^{m} P_i}{m}$$

Here, equal weightage is given to all stations.

2. Thiéssen Polygon Method:—

$$\overline{P} = \frac{P_1A_1 + P_2A_2 + ... + P_iA_i}{A_1 + A_2 + ... + A_i} = \frac{\sum_{i=1}^{m} A_i \times P_i}{\sum_{i=1}^{m} A_i}$$

Weightage is given to different stations.

3. Isohyetal Method:—

$$\overline{P} = \frac{\sum_{i=1}^{m}\left(\frac{P_i + P_{i+1}}{2}\right) \times A_i}{A}$$

$\dfrac{A_i}{A}$ is called weightage factor.

A_i = enclosed area.

Depth Area Duration Analysis (DAD Analysis)

The average depth of rainfall in a given area decreases with area in an exponential relation.

$$P_{avg} = P_o \cdot e^{-k \cdot A^n}$$

P_{avg} – average depth.
P_o – height amount of rainfall.
A – area under consideration.
k, n – constants.

FREQUENCY OF RAINFALL

Return Period (T) : Average time interval between occurence of rainfall of magnitude greater than or equal to specific magnitude (x).

Exceedence Probability (P) : The probability of getting a rainfall of magnitude greater than or equal to a specific magnitude.

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

Similarly, the probability of non-receiving rainfall (q),

$$q = 1 - p$$

Probability of getting the rainfall r times in n successive years.

$$P_{n,r} = {}^nC_r \cdot p^r \cdot q^{n-r}$$

$${}^nC_r = \frac{n!}{r!(n-r)!}$$

When the annual rainfall series is arranged in descending order, the return period (T) for magnitude at position m in the list of total n enteries is given by :

$$T = \frac{n+1}{m}$$

$$\therefore \quad P = \frac{m}{1+n} \qquad \text{(Weibull formula)}$$

Similarly, $$T = \frac{n}{m} \qquad \text{(California formula)}$$

Probable Maximum Precipitation (PMP)

It is the extreme limit of the rainfall in a given duration in an area.

$$PMP = \overline{P} + k\overline{\sigma}$$

$\overline{p}$ – mean of annual rainfall.

k – frequency factor.

$\overline{\sigma}$ – standard deviation.

EVAPORATION

It is the process by which liquid changes from liquid into solid state below its boiling point.

Measurement of Evaporation

Evaporation is estimated by evaporimeters, emperical equations or by analytical methods.

1. **Types of Evaporimeters:—**
   (a) Class A evaporation pans (US class A pan).
   (b) ISI pan (or IMD pan).

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

Value of C_p:

0.70 for Class A pan.

0.80 for ISI pan.

Points to be noted

- Reservoir evaporation volume rate, $V = A \cdot E_p \cdot C_p$.
  A – average exposed area of reservoir.
  E_p – pan evaporation loss rate.
  C_p – pan coefficient.
- Evaporation rate, (E_r)

$$E_r = \frac{R}{L \cdot P}$$

R – radiation $\left(\frac{W}{m^2}\right)$.

L – latent heat of vaporisation $\left(\frac{J}{kg}\right)$.

P – mass density of water $\left(\frac{kg}{m^3}\right)$.

EVAPOTRANSPIRATION

Transpiration is the loss of water from the plants. It is measured by phytometer.

Evapotranspiration is the sum of evaporation and transpiration.

INFILTRATION

During precipitation, a part of the water is absorbed by the soil. This is called infiltration.

Infiltration Capacity (f_c)

The maximum rate at which a given soil absorbs water in a given time is called infiltration capacity. It is expressed in cm/hr or mm/hr. Sandy soil has more infiltration capacity than clayey soil.

If 'f' is the actual rate of infiltration and 'i' is the intensity of rainfall, then

$f = f_c$ if $i \geq f_c$ (intensity of rainfall more than infiltration rate)

$f = i$ if $i < f_c$

Horton's Infiltration Equation

The infiltration capacity decreases with time. This is given by Horton's equation.

According to Horton's equation, rate of infiltration 'f' is given by

$$f = f_c + (f_o - f_c)re^{-kt}$$

$$k = \frac{f_o - f_c}{F_c}$$

f_o – initial rate of infiltration.

f_c – maximum rate of infiltration.

k – a constant depending on soil.

