HYDROLOGY QUESTIONS

INTRODUCTION

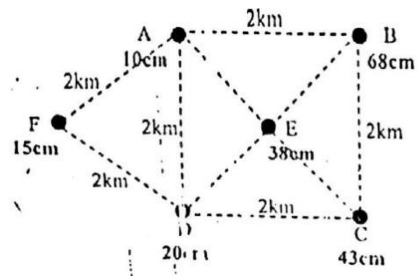
1. Define "Hydrology".
2. Explain with the help of a neat sketch the hydraulic cycle in nature, indicating its various phases.
3. Explain the scope of hydrology in water resources development.
4. Explain 'hydrologic equation? What are the basic data required for hydrological studies?
5. Is your own district affected by floods or droughts? Explain how hydrology is useful in proposing the measures to mitigate these natural disasters.
6. Define Hydrometeorology.
7. List out various practical applications of hydrology. Describe them briefly.

PRECIPITATION

1. Explain how you would determine the optimum number of rain-gauge to be created in a given basin.
2. What factors should be considered in selecting a site for a rain-gauge station? Or Write down the points that should be kept in view for installing the raingauge.
3. Explain a method for estimating the missing rainfall data at a station in a basin.
4. What do you mean by return period? Give some of the formulas which are used to determine the return period.
5. Write short notes on: (i) A.A.R., (ii) Rain-gauge density, (iii) Isohytes
6. What is meant by probable maximum precipitation? Describe methods of estimating PMP. What are its design applications?
7. What is rain-gauge density? How does it affect the accuracy of measurement?
8. What is meant by 75% dependable value of the random variables? How is it obtained from frequency analysis?
9. Distinguish between the following (i) Maximum probable flow and design flood (ii)Annual series and partial series (iii)Return period and exceedance probability
10. Write short notes on (i) (ii) Semi-arid and Arid regions (iii) Double mass curve, and (iv) Depth-Area-Duration curve.
11. Explain the methodology of rain-gauge installation.

Problems

1. Find the mean precipitation for the area shown in figure below by Thiessen polygon method. The area is compound of a square plus an equilateral triangular plot of side 2 km. rainfall readings are in cm at the various station indicated.



2. A watershed has a network of five rain gauges. Annual rainfall recorded by these gauges is given for a year as in the table below. Calculate the optimum number of rain-gauges for this watershed for a 10% error in estimate of mean annual rainfall.

Rain-gauge	1	2	3	4	5
Annual rainfall	50	82	73	64	105

3. A major river basin is divided into four sub-basins with area of 920, 705, 1075 and 1665 km^2. If the average annual rainfall on these sub-basins is 73, 85, 112 and 100 cm, respectively. What is the average annual rainfall for the basin as a whole?
4. Neighboring rain gauge stations A,B,C,D,E and F have normal rainfalls of 610, 554, 468, 606, 563 and 382 mm respectively. During a storm A, B, C, E and F have reported rainfalls of 22, 29, 35, 13and 25 mm respectively, and station D did not report as it was inoperative. Estimate the missing storm rainfall at D by the arithmetic average and normal ratio method.

WATER LOSSES

1. Recommend measures to reduce reservoir evaporation.
2. Enumerate the various water losses.
3. What are the factors which affect infiltration? Sketch a typical curve of infiltration and give its equation.
4. Discuss the factors which affect infiltration.
5. Write short notes on: (i) Pan coefficient (ii) Φ-index (iii) Evapotranspiration (iv) Watershed leakage
6. Explain briefly the evapotranspiration process. What are the factors which affect evapotranspiration?
7. How infiltration capacity can be measured using a double ring infiltrometer? Describe with neat sketch.
8. Define pan coefficient and why it is needed to determine.
9. Distinguish between (i) φ-index and w-index, (ii) Infiltration capacity and infiltration rate and (iii) Evaporation and Transpiration.
10. Is evapotranspiration same as consumptive use? Explain.
11. Explain any one method of determining the infiltration capacity of a soil surface.
12. Evaporation is less on a humid day. Why?

Problems

1. During a daily observation, 10.8 liters of water was added to bring the water surface in the evaporation pan to the stipulated level and the nearby rain gauge measured 3.6 mm of rainfall. What was the evaporation recorded for the day if the diameter of the pan is 122 cm?
2. The cumulative depth of infiltration in an experiment on a tube infiltrometer is observed to the following equation $F = 0.165t^{0.65}$, where F is in cm and t is in minutes. Determine the equation for infiltration depth and the average infiltration rate.
3. F_{cr} a small catchment, the infiltration rate at the beginning of rain was observed to be 90 mm/hr and decreased exponentially to a constant rate of 8 mm/hr after 2.5 hr. The total infiltration during 2.5 hr was 50 mm. Develop the Horton's equation for the infiltration rate at any time t < 2.5 hr.

4. The infiltration capacity in a basin is represented by Horton's equation as $f_p = 3.0+e^{-2t}$, where f_p is in cm/h and t is in hours. Assuming the infiltration to take place at capacity rates in a storm of 60 minutes duration, estimate the depth of infiltration in (i) the first 30 minutes and (ii) the second 30 minutes of the storm.
5. Calculate the amount of water lost by evaporation if: (i) amount of precipitation = 12 mm, (ii) quantity of surface inflow = 120 mm, (iii) ground water flow amount = 75 mm, (iv) surface outflow = 13 mm and (v) storages decreases by 5 mm.
1. The Horton's infiltration equation for a basin is given by $f = 6 + 16e^{-2t}$,where f is in mm/hr and t is in hours. What are the value of initial infiltration rate f_0, final constant infiltration rate f_c and constant k ? if a storm occurs in this basin with na intensity of 22 mm/hr, determine the depth of infiltration for the 45 minutes and the average infiltration for the second 75 minutes.
6. Hourly rainfalls of 2.5, 6 and 3 cm occur over a 20 ha area consisting 4 ha of φ = 5 cm/hr, 10 ha of φ = 3 cm/hr and 6 ha of φ = 1 cm/hr. Drive hourly values of net rain.

RUNOFF

1. Discuss the various factors which affect runoff from a basin.
2. Distinguish between (i) Influent and effluent streams (ii) Drainage density and drainage divide
3. Write short notes on (i) Isochrones (ii) Catchment area

Problems

1. A basin has an area of 26560 km^2, perimeter of 9.5 km and length of the thalweg 230 km. determine: (i) Form factor, (ii) compactness coefficient (iii) elongation ratio and (iv) circularity ratio.
2. A drainage basin has an area of 210 km^2. The average depth of rainfall received by it during a monsoon period is estimated to be 5.68 x 10^7 m^3. Compute the depth of runoff. What percentage of rainfall has become runoff? If all this runoff volume is stored and used to irrigate a crop which requires 60 cm of water, how many hectors can be irrigated?

HYDROGRAPHS

1. Define unit hydrograph. Describe with the help of a neat sketch any four methods of separation of base flow from the hydrograph of runoff.
2. Draw a single peaked hydrograph and indicate its various phases.
3. Write the application of unit hydrograph.
4. Explain the basic propositions of unit hydrograph theory.
5. What are the limitations of unit hydrograph?
6. What do you understand by 6-hour unit hydrograph? Discuss with diagram.
7. Distinguish between the following: (i) An hydrograph and a hyetograph (ii) Lagtime and recession time (iii)concentration curve and recession curve.

Problems

1. The following are the ordinates of a 3-hour unit hydrograph. Derive the ordinates of 6-hour unit hydrograph and plot the same.

Time (hr)	0	3	6	9	12	15	18	21	24
3-hr UGO (cumec)	0	1.5	4.5	8.6	12.0	9.4	4.6	2.3	0.8

2. The runoff data at a stream gauging station for a flood given below. The drainage area is 40 km^2. The duration of rainfall is 3 hours. Derive the three-hr unit hydrograph for the basin and plot the same.

Date	1 – 3 – 1970								2 – 3 - 1970							
Time (hr)	2	5	8	11	14	17	20	23	2	5	8	11	14	17	20	23
Discharge (cumec)	50	47	75	120	225	290	270	145	110	90	80	70	60	55	51	50

3. The ordinates of a 4-hour unit hydrograph are given below. Derive the ordinates of a 8-hour unit hydrograph by the S-curve method.

Time (hr)	0	4	8	12	16	20	24	28	32	36	40	44
4-hr unit hydrograph (cumec)	0	24	82	159	184	151	103	64	36	17	6	0

4. The ordinates of 3-hr unit hydrograph are given as under. Find out the ordinates of 9-hr unit hydrograph.

Time (hr)	0	3	6	9	12	15	18	21
3-hr UGO (m^3/sec)	0	50	75	150	80	50	30	0

5. The design storm of a water shed has the depths of rainfall of 4.9 and 3.9 cm for the consecutive 1-hr periods. The 1-hr UG can be approximated by a triangle of base 6 hr with a peak of 50 cumec occurring after 2 hr from the beginning. Compute the flood hydrograph assuming an average loss rate of 9 mm/hr and constant base flow of 10 cumec. What is the area of water shed and its coefficient of runoff?

6. The design storm over a water shed has depth of rainfall of 4.6, 3.6 and 5.6 cm in successive 1 hr periods. The 1 hr UG can be approximated by a triangle of base 9 hr with a peak cumec occurring 2 hr from the beginning. Compute the flood hydrograph assuming an average loss rate of 6 mm/hr and constant base flow of 5 cumec. What is the area of water shed and its coefficient of runoff.

7. A steady 6h rainfall with intensity of 4 cm/hr produces a peak discharge of 560 cumec. The average storm loss can be assumed as 1cm/hr and base flow 20 cumec. What is the peak discharge of unit hydrograph and its duration? On the same basin determine the discharge from a 6h rainfall at intensity of 3.5 cm /hr, assuming an average loss rate of 1.5cm/hr and base flow of 1.5 cumec.

STREAM GAUGING

1. Define stream gauging?
2. What are the factors that influence the selection of a site for a stream gauging station?
3. Explain “current meter rating curve”. Sketch a typical rating curve.
4. What is the flow rating curve? Explain its uses. Sketch a flow rating curve. How is it prepared?
5. Explain how the stage-discharge rating curve for a stream-gauging station is prepared.
6. Draw the qualitative diagrams of stage-discharge rating curve for (i) Mohananda river and (ii) Brahmaputra river.

Problems

1. Following velocities were recorded in a stream with a current meter. Find the discharge per unit width of stream near the point of measurement. Depth of flow at the point was 5 meter.

Depth above bed (m)	0	1	2	3	4
Velocity (m/sec)	0	0.5	0.7	0.8	0.8

2. Following velocities were recorded in a stream with a current meter. Find the discharge per unit width of stream near the point of measurement by two-point method. Depth of flow at the point was 3.5 meter.

Depth above bed (m)	0	0.7	1.4	2.1	2.8
Velocity (m/sec)	0	2.62	2.94	3.16	3.28

3. A surface float took 10 sec to travel a straight run of a stream of 20 m. What is the appropriate mean velocity of the stream ? If a velocity rod had been used, what time it would have taken to travel the same run?

GROUNDWATER

1. Explain the terms: (i) Transmissibility, (ii) Specific yield, (iii) Storage coefficient and (iv) Cone of depression.
2. State and explain Darcy’s law. Describe its limitations.
3. Define aquifer. Describe different types of aquifer with sketches.
4. Write down the assumptions on which Dupit’s theory of flow for unconfined aquifer is based.
5. Distinguish between the followings: (i) Vadose zone and Phreatic zone, (ii) Specific yield and Specific retention and (iii) Hydraulic conductivity and Transmissibility.
6. Define ground water. Describe the scope of groundwater study.
7. Distinguish between: (i) Zone of aeration and Zone of saturation, (ii) Aquifer and Aquiclude, (iii) Data curve and Type curve, and (v) Darcy velocity and actual velocity.
8. Define well hydraulics. Write a short note on “Movement of ground water”.
9. Draw a sketch to show divisions of sub-surface water.
10. What is meant by overdraft and mining? Write the advantages of groundwater over surface water.
11. What do you understand by safe yield of a ground water basin? Write the name of factors influencing safe yield.

12. Write short notes on (i) Aquifer (ii) Unconfined aquifer
13. Explain with a net sketch the Cooper and Jacob method of determining the aquifer parameter.
14. Derive an expression for the steady state discharge of a well in an unconfined aquifer.
15. What are the assumptions for Theis equation for unsteady radial flow to a well?

Problems

1. A 30 cm well fully penetrates into a confined aquifer 30 m deep. After a long period of pumping at a rate of 1200 lmp, the drawdown in the observation wells at 20 m and 45 m from the pumped well are 2.2 m and 1.8 m respectively. Determine: (i) the transmissibility of the aquifer, (ii) the drawdown in the pumped well
2. A 25 cm well penetrates 30 m below static water level (GWT). After a long period of pumping at a rate of 1800 lmp, the drawdowns in the observation well at 13 m and 38 m from the pumped well are 1.2 m and 0.5 m respectively. Determine: (i) the transmissibility of the aquifer, (ii) the drawdown in the pumped well assuming R= 300 m.
3. An artesian aquifer 30 m thick has a porosity of 25% and bulk modulus of compression 2000 kg/cm2. Estimate the storage coefficient of the aquifer. What fraction of this is attributable to the expansibility of water? Assume, bulk modulus of elasticity of water 2.4 x 104 kg/cm2.
4. In a homogeneous isotropic confined aquifer of constant thickness of 30 m, specific retention of 4%, hydraulic conductivity of 20 m/day and specific yield of 16%, two observation wells 1000 m apart indicate piczometric heads of 7.6 m and 5.4 m respectively above m.s.l. Determine the actual velocity in pores and Reynolds number for the flow assuming uniform flow, average gram diameter of sand 1 mm and vwater = 0.01 cm2/sec.
5. A 30 cm well penetrating a confined aquifer is pumped at a constant rate 700 lpm. The drawdown at an observation well at a radial distance of 100 m is as follows:

Time in day	0.001	0.005	0.01	0.05	0.10	0.50	1.0	5.0	10.0
Drawdown in m	0.083	0.196	0.249	0.376	0.431	0.559	0.614	0.742	0.797

Determine the aquifer parameters using the Chow's method.

6. An artesian aquifer 30 m thick has a porosity of 25% and bulk modulus compression 2000 kg/cm2. Estimate the storages coefficient of the aquifer. What fraction of this is attributable to the expansibility of water?
7. A well is pumped at the constant rate of 8 liters/sec. A match of the well function [u versus w(u)] with drawdown versus time data from an observation well located at a distance of 450 m from the pumped well has produce the following matching values: u = 1, s = 0.21 m, and r2/t = 2055 m2/minute. Calculate the transmissibility and storage coefficient of the aquifer. Also estimate the drawdown in the well at the end of 10 days of pumping.

u	w (u)
6*10-3	4.54
7*10-3	4.39

FLOOD ESTIMATION

1. What do you mean by design flood? What are the methods to determine the maximum flood discharge?
2. Explain the followings: (i) Standard Project Flood, (ii) Maximum Probable flood and (iii) Design Flood.
3. Define recurrence interval as applied to annual flood or rainfall.
4. Define a T-hour U11. What is the probability that a 5-year flood will occur at least once during the next 3 years?
5. Define flood routing. What are the uses of flood routing?

Problems

1. From the analysis of available data on annual flood peaks of a small stream for a period of 35 years, the 50 year and 100 year flood have been estimated to be 660 m^3/s and 740 m^3/s using Gumbel's method. Estimate the 200 year flood for the stream. The values of mean $\bar{y}_n$ and standard deviation σ_n for different period of flood data are as follows:

Period n	35	50	100
$\bar{y}_n$	0.54034	0.54854	0.56002
σ_n	1.12847	1.16066	1.20649

2. During the consumption period of 10 years of a reservoir, a cofferdam is required to be constructed with a capacity to take care if 5 year floods. What is the probability that (i) The flood will not occur at all and (ii) it will occur twice during the construction period?

3. From the analysis of available data on annual flood peaks of a small stream for a period of 35 years, the 50 year and 100 year flood have been estimated to be 660 m^3/s and 740 m^3/s using Gumbel's method. Estimate the 150 year flood for the stream. The value of y_n and σ_n for a record length of n years are given below:

N	35	50	100	150
y_n	0.54034	0.54854	0.56002	0.56161
σ	1.12847	1.6066	1.20649	1.22534

4. The following inflow hydrograph of a specified channel reach is given. Compute the following through channel routing: (i) Outflow hydrograph, (ii) Attenuation and (iii) Travel time in hour. Assume k = 24 hours and x = 0.20.

Time (h)	0	12	24	36	48	60	72	84
Inflow(m^3/s)	32	35	78	262	332	278	230	188
Time (h)	96	108	120	132	144	156	168	180
Inflow(m^3/s)	152	123	100	80	69	58	51	46

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Frequency

Frequency *F* is the percentage of years during which a storm of given magnitude
may be equalled or exceeded.

MOVING AVERAGES CURVE

In order to depict a general trend in the rainfall pattern, the averages of three or five consecutive years are found out progressively by moving the group averaged, one year at a time known as moving average curve

Probable Maximum Precipitation (PMP)

The probable maximum precipitation (PMP) for a given region is the precipitation resulting from the most critical meteorogical combinations that are considered probable of occurrence.

HYDROGRAPHS

Hydrograph

A *hydrograph* is a graph showing discharge (*i.e.,* stream flow at the concentration point) versus time.

Lag time or basin lag

The hydrograph gradually rises and reaches its peak value after a time *tp* (called *lag time* or *basin lag*) measured from the centroid of the hyetograph of net rain.

HYDROGRAPHS

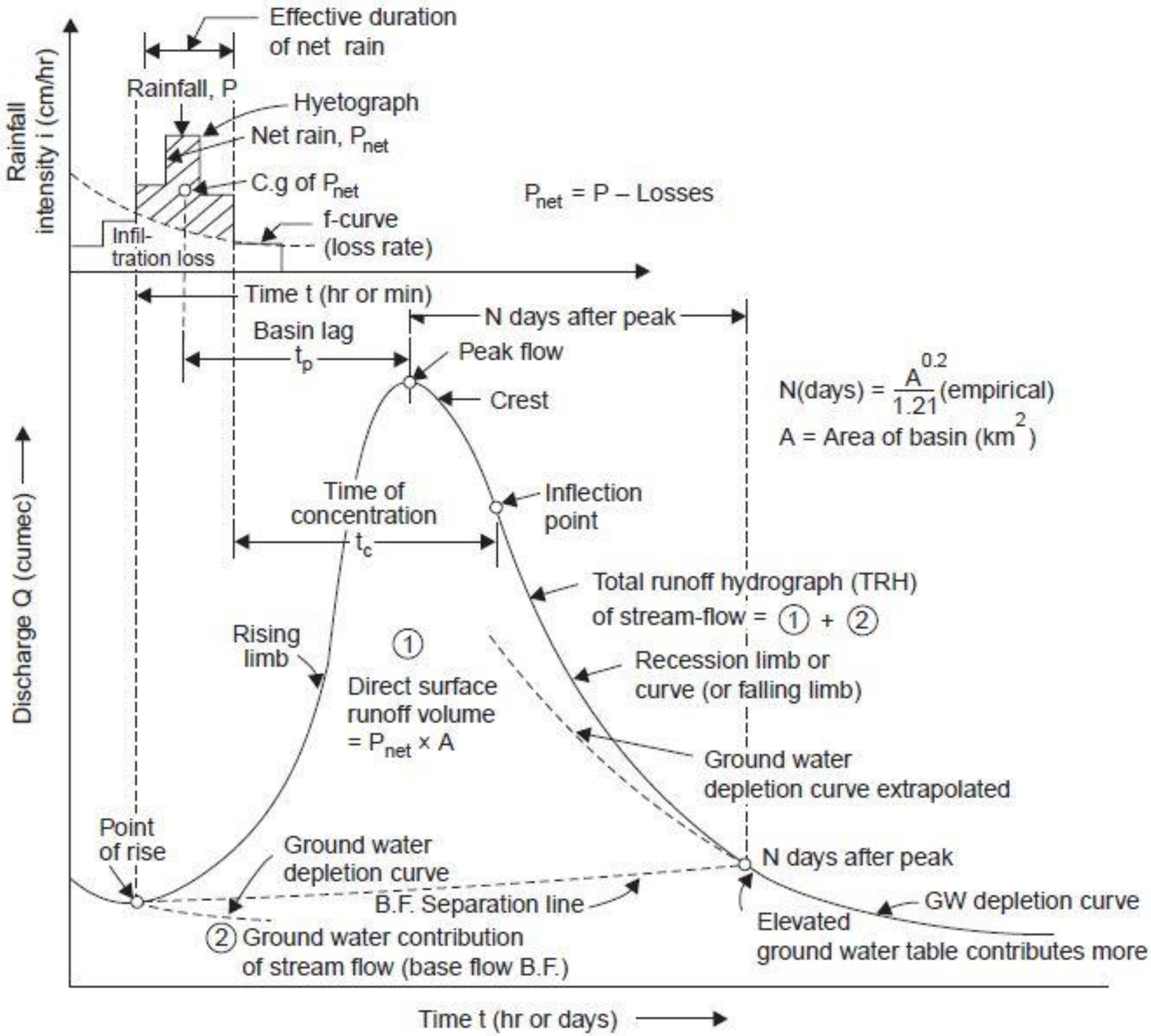


Fig. 5.1 Components of streamflow hydrograph

HYDROGRAPHS

Recession curve

After the peak of hydrograph, GWT declines and the hydrograph again goes on depleting in the exponential form called the *ground water depletion curve* or the *recession curve*

HYDROGRAPHS

Recession curve

After the peak of hydrograph, GWT declines and the hydrograph again goes on depleting in the exponential form called the *ground water depletion curve* or the *recession curve.*

Hydrograph separation

Elements of unit hydrograph

HYDROGRAPHS

Elements of unit hydrograph

Base width (*T*)—The period of direct surface runoff (due to a unit storm) of the unit hydrograph is called the *time base* or the *base width*.

Unit storm—The strom of unit duration (*i.e.,* duration of the unit hydrograph) regardless of its intensity is called *unit storm*.

Unit period—The time duration of the unit storm (*i.e.,* the duration of the unit hydrograph) is called *unit period*.

HYDROGRAPHS

Elements of unit hydrograph

Lag time (*tp*)—The time from the centre of a unit storm to the peak discharge of the corresponding unit hydrograph is called *lag time*.

Recession time (*Tr*)—The duration of the direct surface runoff after the end of the excess or net rainfall, is called *recession time in hydrograph analysis*.

HYDROGRAPHS

Propositions of the Unit Hydrograph

(*i*) ***Same runoff duration.*** For all unit storms of different intensities, the period of surface runoff (*i.e.,* time base, base width or base period) is approximately the same, although they produce different runoff volumes

(*ii*) ***Proportional ordinates.*** For unit storms of different intensities, the ordinates of the hydrograph at any given time, are in the same proportion as the rainfall intensities

HYDROGRAPHS

Propositions of the Unit Hydrograph

(*iii*) ***Principle of superposition.*** If there is a continuous storm and/or isolated storms of uniform intensity net rain, they may be divided into unit storms and hydrographs of runoff for each storm obtained, and the ordinates added with the appropriate time lag to get the combined Hydrograph.

(*iv*) ***Same distribution percentages*****.** If the total period of surface runoff (*i.e.,* time base or base width) is divided into equal time intervals the percentage of surface runoff that occurs during each of these periods will be same for all unit storms of different intensities

HYDROGRAPHS

Limitation of the Unit Hydrograph

1. The design storm continuing for several unit periods may not have the same areal distribution for each time increment.

2. Storm movements also affect the proportions of the unit hydrograph if the basin is large. Hence, the unit hydrograph can not be applied for basins larger than 5000 km^2.

HYDROGRAPHS

Example 5.1 ***(a)*** *The runoff data at a stream gauging station for a flood are given below. The drainage area is 40 km^2. The duration of rainfall is 3 hours. Derive the 3-hour unit hydrograph for the basin and plot the same.*

HYDROGRAPHS

Example 5.1 *(a)*

Date	*Time (hr)*	*Discharge (cumec)*	*Remarks*
1-3-1970	*2*	*50*	
	5	*47*	
	8	*75*	
	11	*120*	
	14	*225*	
	17	*290*	← *Peak*
	20	*270*	
	23	*145*	
2-3-1970	*2*	*110*	
	5	*90*	
	8	*80*	
	11	*70*	
	14	*60*	
	17	*55*	
	20	*51*	
	23	*50*	

HYDROGRAPHS

Example 5.1 *(a)*- ***Solution***

Date	*Time (hr)*	*TRO[1] (cumec)*	*BFO[2] (cumec)*	*DRO[2] (3)–(4) (cumec)*	*UGO[4] (5) ÷ P_{net} (cumec)*	*Time[5] from beginning of surface run off (hr)*
1	*2*	*3*	*4*	*5*	*6*	*7*
1-3-1970	2	50	50	—	—	—
	5	47	47	0	0	0
	8	75	46	29	1.09	3
	11	120	45	75	2.82	6
	14	225	45	180	6.77	9
	17	290	45	245	9.23	12
	20	270	46	224	8.44	15
	23	145	48	97	3.65	18
2-3-1970	2	110	50	60	2.26	21
	5	90	53	37	1.39	24
	8	80	54	26	0.98	27
	11	70	57	13	0.49	30
	14	60	60	0	0	33
	17	55	55	—		
	20	51	51	—		
	23	50	50	—		
				$\Sigma\, DRO$ = 986 cumec		

HYDROGRAPHS

Example 5.1 *(a)*- *Solution*

[1]*TRO*—Total runoff ordinate = gauged discharge of stream

[2]BFO—Base flow ordiante read from graph separation line shown in Fig. 5.10 (*a*). $N = 0.83\ A^{0.2} = 0.89(40)^{0.2} = 1.73$ days $= 1.73 \times 24 = 41.4$ hr from peak, which is seen not applicable here; hence an arbitrary separation line is sketched.

[3]*DRO*—Direct runoff ordinate = *TRO—B.F.O.*

[4]*UGO*—Unit hydrograph ordinate

$$= \frac{DRO}{P_{\text{net}}};\ P_{\text{net}} = \frac{\Sigma DRO\,.\,t}{A} = \frac{986(3 \times 60 \times 60)\text{m}^3}{40 \times 10^6\ \text{m}^2}$$

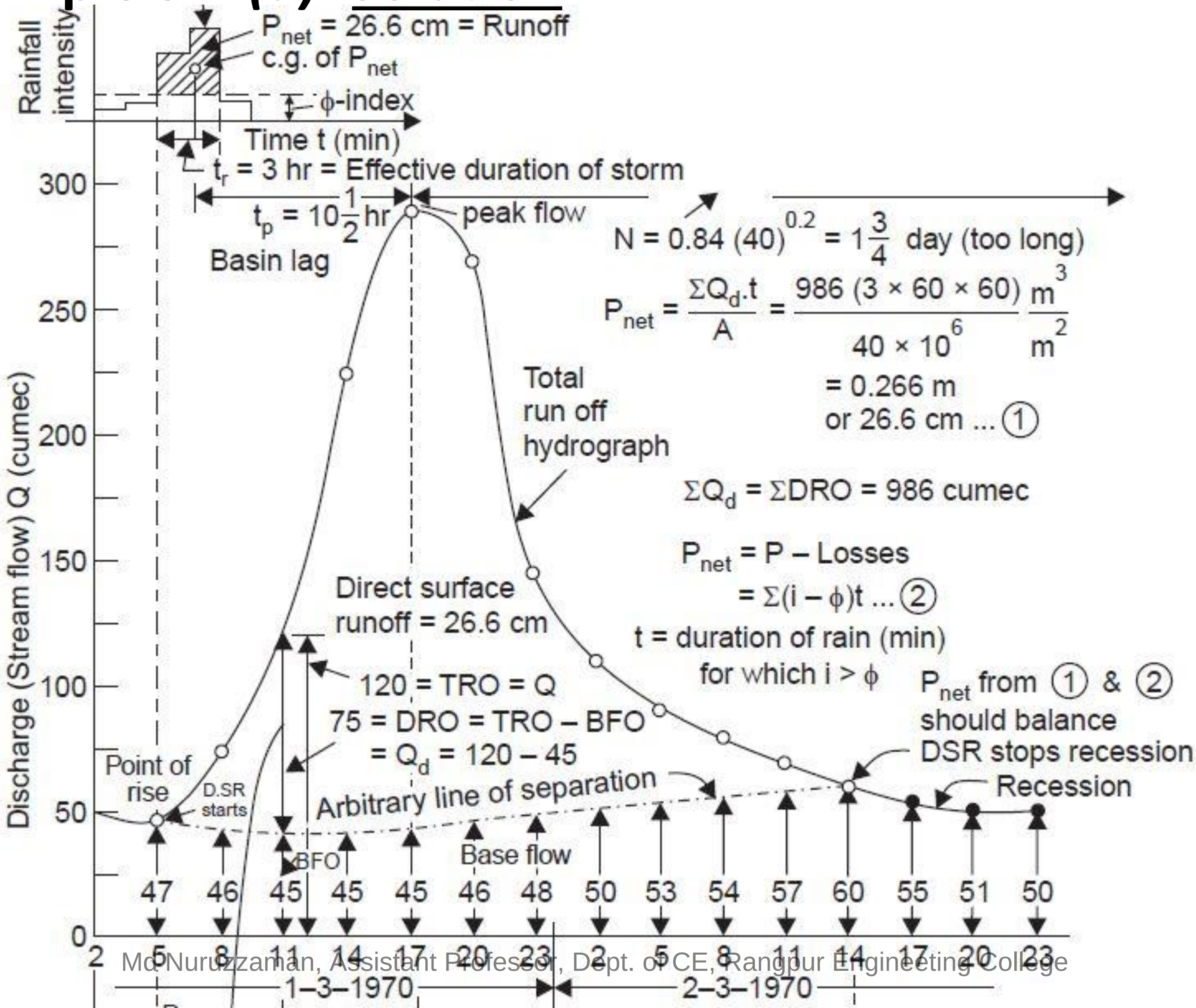
$$= 0.266\ \text{m} = 26.6\ \text{cm}$$

[5]Time from beginning of direct surface runoff is at 5 hr on 1-3-1970, which is reckoned 0 hr for unit hydrograph. The time base for unit hydrograph is 33 hours.