F_c – area under infiltration curve (shaded area)

Infiltration Indices

1. ϕ *index:—*

   Infiltration indices represent average rate of infiltration. ϕ index is the average rainfall intensity above which rainfall is equal to runoff. The amount of rainfall excess of ϕ index is called 'rainfall excess'. The initial loss is considered with infiltration.

$$\phi \text{ index} = \frac{P - R}{t}$$

2. P – Total rainfall at time, t.
   R – total runoff depth.
   t – duration of excess rainfall.

   W-index

   It is the modified equation of ϕ index. Here, initial losses are considered separately.

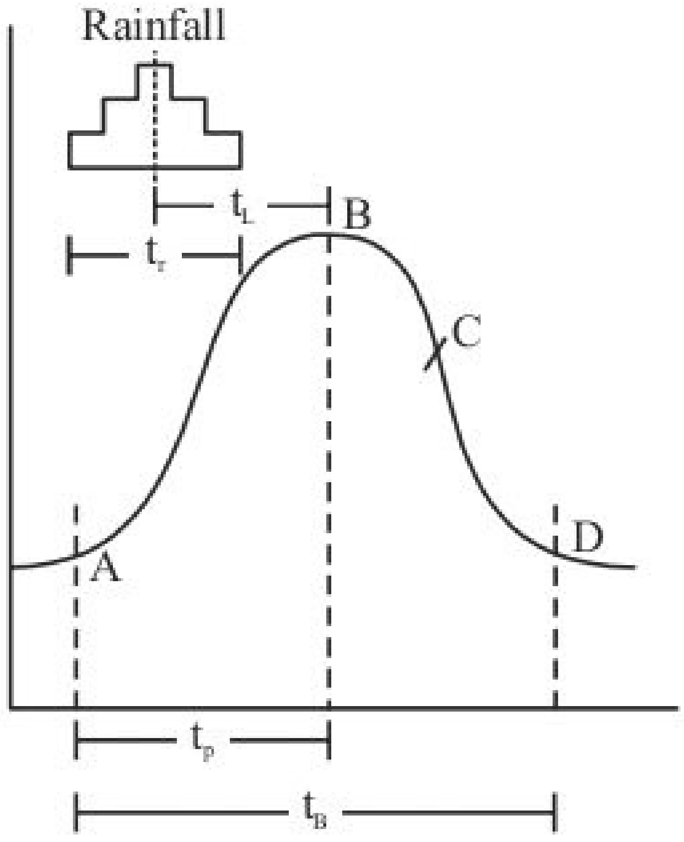
$$W \text{ index} = \frac{P - R - I_L}{t}$$

I_L – initial losses.

HYDROGRAPH

It is the graph of discharge in a stream with time.

Rising limb and crest is controlled by basin and storm (rainfall) characteristics while recession limb is entirely controlled by basin characteristics.

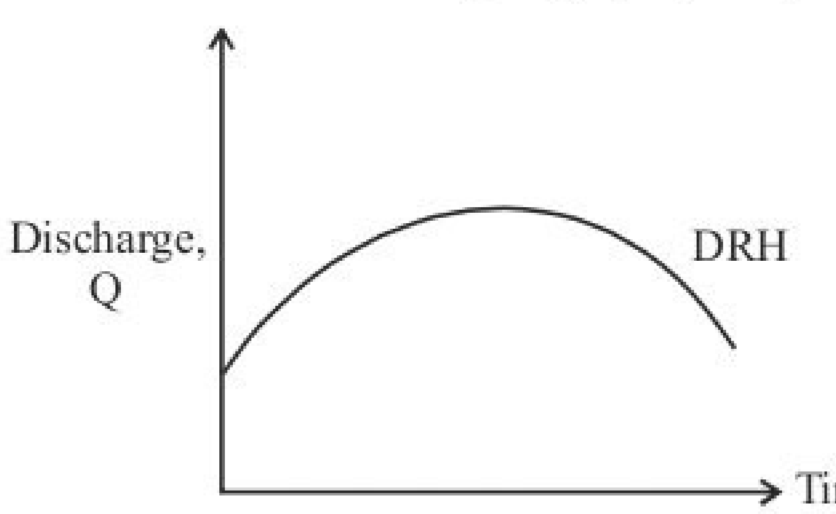


t_B – time base
t_p – time till peak discharge from starting time
t_r – rainfall duration
t_L – lag time, i.e. time between centre of mass of rainfall to C.M. of hydrograph
AB – rising limb
BD – recession club

Base Flow Separation

The base flow is separated from the total storm hydrograph to obtain the relationship between surface flow hydrograph and effective rainfall.