The 3-hour unit hydrogryph is plotted in Fig. 5.10 (*b*) to a different vertical scale and its peak is 9.23 cumec.

HYDROGRAPHS

Example 5.1 *(a)*- *Solution*



HYDROGRAPHS

Example 5.1 *(a)*- <u>*Solution*</u>

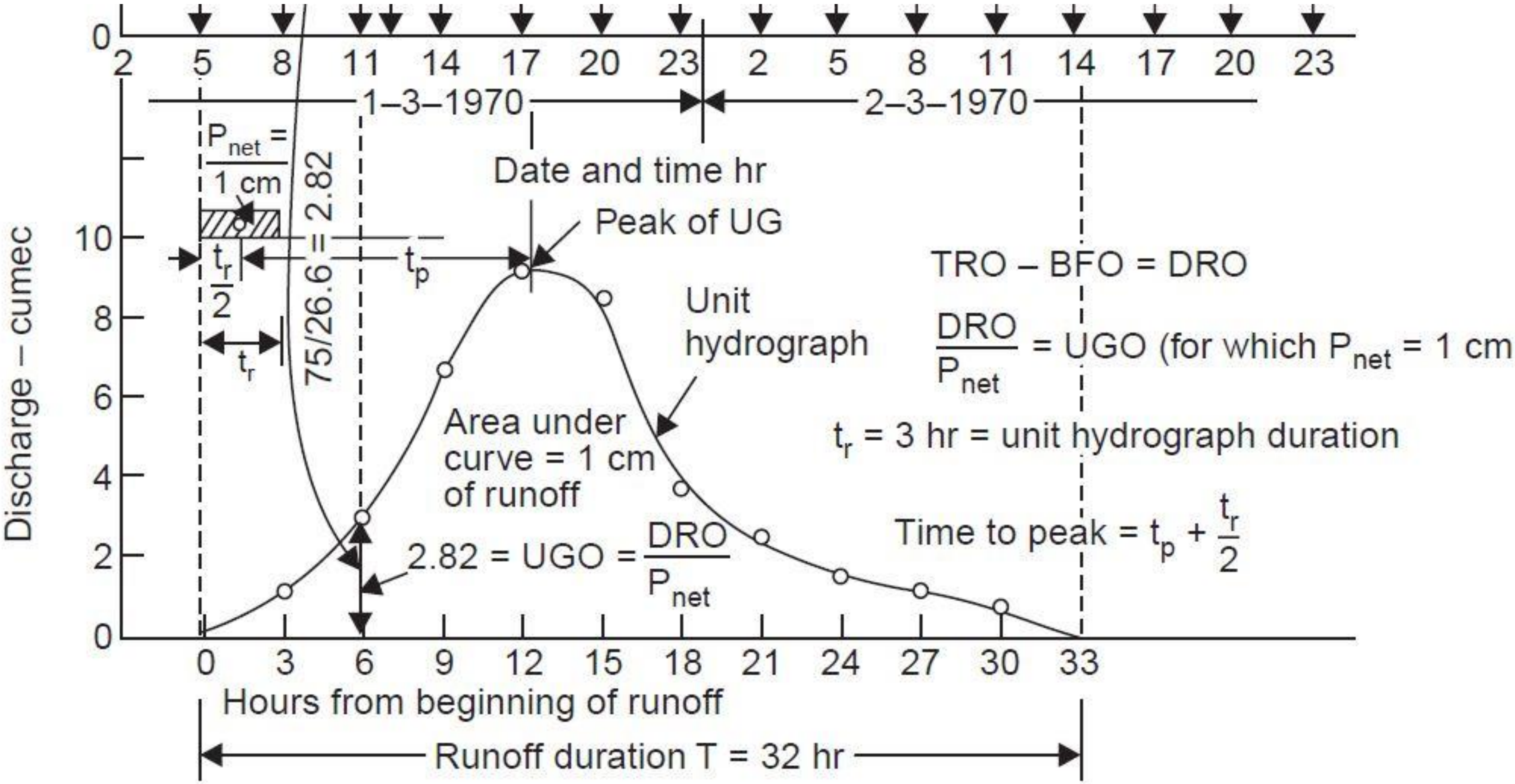


Fig. 5.10 Derivation of a unit hydrograph (Example 5.1)

HYDROGRAPHS

Example 5.4 *The ordinates of a 4-hour unit hydrograph for a particular basin are given below. Derive the ordinates of (i) the S-curve hydrograph, and (ii) the 2 hour unit hydrograph, and plot them, area of the basin is 630 km*^{2}.

HYDROGRAPHS

INSTANTANEOUS UNIT HYDROGRAPH

The IUH is a hydrograph of runoff resulting from the instantaneous application of 1 cm net rain on the drainage basin.

SYNTHETIC UNIT HYDROGRAPHS

There are many drainage basins (catchments) for which no streamflow records are available and unit hydrographs may be required for such basins. In such cases, hydrographs may be synthesised directly from other catchments, which are hydrologically and meteorologically homogeneous, or indirectly from other catchments through the application of empirical relationship.

HYDROGRAPHS

APPLICATION OF UNIT HYDROGRAPH

The application of unit hydrograph consists of two aspects:

(*i*) From a unit hydrograph of a known duration to obtain a unit hydrograph of the desired duration, either by the *S*-curve method or by the principle of superposition.

(*ii*) From the unit hydrograph so derived, to obtain the flood hydrograph corresponding to a single storm or multiple storms. For design purposes, a design storm is assumed, which with the help of unit hydrograph, gives a design flood hydrograph. While the first aspect is already given, the second aspect is illustrated in the following example.

HYDROGRAPHS

Example 5.11 *The design storm of a water shed has the depths of rainfall of 4.9 and 3.9 cm for the consecutive 1-hr periods. The 1-hr UG can be approximated by a triangle of base 6 hr with a peak of 50 cumec occurring after 2 hr from the beginning. Compute the flood hydrograph assuming an average loss rate of 9 mm/hr and constant base flow of 10 cumec. What is the area of water shed and its coefficient of runoff?*

HYDROGRAPHS

Example 5.11 (Solution)

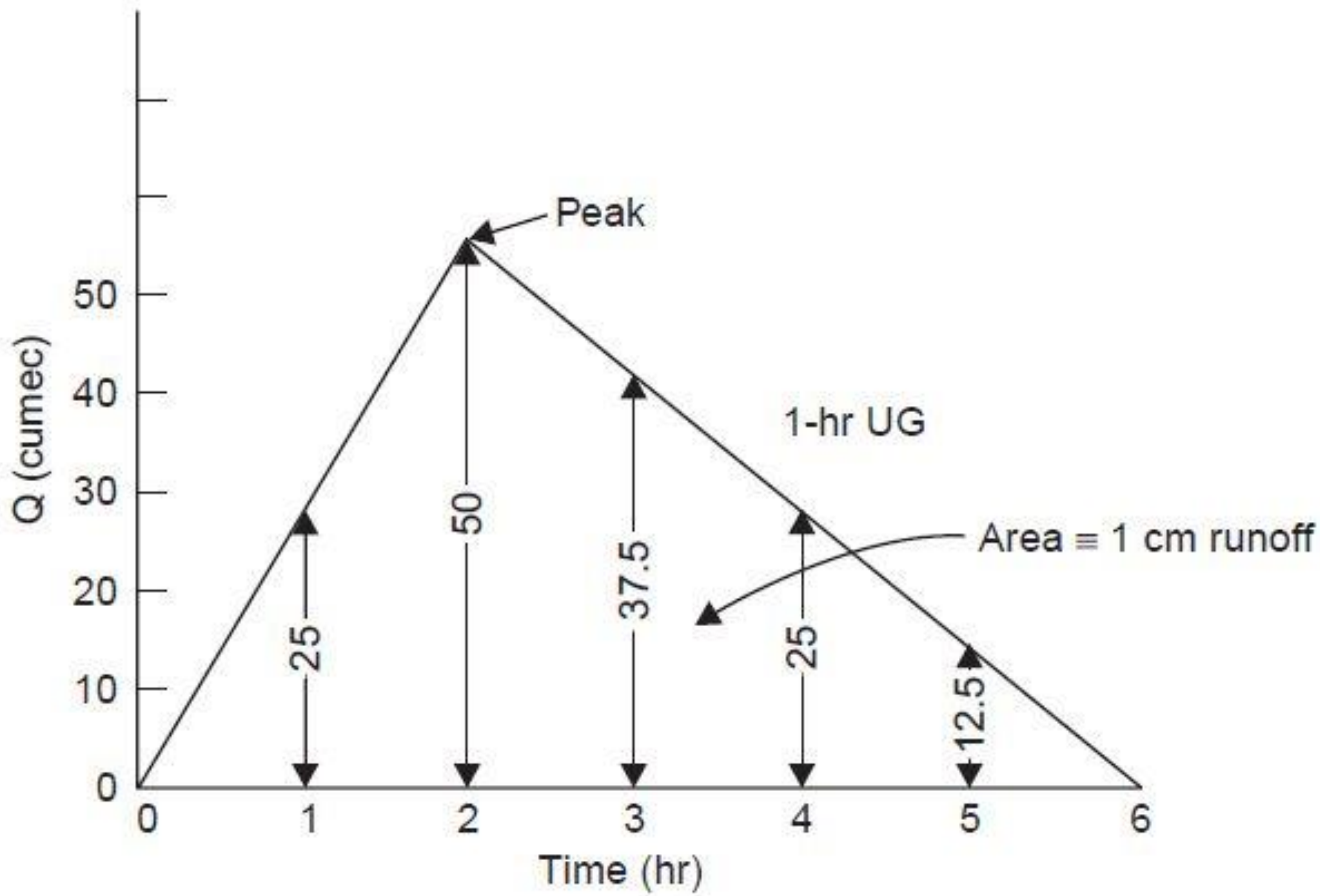


Fig. 5.34 (Example 5.11)

HYDROGRAPHS

Example 5.11 (Solution)

Table 5.10 Computation of design flood hydrograph (Example 5.11)

Time (hr)	*UGO* (cumec)*	*DRO due to rainfall excess (cumec)*		*Total (cumec)*	*BF (cumec)*	*TRO (cumec)*	*Remarks*
		4.9 – 0.9 = 4 cm	*3.9 – 0.9 = 3 cm*				
1	0	0	—	0	10	10	
2	25	100	0	100	10	110	
3	50	200	75	275	10	285	
4	37.5	150	150	300	10	**310**	← Peak flood†
5	25	100	112.5	212.5	10	222.5	
6	12.5	50	75	125	10	135	
7	0	0	37.5	37.5	10	47.5	
8	—	—	0	0	10	10	

*Ordinates by proportion in the triangular UG. †–Peak flood of 310 cumec, after 4 hr from the commencement of the storm.

HYDROGRAPHS

Example 5.11 (Solution)

(*ii*) Area of water shed—To produce 1-cm net rain over the entire water shed (A km^2).

Volume of water over basin = Area of UG (triangle)

$$(A \times 10^6)\,\frac{1}{100} = \frac{1}{2}\,(6 \times 60 \times 60)\,50$$

from which, A = **54 km²**

(*iii*) Coefficient of runoff $\quad C = \dfrac{R}{P} = \dfrac{(4.9 - 0.9) + (3.9 - 0.9)}{4.9 + 3.9} = \mathbf{0.795}$

HYDROGRAPHS

Example 5.13 *The successive three-hourly ordinates of a 6-hr UG for a particular basin are 0, 15, 36, 30, 17.5, 8.5, 3, 0 cumec, respectively. The flood peak observed due to a 6-hr storm was 150 cumec. Assuming a constant base flow of 6 cumec and an average storm loss of 6 mm/hr, determine the depth of storm rainfall and the streamflow at successive 3 hr interval.*

HYDROGRAPHS

Example 5.13 *(Solution)*

Solution

$$\text{DRO peak} = \text{Flood peak} - \text{BF}$$
$$= 150 - 6 = 144 \text{ cumec}$$
$$P_{net} = \frac{DRO_{peak}}{UG_{peak}} = \frac{144}{36} = 4 \text{ cm}$$

Depth of storm rainfall,

$$P = P_{net} + \text{losses} = 4 + 0.6 \times 6 = 7.6 \text{ cm.}$$
$$\text{DRO} = \text{UGO} \times P_{net}; \quad \text{DRO} + \text{BF} = \text{TRO}$$

Hence, multiplying the given UGO by 4 cm and adding 6 cumec, the stream flow ordinates at successive 3-hr intervals are: 6, 66, 150, 126, 76, 40, 18, 6 cumec, respectively.

RUNOFF

Overland flow

When a storm occurs, a portion of rainfall infiltrates into the ground and some portion may evaporate. The rest flows as a thin sheet of water over the land surface which is termed as *overland flow.*

Underflow

If there is a relatively impermeable stratum in the subsoil, the infiltrating water moves laterally in the surface soil and joins the stream flow, which is termed as underflow (subsurface flow) or interflow.