The surface runoff hydrograph obtained by base flow separation is called Direct Runoff Hydrograph (DRH).

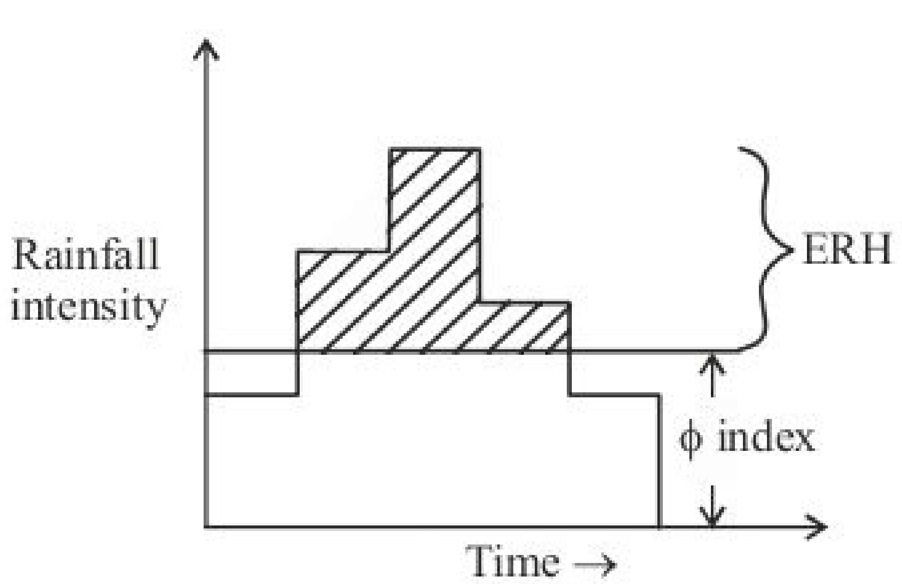


Total area of DRH gives total runoff in that area.

When initial losses and infiltration losses are deducted from the hyetograph, Effective Rainfall Hyetograph (ERH) is obtained. Both DRH and ERH represent same quantity but different units.

Unit Hydrograph (UH)

UH is the DRH resulting from one unit depth (1 cm) of rainfall excess occurring uniformly over the basin and at a uniform rate for a specified duration (D). It is called D-hour unit hydrograph.



Eq.: 6 hour unit hydrograph means uniform intensity of rainfall is

$$\frac{1 \text{ cm}}{6 \text{ hr}} = \left(\frac{1}{6}\right) \text{cm/hr.}$$

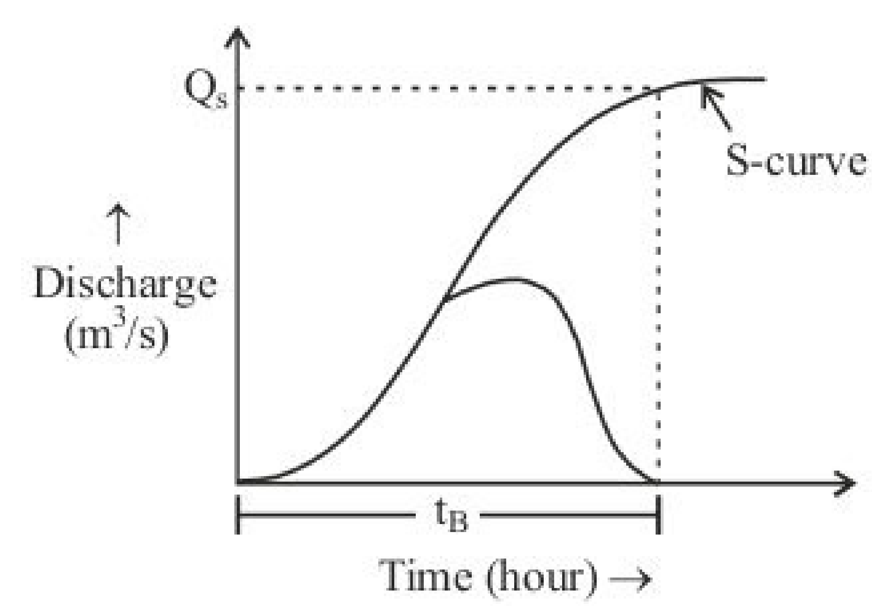
Area of UH = Catchment Area × Unit Depth

Basic Assumptions of UH

1. Time Invariance:—
   The DRH for a given effective rainfall in a catchment is always the same irrespective of when it occurs.
2. Linear Response:—
   If the rainfall excess in duration D hours is r times the unit depth, the ordinate of the DRH will be equal to r times the ordinate of the corresponding D-h UH.

S-Curve or S-Hydrograph

It is the direct runoff hydrograph resulting from a continuous effective rainfall of uniform intensity $\frac{1}{\Delta t}$ cm/hr, as the curve is of shape of S, it is called S-curve. It is obtained by summation of an infinite series of Δt of unit hydrograph each unit hydrograph lack by Δt hr with respect to the previous UH.



The value reaches maximum at time equal to base time of first UH.

$$Q_s = 2.778 \frac{A}{D} \text{ m}^3\text{/s}$$

RUNOFF

The portion of precipitation flowing off from a catchment area through a surface channel is called runoff.

Direct Runoff : Water flows through surface and enters a stream.

Base Runoff : Water enters stream as ground water, so it takes more time.

Runoff Coefficient (k) : The portion of rainfall that forms runoff.

$$k = \frac{\text{runoff}}{\text{rainfall}}$$

Maximum Flood Estimation

1. Rational Method:—

Peak flood discharge, $Q_p = \frac{k \cdot P_c \cdot A}{36}$

k – coefficient of runoff = $\frac{\text{runoff}}{\text{rainfall}}$.

P_c – mean design intensity of rainfall for duration, t_c and return period T and exceedence probability p.
A – drainage area.
t_c – time of concentration
$t_c = 0.0195\ L^{.77}\ S^{-0.385}$ (Kirpich equation)

2. Empirical Formulae:—

(a) **Dicken's Formula:**

Used in central and northern parts of country.

$$Q_p = C_D \cdot A^{\frac{3}{4}}$$

Q_p – maximum flood discharge.
C_D – Dicken's constant (6 to 30).

(b) **Ryre's Formula:**

$$Q_p = C_R \cdot A^{\frac{2}{3}}$$

C_R – Ryre's formula (6.8 to 10.2).

(c) **Inglis' Formula:**

$$Q_p = \frac{124 \times A}{\sqrt{A + 10.4}}.$$

Flood Routing

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

Basic equation: $I - Q = \frac{ds}{dt}$

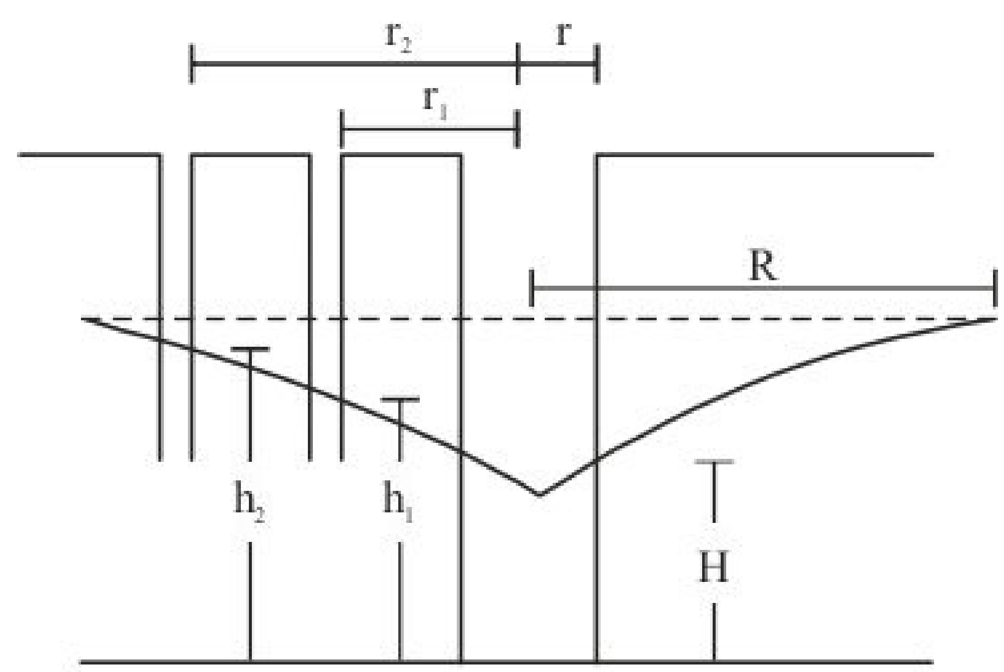
I – Inflow rate
Q – Outflow rate
$\frac{ds}{dt}$ – storage per unit time (i.e. change in storage with time).