The term direct runoff is used to include the overland flow and the interflow.

RUNOFF

Depression storage

When the overland flow starts (due to a storm) some flowing water is held in puddles, pits and small ponds; this water stored is called *depression storage.*

Detention storage

The volume of water in transit in the overland flow which has not yet reached the stream channel is called *surface detention* or *detention storage.*

Bank storage

RUNOFF

Catchment

The entire area of a river basin whose surface runoff (due to a storm) drains into the river in the basin is considered as a hydrologic unit and is called *drainage basin*, watershed or catchment area of the river flowing.

Drainage divide

The boundary line, along a topographic ridge, separating two adjacent drainage basins is called *drainage divide*

Concentration point

The single point or location at which all surface drainage from a basin comes together or concentrates as outflow from the basin in the stream channel is called *concentration point* or *measuring point*

Concentration time

The time required for the rain falling at the most distant point in a drainage area (*i.e.,* on the fringe of the catchment) to reach the concentration point is called the concentration time.

RUNOFF

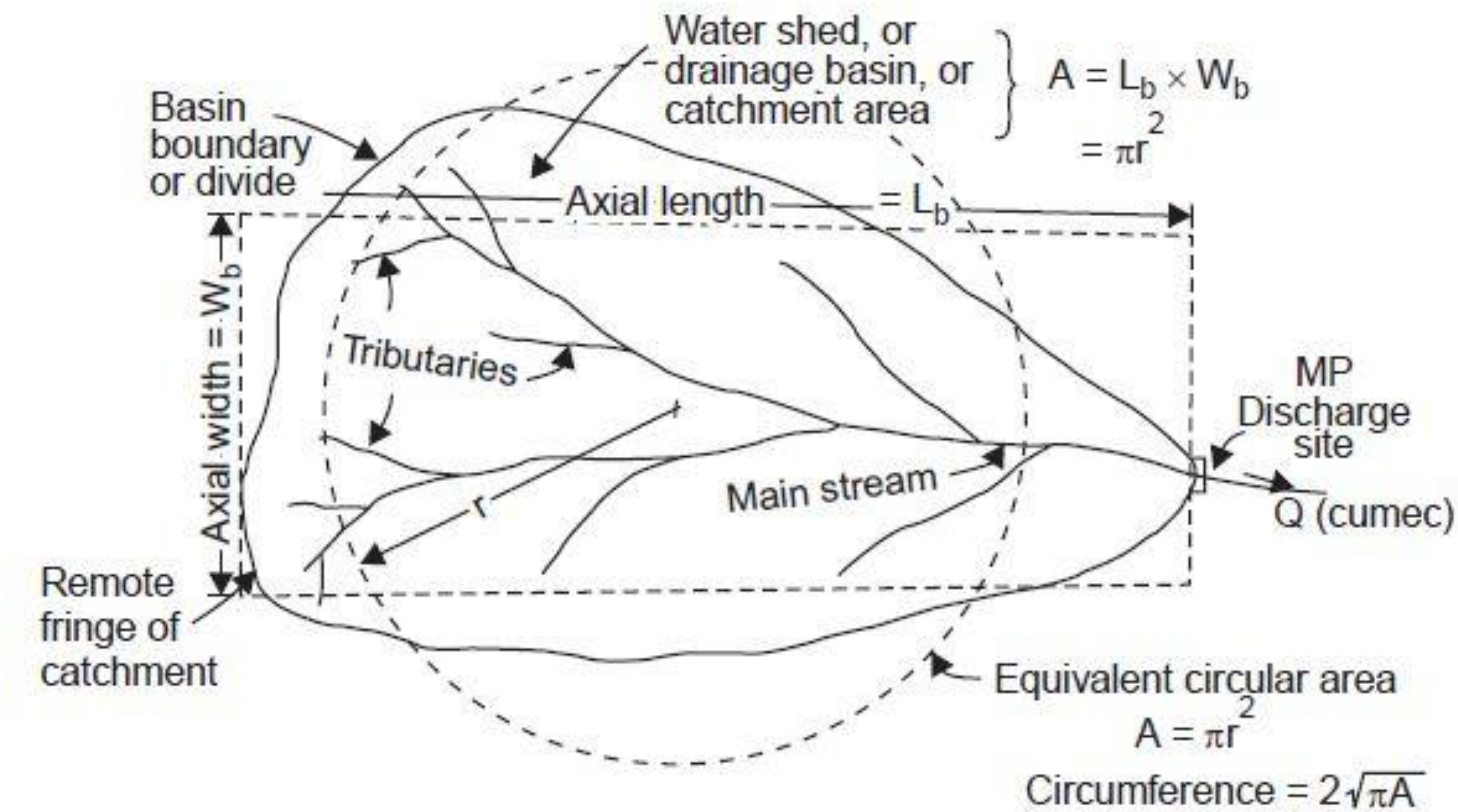


Fig. 4.3 Drainage basin characteristics

RUNOFF

The characteristics of the drainage net may be physically described by:

(*i*) the number of streams (*ii*) the length of streams

(*iii*) stream density (*iv*) drainage density

The stream density of a drainage basin is expressed as the number of streams per square kilometre.

$$\text{stream density, } D_s = \frac{N_s}{A} \qquad \text{...(4.1)}$$

where N_s = number of streams

A = area of the basin

Drainage density is expressed as the total length of all stream channels (perennial and intermittent) per unit area of the basin and serves as an index of the areal channel development of the basin

$$\text{Drainage density, } D_d = \frac{L_s}{A} \qquad \text{...(4.2)}$$

where L_s = total length of all stream channels in the basin.

Drainage density varies inversely as the length of overland flow and indicates the drainage effeciency of the basin. A high value indicates a well-developed network and torrential runoff causing intense floods while a low value indicates moderate runoff and high permeability of the terrain.

$$\text{Average stream slope} = \frac{\text{total fall of the longest water course}}{\text{length of the longest water course}}$$

RUNOFF

Elongation ratio

Elongation ratio (*Er*)', defined as the ratio of the diameter of a circle of the same area as the basin to the maximum basin length; the values range from 0.4 to 1.0.

(*i*) form factor (*ii*) compactness coefficient

Form factor, $$F_f = \frac{W_b}{L_b} = \frac{A}{L_b^2} \qquad \text{...(4.4)}$$

$$\therefore \qquad A = W_b \,.\, L_b$$

where W_b = axial width of basin

L_b = axial length of basin, *i.e.*, the distance from the measuring point (MP) to the most remote point on the basin.

Compactness coefficient, $$C_c = \frac{P_b}{2\sqrt{\pi A}} \qquad \text{...(4.5)}$$

where P_b = perimeter of the basin

$2\sqrt{\pi A}$ = circumference of circular area, which equals the area of the basin.

If R is the radius of an equivalent circular area,

$$A = \pi R^2, \qquad R = \sqrt{\frac{A}{\pi}}$$

Circumference of the equivalent circular area = $2\pi R = 2\pi \sqrt{\dfrac{A}{\pi}} = 2\sqrt{\pi A}$

Example 4.2 *A basin has an area of 26560 km2, perimeter 965 km and length of the thalweg 230 km. Determine: (i) form factor, (ii) compactness coefficient, (iii) elongation ratio, and (iv) circularity ratio.*

Example 4.2 (Solution)

Solution (*i*) Form factor, $F_f = \dfrac{A}{L_b^2} = \dfrac{26560}{230^2} = \mathbf{0.502}$

An inverted factor will give **2**

(*ii*) Compactness Coefficient C_c

Radius R of an equivalent circular area is given by

$$26560 = \pi R^2 \qquad \therefore \qquad R = 91.9 \text{ km}$$

$$C_c = \frac{P_b}{2\pi R} = \frac{965}{2\pi\,(91.9)} = \mathbf{1.67}$$

(*iii*) Elongation ratio $E_r = \dfrac{2R}{L_b} = \dfrac{2\,(91.9)}{230} = \mathbf{0.8}$

(*iv*) Circularity ratio C_r

Radius R' of a circle of an equivalent perimeter as the basin is given by

$$2\pi R' = 965 \qquad \therefore \qquad R' = 153.5 \text{ km}$$

$$\therefore \qquad C_r = \frac{A}{\pi R'^2} = \frac{26560}{\pi\,(153.5)^2} = \mathbf{0.358}$$

RUNOFF

Streams may be classified as:

(*i*) Influent and Effluent streams

(*ii*) Intermittent and perennial streams

Influent streams

If the GWT is below the bed of the stream, the seepage from the stream feeds the ground-water resulting in the build up of water mound. Such streams are called influent streams

Effluent streams

When the GWT is above water surface elevation in the stream, the ground water feeds the stream. Such streams are called effluent streams.

RUNOFF

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RUNOFF

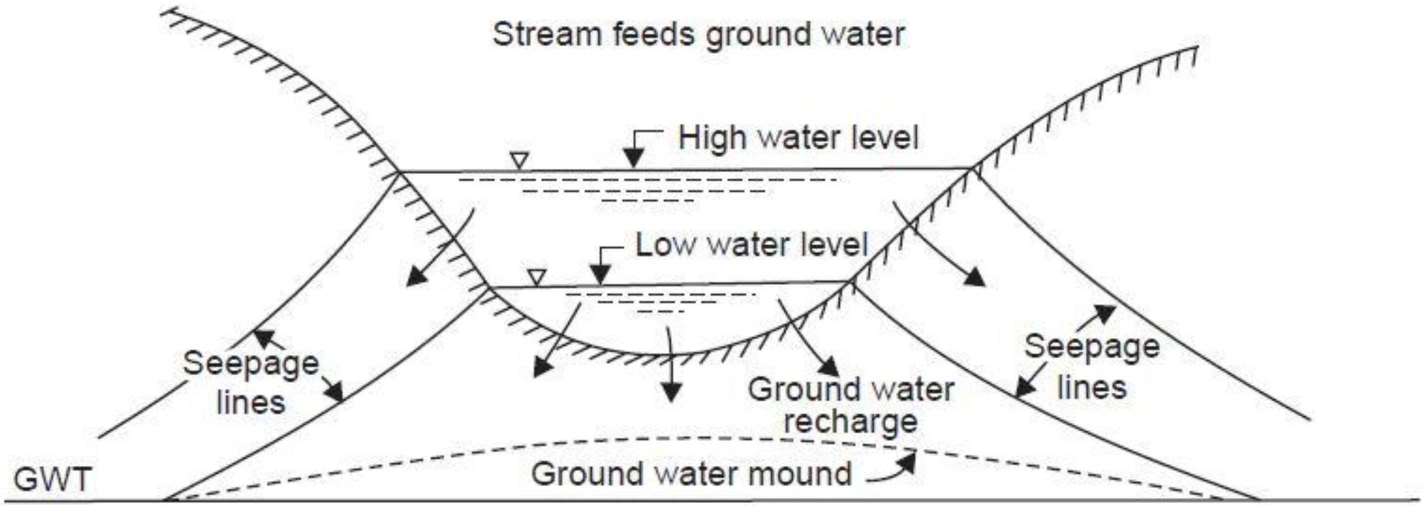


Fig. 4.6 Influent streams

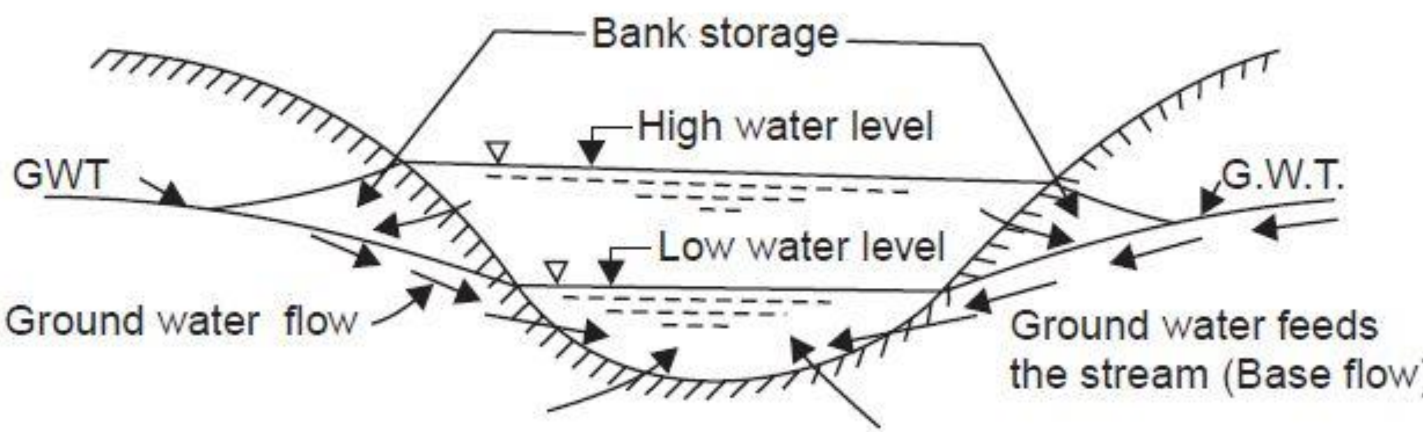


Fig. 4.7 Effluent streams

RUNOFF

4.5 ISOCHRONES

The lines joining all points in a basin of some key time elements in a storm, such as beginning of precipitation, are called isochrones (Fig. 4.8). They are the time contours and represent lines of equal travel time and they are helpful in deriving hydrographs.