Dupits Theory for Steady Radial Flow to a Well

Steady state discharge, $Q = \dfrac{\pi k\left(H^2 - h^2\right)}{\log_e\left(\frac{R}{r}\right)}$,

$$\text{or } Q = \frac{\pi k\left(H^2 - h_1^{\ 2}\right)}{\log_e\left(\frac{R}{r_1}\right)} = \frac{\pi k\left(H^2 - h_2^{\ 2}\right)}{\log_e\left(\frac{R}{r_2}\right)} = \frac{\pi k\left(h_1^{\ 2} - h_2^{\ 2}\right)}{\log_e\left(\frac{r_1}{r_2}\right)}$$

where,
H – depth of water in well from the impervious layer.
h_1, h_2 – height of water in observation wells.
r_1, r_2 – distance of observation well from well.
R – radius of influenze.



For confined aquifer

$$Q = \frac{2\pi kb\left(H - h\right)}{\log_e\left(\frac{R}{r}\right)} = \frac{2\pi kb\left(H - h_1\right)}{\log_e\left(\frac{R}{r_1}\right)}$$

$$= \frac{2\pi kb\left(H - h_2\right)}{\log_e\left(\frac{R}{r_2}\right)} = \frac{2\pi kb\left(h_1 - h_2\right)}{\log_e\left(\frac{r_1}{r_2}\right)}$$

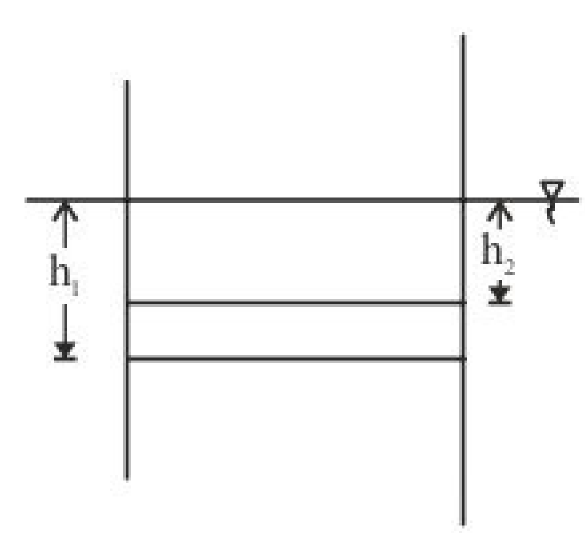
Recuperation Test

Water is pumped from a well and time taken to increase water to required height is taken.

$$\frac{k}{A} = \frac{1}{t} \times \log_e\left(\frac{h_1}{h_2}\right)$$

h_1 – depressed head by pumping.
h_2 – depressed head after t seconds.
$\frac{k}{A}$ – specific yield of well

$$Q = \left(\frac{k}{A}\right) \cdot A \cdot H$$



EXERCISE

1. 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
2. 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
3. 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
4. The correct match of Group I with Group II is

Group I	Group II
P. Evapotranspiration	1. Penman method
Q. Infiltration	2. Synder's method
R. Synthetic Unit Hydrograph	3. Muskingum method
S. Channel Routing	4. Horton's method

   (a) P-1, Q-3, R-4, S-2 (b) P-1, Q-4, R-2, S-3
   (c) P-3, Q-4, R-1, S-2 (d) P-4, Q-2, R-1, S-3
5. 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
6. The ratio of actual evapotranspiration to potential evapotranspiration 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
7. Group I contains parameters and Group II lists methods/instruments.