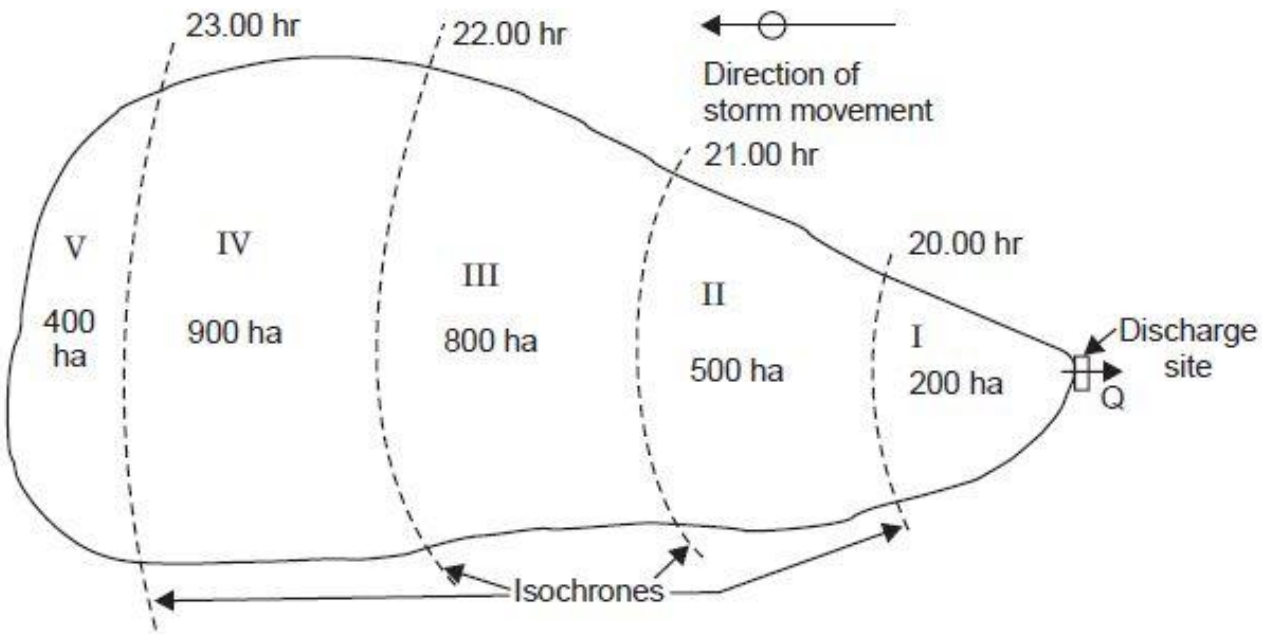


Fig. 4.8 Isochrones

RUNOFF

FACTORS AFFECTING RUNOFF

(*i*) Storm characteristics
- Type or nature of storm and season
- Intensity
- Duration
- Areal extent (distribution)
- Frequency
- Antecedent precipitation
- Direction of storm movement

(*ii*) Meteorological characteristics
- Temperature
- Humidity
- Wind velocity,
- Pressure variation

RUNOFF

FACTORS AFFECTING RUNOFF

(*iii*) Basin characteristics

- Size
- Shape
- Slope
- Altitude (elevation)
- Topography
- Geology (type of soil)
- Land use /vegetation
- Orientation
- Type of drainage net
- Proximity to ocean and mountain ranges

(*iv*) Storage characteristics

- Depressions
- Pools and ponds / lakes
- Stream
- Channels
- Check dams (in gullies)
- Upstream reservoir /or tanks
- Flood plains, swamps
- Ground water storage in pervious deposits (aquifers)

RUNOFF

Maximum flood discharge

It is the discharge in times of flooding of the catchment area, *i.e.,* when the intensity of rainfall is greatest and the condition of the catchment regarding humidity is also favourable for an appreciable runoff.

Runoff Estimation

(*i*) Empirical formulae, curves and tables

(*ii*) Infiltration method

(*iii*) Rational method

(*iv*) Overland flow hydrograph

(*v*) Unit hydrograph method

(*vi*) Coaxial Graphical Correlation and API

RUNOFF

Empirical formulae, curves and tables

(*i*) *Empirical formulae, curves and tables*. Several empirical formulae, curves and tables relating to the rainfall and runoff have been developed as follows:

Usually, $$R = a\,P + b \qquad \text{...(4.7)}$$

sometimes, $$R = a\,P^n \qquad \text{...(4.8)}$$

where R = runoff, P = rainfall, a, b, and n, are constants. Eq. (4.7) gives a straight line plot on natural graph paper while Eq. (4.8) gives an exponential curve on natural graph paper, Fig. 4.9 *a* and a straight line plot on log-log paper Fig. 4.9 *b*; the constants can be obtained from the straight line plots as shown in Fig. 4.9. Also see Chapter 13, and Ex. 13.4 with Computer Program—C.

For example, C.C. Inglis' formula for Bombay—Deccan catchments (Ghat areas)

$$R = 0.85P + 30.5 \qquad \text{...(4.9)}$$

and for plains $$R = \frac{(P - 17.8)P}{254} \qquad \text{...(4.10)}$$

RUNOFF

Empirical formulae, curves and tables

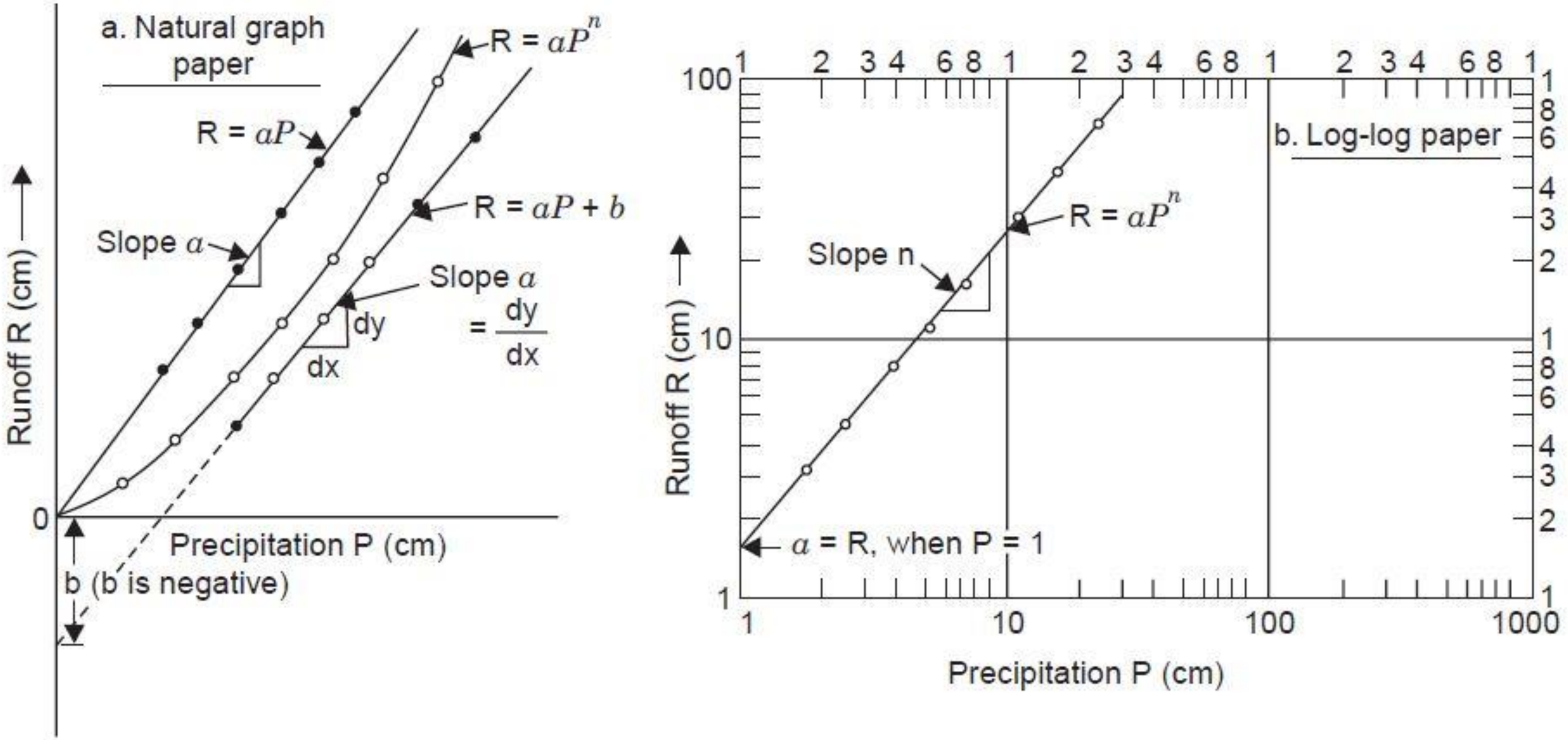


Fig. 4.9 Rainfall-Runoff correlation

RUNOFF

Rational Method

A rational approach is to obtain the yield of a catchment by assuming

a suitable runoff coefficient.

Yield = CAP ...(4.19)

where A = area of catchment

P = precipitation

C = runoff coefficient

RUNOFF

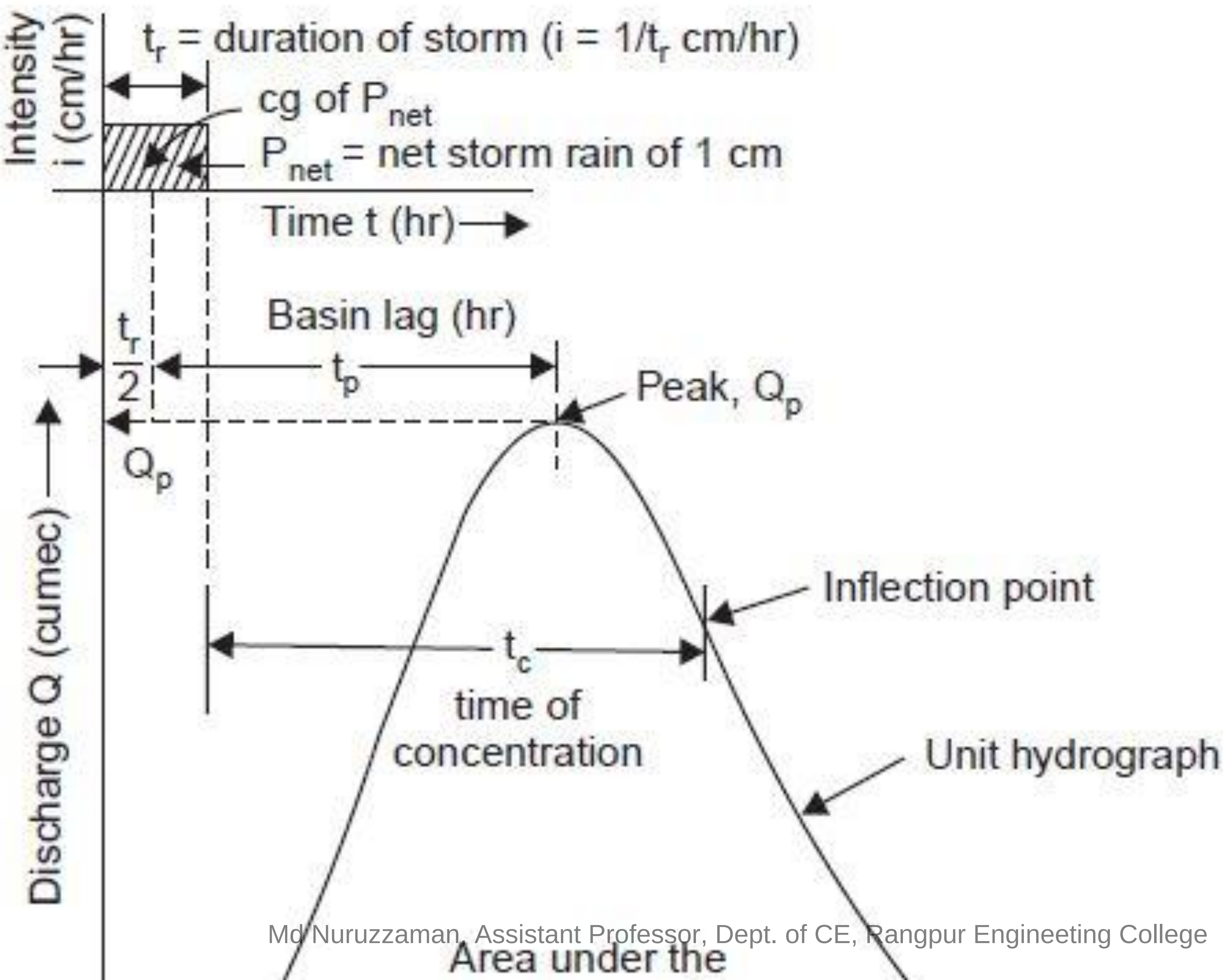
Type of catchment	Value of C
Rocky and impermeable	0.8–1.0
Slightly permeable, bare	0.6–0.8
Cultivated or covered with vegetation	0.4–0.6
Cultivated absorbent soil	0.3–0.4
Sandy soil	0.2–0.3
Heavy forest	0.1–0.2

RUNOFF

<u>Unit Hydrograph Method</u>

The hydrograph of direct surface discharge measured at the outlet of drainage area, which produces a unit depth of direct runoff (*i.e.,* a *P*net of 1 cm over the entire area of the catchment) resulting from a unit storm of specified duration (called *unit period*) is called a *unit hydrograph* of that duration.

RUNOFF



t_r = duration of storm ($i = 1/t_r$ cm/hr)
Intensity i (cm/hr)
cg of P_{net}
P_{net} = net storm rain of 1 cm
Time t (hr)
Basin lag (hr)
$\frac{t_r}{2}$
t_p
Peak, Q_p
Q_p
Discharge Q (cumec)
Inflection point
t_c
time of concentration
Unit hydrograph
Area under the

RUNOFF

Assumptions of unit hydrograph

(*i*) The net rainfall is of uniform intensity within its duration (*i.e.,* unit period).

(*ii*) The net rainfall uniformly occurs over the entire area of the drainage basin.

(*iii*) For a given drainage basin, the base period of the hydrographs of direct runoff corresponding to net rains of different intensities but same unit duration, is constant.

(*iv*) The ordinates of direct runoff hydrographs due to net rains of different intensities (but same unit duration) are proportional.

(*v*) A unit hydrograph reflects all the physical characteristics of the basin

RUNOFF

Application of the Unit Hydrograph

First a unit hydrograph of suitable unit duration is derived from an observed flood hydrograph for the drainage basin due to a known storm (storm loss and net rain). The unit hydrograph so derived can be applied for any other storm (of the same duration but producing different net rain) occurring on the basin and the resulting flood hydrographs can be obtained.

RUNOFF

Example 4.5 *A small watershed consists of 1.5 km² of cultivated area (c = 0.2), 2.5 km² under forest (c = 0.1) and 1 km² under grass cover (c = 0.35). There is a fall of 20 m in a watercourse of length 2 km. The I–D–F relation for the area is given by* $I = \frac{80\, T^{0.2}}{(t+12)^{0.5}}$*, I in cm/hr, T–yr, t-min.*

Estimate the peak rate of runoff for a 25-year frequency.

Solution Time of concentration (Kirpich's formula–modified)

$$t_c \approx 0.02\, L^{0.8}\, S^{-0.4}, \quad t_c \text{ in min, L in metres}$$

$$= 0.02\,(2000)^{0.8} \left(\frac{20}{2000}\right)^{-0.4} = 55 \text{ min} = t$$

$$I = \frac{80 \times 25^{0.2}}{(55+12)^{0.5}} = 18.6 \text{ cm/hr}$$

$$Q = CIA = 2.78\, I\, (\Sigma\, C_i\, A_i) = 2.78 \times 18.6\,(1.5 \times 0.2 + 2.5 \times 0.1 + 1 \times 0.35)$$

$$= \mathbf{46.5\ Cumec}$$

STREAM GAUGING

Stream gauging

Measuring the discharge of the stream draining it is termed as *stream gauging.*

Gauging station

A *gauging station* is the place or section on a stream where discharge measurements are made.

STREAM GAUGING

METHODS OF MEASURING STREAM FLOW

1. Venturiflumes or standing wave flumes
2. Weirs or anicuts:
3. Slope-area method
4. Contracted area methods:
5. *Sluiceways, spillways and power conduits*
6. *Salt-concentration method*
7. *Area-velocity methods*
   - *Float*
   - *Rod*
   - *Current meter*

STREAM GAUGING

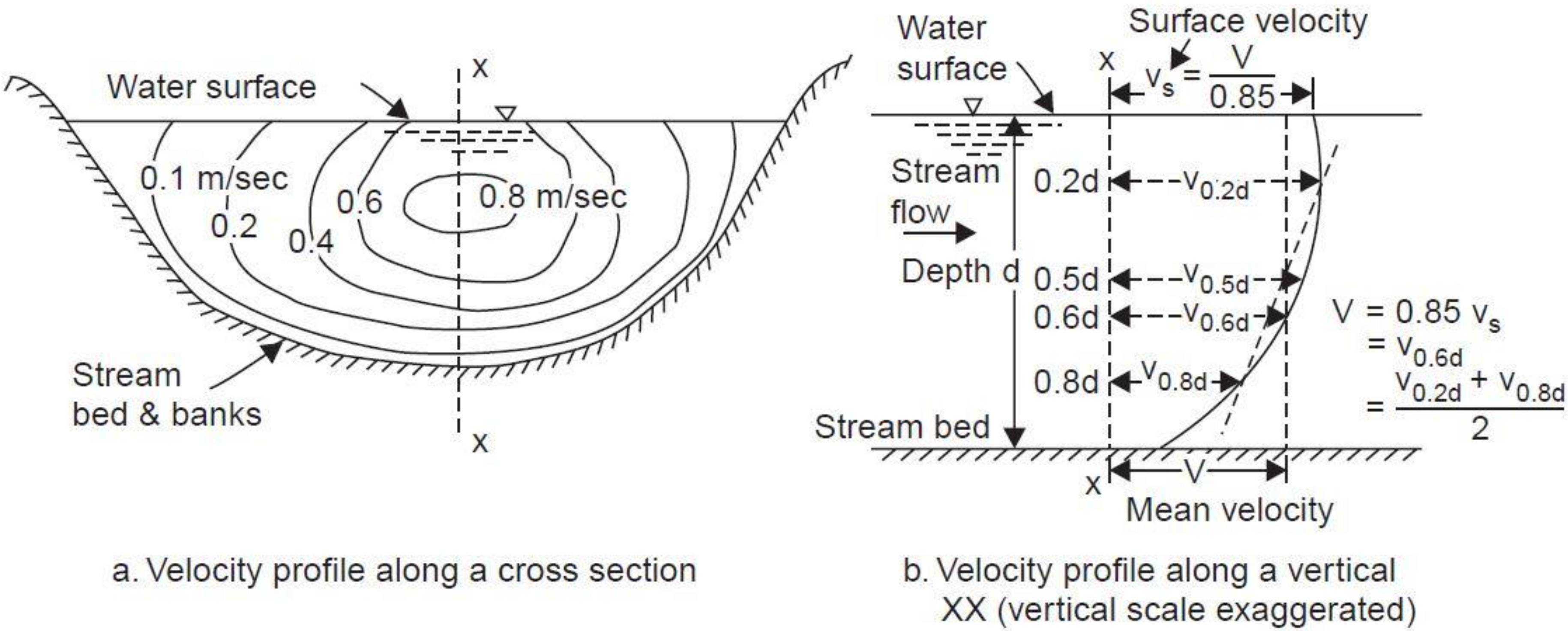


Fig. 6.1 Horizontal and vertical velocity profiles in a stream

STREAM GAUGING

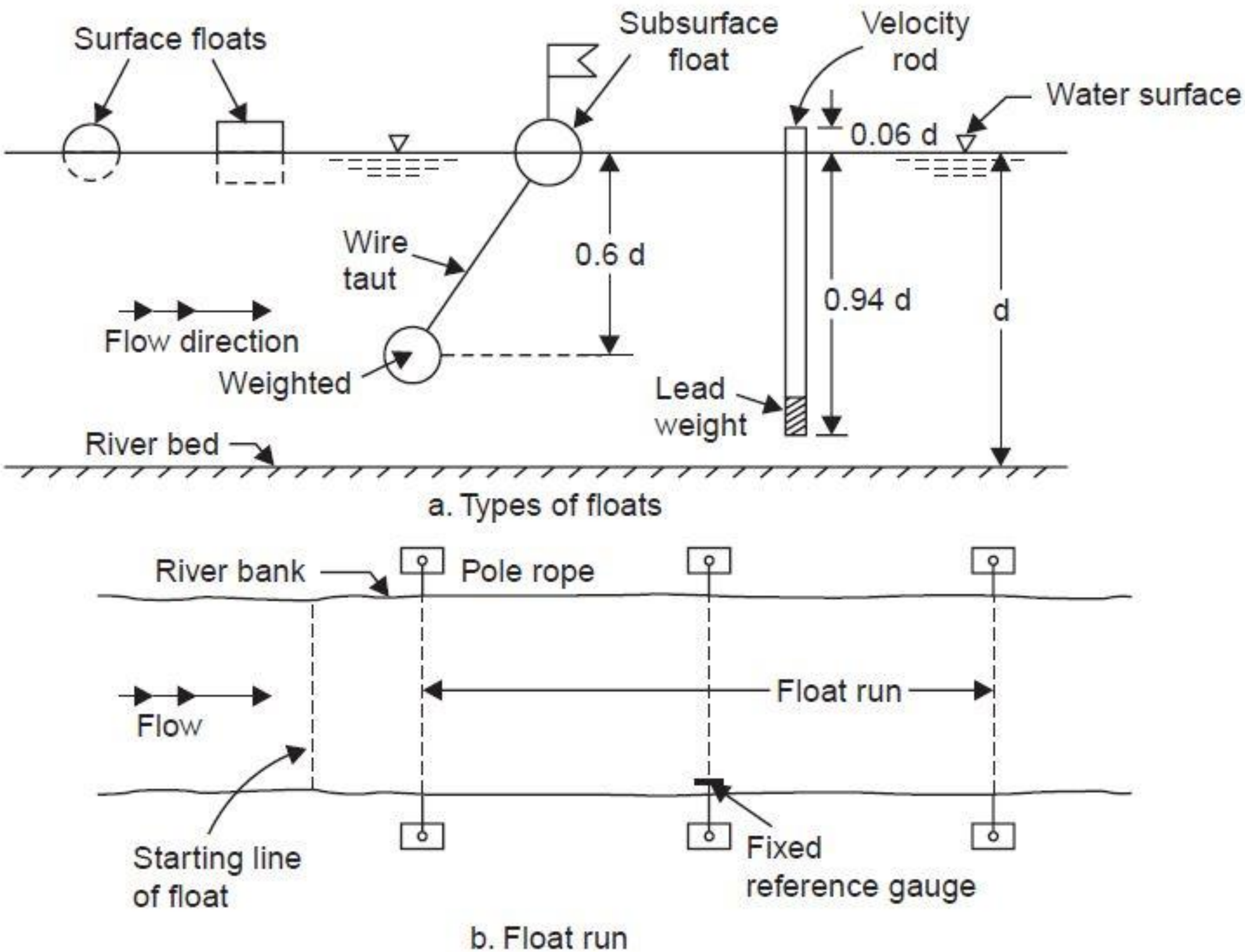


Fig. 6.2 Velocity determination by floats

STREAM GAUGING

Current meter

The current meter is an instrument, which has a rotating element which when placed in flowing water, the speed of revolutions has a definite relation with the velocity of flow past the element.

STREAM GAUGING

Rating of the Current Meter

The relationship between the revolutions per second (N, rps) of the meter and the velocity of flow past the meter (v, m/sec) has to be first established, or if the rating equation is given by the maker, it has to be verified. This process of calibration of the meter is called *rating of the current meter*.

The rating equation is of the form

$$v = aN + b$$

where a and b are constants (determined from rating of the current meter).

Rating of the Current Meter (Method)

The rating is done in a masonry tank of approximate dimensions 90 m × 2.4 m × 2.1 m, Fig. 6.4. The meter is towed in still water in the tank either by a pushing trolley (from which the meter is suspended) by men specially trained for the purpose or by an electric motor to move the trolley at a constant speed on a track by the side of the tank, the distances being painted in *m* and *cm* in enamel on the track. A metronome adjusted to give ticks at every 2, 3, 4, 5, 6, 7, 8, 10 sec is kept on the trolley. The men pushing the trolley would have been trained to put paces uniformly to synchronise with the ticking of the metronome. When motorized speeds are adjusted to give different velocities. A *cantilever beam* is fixed to the trolley such that the projecting end is at the centre of the rating tank from which the meter is hung from a *suspension rod*. The meter should be immersed about 1 m below the water surface during rating. The observer sits in the trolley, notes the time and distance traversed by the trolley for a fixed number of revolutions made by the meter (say, 10-100 depending on the speed). This operation is repeated for different pushing velocities of the trolley. A current meter rating curve is drawn as 'pushing velocity vs. rps', which plots a straight line and the constants *a* and *b* are determined as shown in Fig. 6.5.

STREAM GAUGING

Rating of the Current Meter (Method)

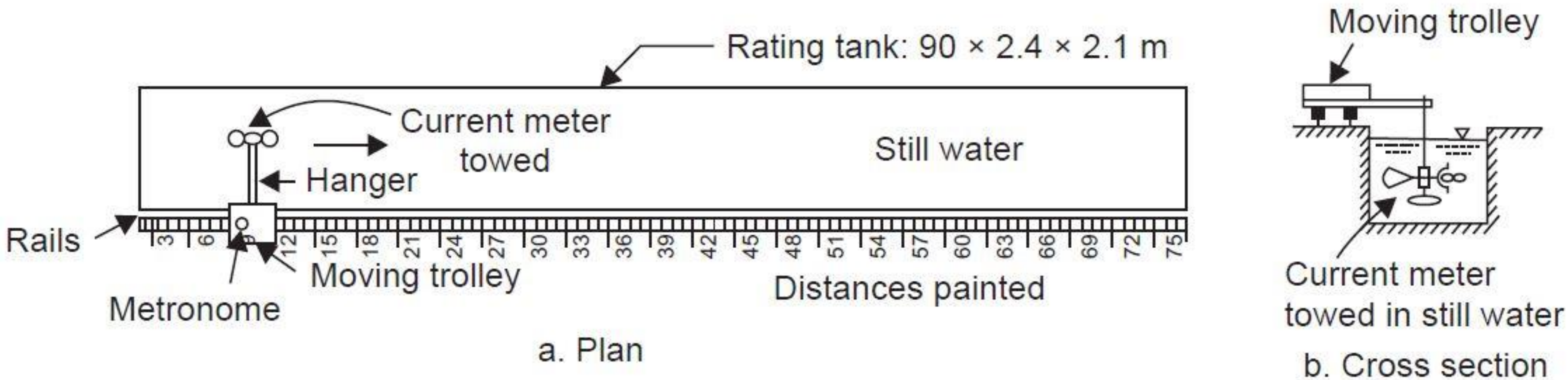


Fig. 6.4 Current meter rating tank

STREAM GAUGING

Rating of the Current Meter (Method)