Group I	Group II
P. Streamflow velocity	1. Anemometer
Q. Evapotranspiration rate	2. Penman's method
R. Infiltration rate	3. Horton's method
S. Wind velocity	4. Current meter

   The correct match of Group I with Group II is
   (a) P-1, Q-2, R-3, S-4 (b) P-4, Q-3, R-2, S-1
   (c) P-4, Q-2, R-3, S-1 (d) P-1, Q-3, R-2, S-4
8. Standard rain guage adopted in India is
   (a) Natural siphon type (b) Symon's rain guage
   (c) Tipping bucket type (d) Weighing type
9. Which of the following rain guages give mass curve?
   (a) Natural siphon type (b) Weighting bucket type
   (c) Tipping bucket type (d) Both (a) and (c)
10. The intensity of rainfall and time interval of typical storm are

Time Interval (min)	Intensity of Rainfall (mm/min)
0-10	0.7
10-20	1.1
20-30	2.2
30-40	1.5
40-50	1.2
50-60	1.3
60-70	0.9
70-80	0.4

   The maximum intensity of rainfall for 20 minutes duration of storm is
   (a) 1.5 mm/min (b) 1.85 mm/min
   (c) 2.2 mm/min (d) 3.7 mm/min
11. During a 6-hour storm, the rainfall intensity was 0.8 cm/hour on a catchment area 8.6 km^2. The measured run-off volume during the period was 2,56,000 m^3. The total rainfall was lost due to infilteration, evaporation and transpiration in cm/hr is
   (a) 0.8 (b) 0.304
   (c) 0.494 (d) cannot be determined
12. What is the pan co-efficient for an ISI pan used for measuring evaporation?
   (a) 0.8 (b) 0.7
   (c) 0.6 (d) 1
13. The plan area of a reservior is 1 km^2. The water level in the reservior is observed to decline by 20 cm in a certain period. During this period, the reservior received a surface inflow of 10 hectare m and 20 hectare meters are abstracted from the reservior for irrigation and power. The pan evaporation and rainfall recorded during the same period was at a nearly meteorological station are 12 cm and 3 cm respectively. The calibrated pan factor is 0.7. The seepage loss from the reservior during this period in hectare m is
   (a) 0 (b) 1
   (c) 2.4 (d) 4.6
14. Total area of DRH is equal to
   (a) Total rainfall (b) Total transpiration
   (c) Total evapotranspiration (d) Run-off volume

15. Match the following:–

P.	Rainfall intensity	1.	Isohyeto
Q.	Rainfall excess	2.	Cumulative rainfall
R.	Rainfall averaging	3.	Hyetograph
S.	Mass curve	4.	Direct run-off hydrograph

***Codes*:**

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

16. What is unity in a unit run-off hydrograph?
(a) Duration of storm (b) Area of basin
(c) Depth of run-off
(d) Base period of hydrograph

17. While applying the rational formulae for computing the design discharge, the rainfall duration is stimulated 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 possible of the smallest rainfall duration for which the rational formulae is applicable
(d) None of these

18. When the outflow from a storage reservior is uncontrolled in a freely operating spillway, the peak of outflow hydrograph occurs at
(a) point of intersection of the inflow and outflow hydrographs
(b) a point, after the intersection of inflow and outflow hydrographs
(c) the tail of inflow hydrographs
(d) a point before the intersection of inflow and outflow hydrograph

19. By using rods, the velocity obtained is
(a) mean velocity (b) maximum velocity
(c) minimum velocity (d) surface velocity

20. An aquifer is made of sand having porosity 30%. The specific yield of aquifer is
(a) 30% (b) > 30%
(c) < 30% (d) data insufficient

21. Water is pumped from a well tapping an unconfined aquifer at a certain discharge rate and the steady state drawdown (X) in an observation well is monitored. Subsequently, the pumping discharge is doubled and the steady state drawdown in the observation well is found to be more than double. This disproportionate drawdown is caused by
(a) well losses
(b) decrease in saturated thickness of acquifer
(c) non-linear flow
(d) delayed gravity field