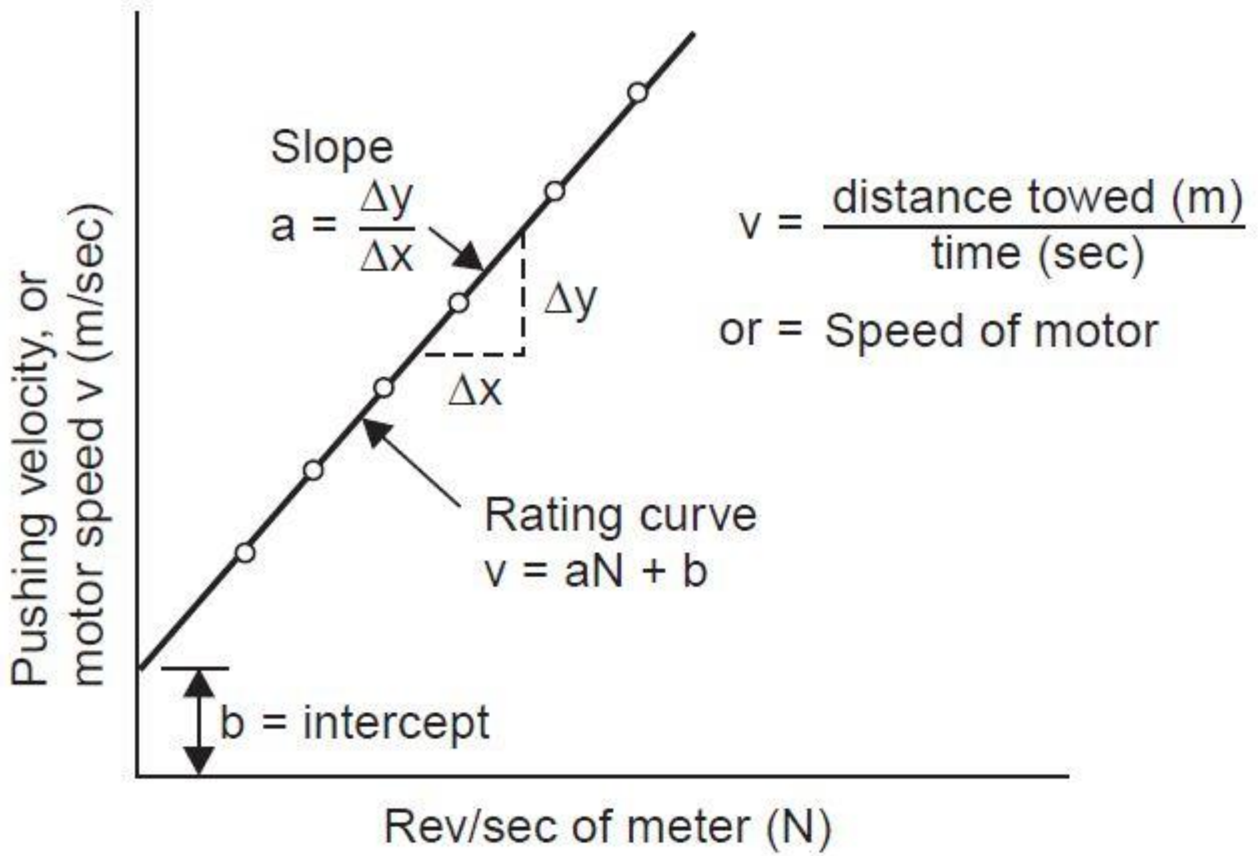
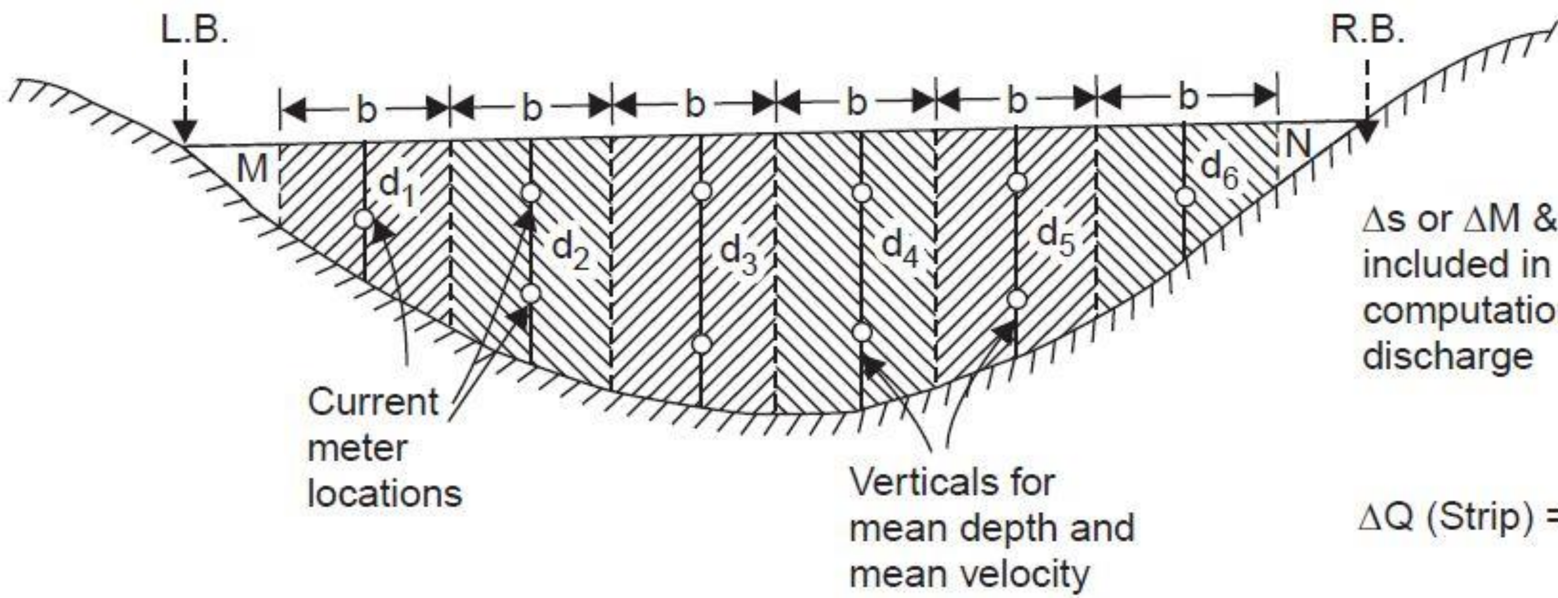


Fig. 6.5 Current meter rating curve

STREAM GAUGING

Stage-Discharge-Rating Curve

1. Mid-section method



Δs or ΔM & N not included in computation of discharge

$$\Delta Q\ (\text{Strip}) = (b.d)\,\frac{v_{.2d} + v_{.8d}}{2}$$

or

$$= (b.d)\, v_{.6d}$$

a. Mid-section method

STREAM GAUGING

Stage-Discharge-Rating Curve

1. Mid-section method

$$\Delta Q = (bd)\, v_{0.6d} \text{ in shallow strips} \qquad \text{...(6.8)}$$

$$\Delta Q = (bd) \times \frac{v_{0.2d} + v_{0.8d}}{2} \quad \text{in deep water strips} \qquad \text{...(6.8 } a\text{)}$$

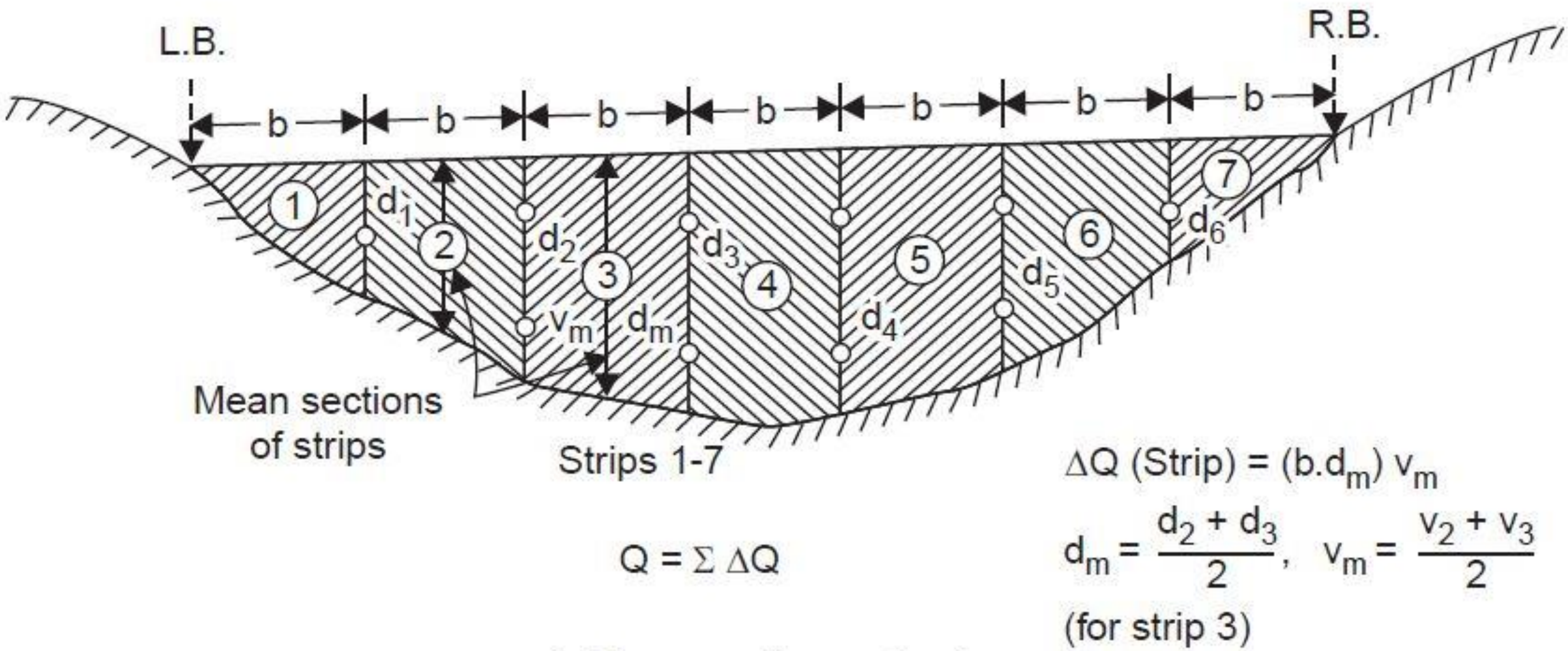
stream discharge, $Q = \Sigma\, \Delta Q$ ...(6.8 b)

In this method, the discharge in the two-triangular bits near the ends are not included in the discharge computation.

STREAM GAUGING

Stage-Discharge-Rating Curve

2. Mean section method



b. Mean-section method

Fig. 6.7 Mid-section and Mean-section methods

STREAM GAUGING

Stage-Discharge-Rating Curve

2. Mean section method

(*ii*) *Mean-section method*. In this method, the elemental strip is taken between two verticals and the mean depth is taken as the average of the depths in the two verticals (determined by sounding). The width of the strip is distance b between the two verticals. The velocity in the strip is taken as the average of the mean velocity determined in the two verticals (by one-point or two-points method), Fig. 6.7 (*b*). The discharge in the elemental strip is given by

$$Q = b\left(\frac{d_1 + d_2}{2}\right)\left(\frac{V_1 + V_2}{2}\right) \quad \text{...(6.9)}$$

V_1, V_2 determined as $v_{0.6d}$ in shallow strip

and $\dfrac{v_{0.2d} + v_{0.8d}}{2}$ in deep water strip ...(6.9 *a*)

Stream discharge, $Q = \Sigma\, \Delta Q$ ...(6.9 *b*)

The mean section method is considered to be slightly more accurate, but the mid-section method is faster and is generally used.

STREAM GAUGING

SELECTION OF SITE FOR A STREAM GAUGING STATION

(i) The section should be straight and uniform for a length of about 10 to 20 times the width of the stream.

(*ii*) The bed and banks of the stream should be firm and stable so as to ensure consistency of area-discharge relationship, *i.e.,* the cross section should not be subjected to change by silting or scouring, during different stages of flow; a smooth rock, shingle or clay bed is favourable, while a fine sandy bed is unfavourable.

(*iii*) The bed and banks should be free from vegetal growth, boulders or other obstructions like bridge piers, etc.

(*iv*) There should be no larger overflow section at flood stage. The best cross section is one with *V*-shape, so that there is sufficient depth for immersing the current meter without being affected by the bed roughness of the stream.

STREAM GAUGING

SELECTION OF SITE FOR A STREAM GAUGING STATION

(*v*) The part of the reach having the most regular transverse section and steady flow with the current normal to the metering section and velocities in the range of 0.3–1.2 m/sec should be selected.

(*vi*) To ensure consistency between stage and discharge, there should be a good control section far downstream of the gauging site. This control may be in the form of steep rapids, large rocky boulders, restricted passages, crest of weirs or anticuts etc.

(*vii*) The sites above the confluence of rivers are best avoided if the flow is affected by back water conditions due to the varying discharges in the tributaries.

(*viii*) The stream gauging station should be easily accessible.

STREAM GAUGING

FOLLOWING VELOCITIES WERE RECORDED IN A STREAM WITH A CURRENT METER. FIND THE DISCHARGE PER UNIT WIDTH OF STREAM NEAR THE POINT OF MEASUREMENT BY TWO-POINT METHOD. DEPTH OF FLOW AT THE POINT WAS 3.5 METER

DEPTH ABOVE BED (M)	0	0.7	1.4	2.1	2.8
VELOCITY (M/SEC)	0	2.62	2.94	3.16	3.28

WATER LOSSES

Rainfall–Losses = Runoff

WATER LOSSES

WATER LOSSES

(*i*) Interception loss-due to surface vegetation, *i.e.,* held by plant leaves.

(*ii*) Evaporation:

(*a*) from water surface, *i.e.,* reservoirs, lakes, ponds, river channels, etc.

(*b*) from soil surface, appreciably when the ground water table is very near the soil
surface.

(*iii*) Transpiration—from plant leaves.

(*iv*) Evapotranspiration for consumptive use—from irrigated or cropped land.

(*v*) Infiltration—into the soil at the ground surface.

(*vi*) Watershed leakage—ground water movement from one basin to another or into the sea.

WATER LOSSES

Interception loss—The precipitation intercepted by foliage (plant leaves, forests) and buildings and returned to atmosphere (by evaporation from plant leaves) without reaching the ground surface is called *interception loss.*

WATER LOSSES

Interception loss—The precipitation intercepted by foliage (plant leaves, forests) and buildings and returned to atmosphere (by evaporation from plant leaves) without reaching the ground surface is called *interception loss*.

WATER LOSSES

EVAPORATION

Evaporation from water surfaces (Lake evaporation)

Methods of Estimating Lake Evaporation

Evaporation from water surfaces can be determined from the following methods :

(*i*) The storage equation

$P + I \pm Og = E + O \pm S$ ...(3.4)

where P = Precipitation

I = surface inflow

Og = subsurface inflow or outflow

E = evaporation

O = surface outflow

S = change in surface water storage

(*ii*) Auxiliary pans like land pans, floating pans, colarado sunken pans, etc.

(*iii*) Evaporation formula like that of Dalton's law

(*iv*) Humidity and wind velocity gradients

(*v*) The energy budget—this method involves too many hydrometeorological factors (variables) with too much sophisticated instrumentation and hence it is a specialist approach

(*vi*) The water budget—similar to (*i*)

(*vii*) Combination of aerodynamic and energy balance equations—Penman's equation (involves too many variables)

WATER LOSSES

EVAPORATION PANS

(i) Floating pans

(ii) Land pan.

(iii)Colarado sunken pan.

Pan coefficient

The small volume of water in the metallic pan is greatly affected by temperature fluctuations in the air or by solar raditions in contrast with large bodies of water (in the reservoir) with little temperature fluctuations. Thus the pan evaporation data have to be corrected to obtain the actual evaporation from water surfaces of lakes and reservoirs, *i.e.,* by multiplying by a coefficient called pan coefficient and is defined as Pan coefficient.

WATER LOSSES

Measures to Reduce Lake Evaporation

1. Storage reservoirs of more depth and less surface area, *i.e.,* by choosing a cross section of the reservoir like a deep gorge
2. By growing tall trees like Causerina on the windward side of the reservoirs to act as wind breakers.
3. By spraying certain chemicals or fatty acids and formation of films.
4. By allowing flow of water, temperature is reduced and evaporation is reduced; *i.e.,* by designing the outlet works so that the warmer surface water can be released.
5. By removing the water loving weeds and plants like Phreatophytes from the periphery of the reservoir.