22. Two observation wells penetrated into a confined aquifer and located 1.5 km apart in the direction of flow. Indicate head of 45 m and 20 m. If the well of permeability of aquifer is 30 m/day and porosity is 0.25. The time of travel of an inert to travel from one well to another is
(a) 416.7 days (b) 500 days
(c) 750 days (d) 3000 days

23. A tube well of 50 cm diameter penetrates fully in an artesian aquifer. Strainer length is 15m. The aquifer consists of sand of effective size of 0.2 mm having coefficient of permeability equal to 50 m/day. Assume radius of drawdown equal to 150 metres. What is the yield from the well under a drawdown of 3 m?
(a) 20.6 lit/sec (b) 23.6 lit/sec
(c) 25.6 lit/sec (d) 28.3 lit/sec

24. A tube well penetrates fully an unconfined aquifer.
Diameter of the well = 30 cm
Drawdown = 2m
Effective length of the strainer under the above drawdown = 10 m
Coefficient of permeability of acquier = 0.05 cm/sec
Radius of zero drawdown = 300m
What is discharge from the tubewell under given conditions?
(a) 6 lit/sec (b) 8 lit/sec
(c) 9 lit/sec (d) 12 lit/sec

25. Peak of a flood hydrograph due to a six-hour storm is 470 m^3/sec. The average depth of rainfall is 8.0 cms. Assume an infiltration loss of 0.25 cm/hour and a constant base flow of 15m^3/sec. The peak discharge of a 6 hour unit hydrograph for this catchment, will be
(a) 50m^3/sec (b) 60m^3/sec
(c) 70 m^3/sec (d) 90 m^3/sec

26. An open well in fine sand give a discharge of 0.003 cumec when worked under a depression head of 2.5 metres. The well diametre will be
(a) 2.4 m (b) 2.8 m
(c) 3.0 m (d) 3.4 m

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

HINTS & EXPLANATIONS

1. (d) $f = 6.8 + 8.7\,e^{-t}$

$t = 0$, $f = 6.8 + 8.7 = 15.5 > 10$ mm

$t = 0$ to 1

$$\text{Infiltration} = \int_0^1 \left(6.8 + 8.7\,e^{-t}\right)dt$$

$$= \left[6.8t + \frac{8.7\,e^{-t}}{-1}\right]_0^1$$

$$= 12.3\text{ mm} > 10\text{ mm}$$

$\therefore$ No excess rainfall $t = 1$ to 2

$$\text{Total infiltration} = \int_1^2 \left(6.8 + 8.7\,e^{-t}\right)dt$$

$$= \left[6.8t + \frac{8.7\,e^{-t}}{-1}\right]_1^2$$

$$= 8.82 < 20\text{ mm}$$

$\therefore$ Rainfall excess $= 20 - 8.82 = 11.17$ mm

$t = 2$ to 3

$$\text{Total infiltration} = \int_2^3 \left(6.8 + 8.7\,e^{-t}\right)dt$$

$$= 7.54 > 10\text{ mm}$$

Rainfall excess $= 10 - 7.54 = 2.45$

Total rainfall excess $= 10 + 11.17 + 2.45 = 13.63$ mm.

2. (c) Infiltration (i)

If rainfall $> \phi$ index, $i = \phi$ index

If rainfall $< \phi$ index, i = rainfall

$\therefore$ $i_{1\text{st hour}} = 9$ mm,

$i_{2\text{nd hour}} = 10$ mm

$i_{3\text{rd hour}} = 10$ mm

$i_{4\text{th hour}} = 9$ mm.

Runoff = rainfall $- i$

$= 0 + (28 - 10) + (12 - 10) + 0$

$= 20$ mm.

3. (b) Flood routing reduces peak and increase time base.

6. (c) For soil moisture at field capacities, AET = PET

For soil moisture at permanent willing point, AET ≈ 0

$\frac{\text{AET}}{\text{PET}}$ have value between 0 and 1.

10. (b) For two consecutive 10 min, i.e. total of 20 min interval, maximum intensities are 2.2 mm/min and 1.5 mm/min (20-30 and 30-40).

$$\text{Maximum intensity for 20 min} = \frac{\text{total depth of rainfall}}{\text{total time}}$$

$$= \frac{2.2 \times 10 + 1.5 \times 10}{20} = \frac{37}{20} = 18.5\text{ mm/min.}$$

11. (b) $P = i \times t$

$= 0.8 \times 6 = 4.8$ cm

$$\text{Run-off depth, } R = \frac{\text{Volume of run-off}}{\text{Area}}$$

$$= \frac{256000}{8.6 \times 10^6} = 0.02976\text{ m} = 2.97\text{ m}$$

$$\text{Loss rate} = \frac{P - R}{r}$$

$$= \frac{4.8 - 2.97}{6} = 0.304\text{ cm/hr.}$$

13. (d) Inflow is due to surface inflow and rainfall

$\therefore$ I = surface inflow + rainfall

$= 10 + 0.03 \times 100$

$= 13$ ha.m

Outflow is due to irrigation and power, evaporation and seepage

Q = irrigation and power + evaporation + seepage

$= 20 + 0.7 \times 0.12 \times 100$ + seepage

$= 28.4$ + seepage

Change in storage = inflow – outflow

i.e. $\frac{ds}{dt} = I - Q$

$= -0.2 \times 100 = 13 - (28.4 + \text{seepage})$

$\therefore$ Seepage = 4.6 ha.m

22. (c) Discharge velocity,

$$V = k \cdot i$$

$$= k \cdot \frac{h_f}{L}$$

$$= 30 \times \frac{40 - 20}{1.5 \times 10^3}$$

$$= 0.5\text{ m/day}$$

$$\text{Seepage velocity, } V_s = \frac{V}{\eta} = \frac{0.5}{0.25} = 2\text{ m/day}$$

$$\text{Travel time} = \frac{\text{distance}}{\text{actual velocity}}$$

$$= \frac{1.5 \times 10^3}{2} = 750\text{ days.}$$

23. (b) Here, b = thickness of acquifer

= Length of strainer = 15m

s = drawdown = 3 m

k = co-efficient of permeability = 50 m/day

R = 150 m; r = 15 cm = 0.15 m

$$\therefore \text{ Discharge, } Q = \frac{2.72bks}{\log_{10}\frac{R}{r}}$$

$$= \frac{2.72 \times 15 \times 50 \times 3}{\log_{10} \frac{150}{0.15}}$$

$= 2040 \text{ m}^3\text{/day}$

$= 88 \text{ m}^3\text{/hour} = 23.6 \text{ lit/sec.}$

24. (c) Here, $k = 0.05 \text{ cm/sec} = \frac{0.05}{100} \text{m/sec}$

$= 5 \times 10^{-4} \text{ m/sec}$

s = drawdown = 2 m; R = 300 m;

L = effective length of strainer = 10 m

$$\text{Discharge, } Q = \frac{2.27ks\left(L + \frac{S}{2}\right)}{\log_{10} \frac{R}{r}}$$

$$= \frac{2.72 \times 5 \times 10^{-4} \times 2(10+1)}{\log_{10} \frac{300}{0.15}} \text{m}^3\text{/sec}$$

$= 9.05 \times 10^{-3} \text{ m/sec}$

$= 0.009$ cumec.

$= 9.05$ lit/sec.

25. (c) Peak discharge of flood hydrograph = $470\text{m}^3\text{/sec}$

Base flow = $15\text{m}^3\text{/sec}$

Peak discharge of surface run-off hydrograph

$= 470 - 15 = 455 \text{ m}^3\text{/sec}$

Rainfall Excess = $8.0 - 0.25 \times 6 = 6.5$ cm

Peak discharge of unit hydrograph

$$= \frac{455}{6.5} = 70\text{m}^3\text{/sec}$$

26. (d) Required discharge, Q = 0.003 cumec = 0.003×3600
$= 10.8\text{m}^3\text{/hour}$

$$\text{Now, } Q = \left(\frac{K}{A}\right) A.H$$

For fine sand, $\frac{K}{A} = 0.5 \text{ cm}^3\text{/hour per m}^2$ of area, under unit depression head

H = depression head = 2.5 m

$\therefore$ $10.8 = 0.5 \times A \times 2.5$

$$A = \frac{10.8}{0.5 \times 2.5} \text{m}^2 = 8.64\text{m}^2$$

$\therefore$ Well diameter, $d = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 \times 8.64}{\pi}} = 3.32\text{m} \approx 3.4\text{ m}$