WATER LOSSES

Measures to Reduce Lake Evaporation

6. By straightening the stream-channels the exposed area of the water surface (along the length) is reduced and hence evaporation is reduced.
7. By providing mechanical coverings like thin polythene sheets to small agricultural ponds and lakes.
8. By developing undergound reservoirs, since the evaporation from a ground water table is very much less than the evaporation from a water surface.
9. If the reservoir is surrounded by huge trees and forest, the evaporation loss will be less due to cooler environment.

WATER LOSSES

SOIL EVAPORATION

The evaporation from a wet soil surface immediately after rain or escape of water molecules with more resistance when the water table lies within a metre from the ground is called *soil evaporation.*

Evaporation opportunity

soil evaporation is expressed as a percentage of evaporation from free water surface, which is called evaporation opportunity.

WATER LOSSES

Transpiration

Transpiration is the process by which the water vapour escapes from the living plant leaves and enters the atmosphere.

Transpiration Ratio

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

$$Transpiration\ ratio = \frac{Weight\ of\ water\ transpired}{Weight\ of\ dry\ matter\ produced}$$

WATER LOSSES

Evapotranspiration

Evapotranspiration (*Et*) or consumptive use (*U*) is the total water lost from a cropped (or irrigated) land due to evaporation from the soil and transpiration by the plants or used by the plants in building up of plant tissue.

Potential evapotranspiration

Potential evapotranspiration (*Ept*) is the evapotranspiration from the short green vegetation when the roots are supplied with unlimited water covering the soil. It is usually expressed as a depth (cm, mm) over the area.

WATER LOSSES

Estimation of Evapotranspiration

(*i*) Tanks and lysimeter experiments

(*ii*) Field experimental plots

(*iii*) Installation of sunken (colarado) tanks

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

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

WATER LOSSES

(*i*) *Blaney-Criddle method.* This method is used throughout the world for the consumptive use determinations and is given by :

$$U = \Sigma \frac{ktp}{100} \quad \text{in FPS units} \qquad ...(3.10)$$

and

$$U = \Sigma \frac{kp\,(4.6t + 81.3)}{100} \quad \text{in metric units} \qquad ...(3.10\ a)$$

$$U = \Sigma\, kf = K\, \Sigma f = KF \qquad ...(3.10\ b)$$

$$f = \frac{tp}{100} \quad \text{in FPS units} \qquad ...(3.10\ c)$$

$$f = \frac{p(4.6t + 81.3)}{100} \quad \text{in metric units} \qquad ...(3.10\ d)$$

where U = seasonal consumptive use (inches in FPS units and cm in metric units)

t = mean monthly temperature (°F in FPS units and °C in metric units)

p = monthly percentage of hours of bright sunshine (of the year)

k = monthly consumptive use coefficient determined from experimental data

f = monthly consumptive use factor

K, F = seasonal values of consumptive use coefficient and factor, respectively

Σ refers for the summation for all the months of the growing season.

WATER LOSSES

Example 3.2 *Determine the evapotranspiration and irrigation requirement for wheat, if the water application efficiency is 65% and the consumptive use coefficient for the growing season is 0.8 from the following data :*

WATER LOSSES

Solution

Month	*Mean monthly temp. (°C)* t	*Monthly % of sunshine (hours)* p	*Effective rainfall (cm)* P_e	*Monthly con-sumptive use factor* $f = \frac{p(4.6t + 81.3)}{100}$
Nov.	18	7.20	2.6	11.82
Dec.	15	7.15	2.8	10.74
Jan.	13.5	7.30	3.5	10.48
Feb.	14.5	7.10	2.0	10.50
			$\Sigma P_e = 10.9$	$\Sigma f = 43.54$

Seasonal consumptive use, $U = K \Sigma f$

$$= 0.8 \times 43.54$$

$$= \mathbf{34.83\ cm}$$

Field irrigation requirement,

$$\text{F.I.R.} = \frac{U - \Sigma P_e}{\eta_i} \quad ...(3.11)$$

where η_i = water application efficiency

F.I.R. = Field irrigation requirement

$$\therefore \quad \text{F.I.R.} = \frac{34.83 - 10.90}{0.65} = \mathbf{36.9\ cm}$$

WATER LOSSES

Infiltration

Water entering the soil at the ground surface is called infiltration.

Infiltration Capacity

The maximum rate at which the soil in any given condition is capable of absorbing water is called its infiltration capacity

WATER LOSSES

<u>Horton's equation</u>

<u>Methods of Determining Infiltration</u>

(*i*) Infiltrometers

(*ii*) Observation in pits and ponds

(*iii*) Placing a catch basin below a laboratory sample

(*iv*) Artificial rain simulators

(*v*) Hydrograph analysis

WATER LOSSES

Double-ring infiltrometer

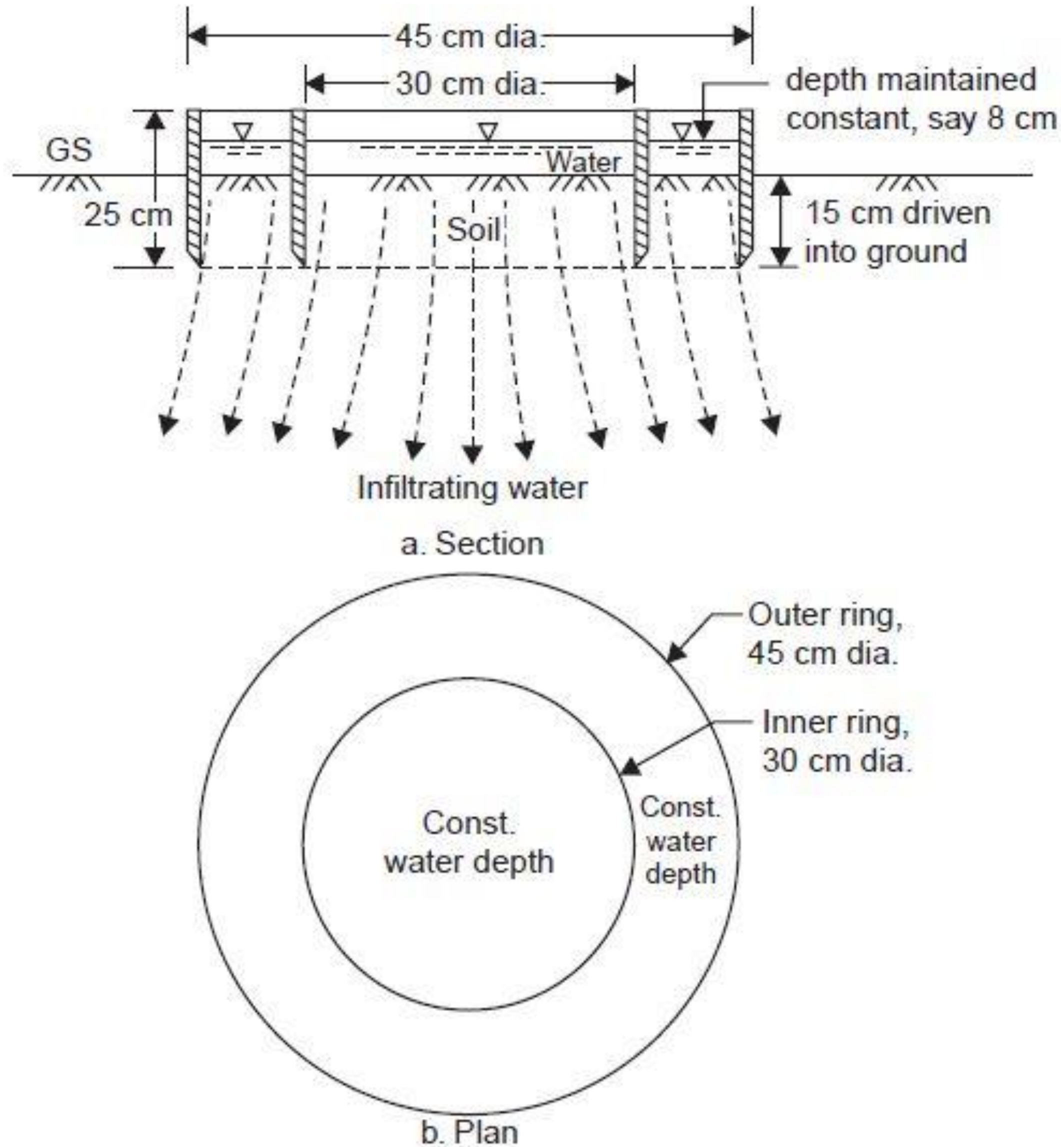


Fig. 3.7 Double ring infiltrometer

WATER LOSSES

INFILTRATION INDICES

(*i*) ϕ-*index*—The ϕ-index is defined as that rate of rainfall above which the rainfall volume equals the runoff volume.

$$\phi\text{-index} = \frac{\text{basin recharge}}{\text{duration of rainfall}}$$

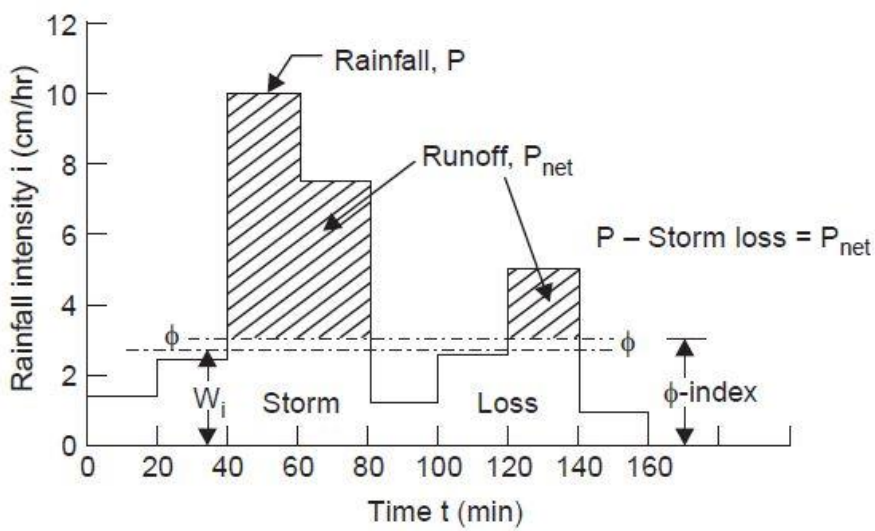


Fig. 3.12 Infiltration loss by ϕ-index

WATER LOSSES

INFILTRATION INDICES

(*ii*) *W-index*—The *W*-index is the average infiltration rate during the time rainfall intensity exceeds the infiltration capacity rate, *i.e.*,

$$W\text{-index} = \frac{F_p}{t_R} = \frac{P - Q - S}{t_R} \qquad \ldots(3.15)$$

where P = total rainfall

Q = surface runoff

S = effective surface retention

t_R = duration of storm during which $i > f_p$

F_p = total infiltration

(iii) f_{ave}-index

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

WATER LOSSES

Example 3.6 *The rates of rainfall for the sucessive 30 min period of a 3-hour storm are: 1.6, 3.6, 5.0, 2.8, 2.2, 1.0 cm/hr. The corresponding surface runoff is estimated to be 3.6 cm. Establish the* ϕ*-index. Also determine the W-index.*

Solution Construct the hyetograph as shown in Fig. 3.13 (*a*)

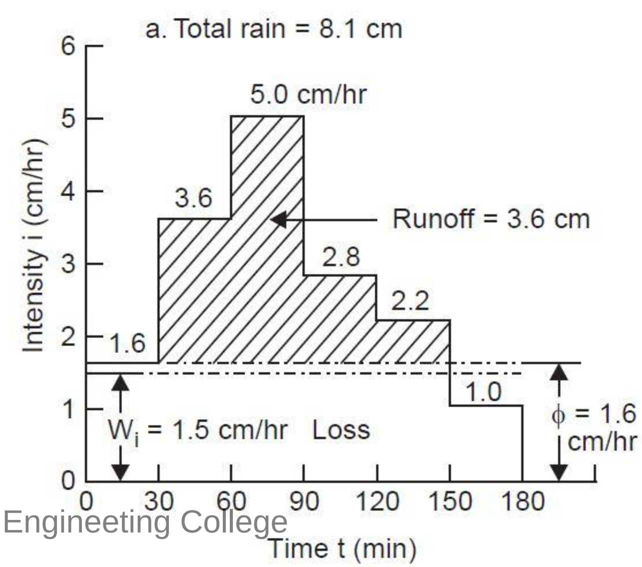
$$\Sigma(i - \phi)t = P_{\text{net}}, \quad \text{and thus it follows}$$

$$\left[(3.6 - \phi) + (5.0 - \phi) + (2.8 - \phi) + (2.2 - \phi)\right] \frac{30}{60} = 3.6$$

$$\therefore \qquad \phi = \mathbf{1.6\ cm/hr}$$

$$P = (1.6 + 3.6 + 5.0 + 2.8 + 2.2 + 1.0)\,\frac{30}{60} = \mathbf{8.1\ cm}$$

$$W\text{-}index = \frac{P - Q}{t_R} = \frac{8.1 - 3.6}{3} = \mathbf{1.5\ cm/hr}$$



WATER LOSSES

Supra rain technique

The rainfall in excess of a particular value of ϕ-index for the entire pattern of storm rainfall is called *supra rain.*

Watershed Leakage

The rain water after infiltrating into the ground may percolate through the subsoil and build up the ground water table (GWT). This ground water through the water bearing strata may flow into the adjacent basin or directly into the sea if the water bearing strata outcrops into the sea. This is called *watershed leakage*.

WATER LOSSES

3.13 WATER BALANCE

The input items into a basin are essentially precipitation (P) and subsurface inflow (G_i) while the water losses are evaporation (E), evapotranspiration (E_t) and subsurface outflow (G_0). The balance goes to recharge ground water (G_r), increase the soil moisture (SMA) and as surface runoff (streamflow, R).

The water balance equation can be written as

$$P + G_i = E + E_t + G_0 + \text{SMA} + G_r + R$$

FLOOD ESTIMATION &ROUTING

Flood routing

Flood routing is the process of determining the reservoir stage, storage volume of the outflow hydrograph corresponding to a known hydrograph of inflow into the reservoir.

Design flood

The maximum flood that any structure can safely pass is called the ‘design flood’ and is selected after consideration of economic and hydrologic factors.

FLOOD ESTIMATION &ROUTING

Standard Project Flood (SPF)

This is the estimate of the flood likely to occur from the most severe combination of the meteorological and hydrological conditions, which are reasonably characteristic of the drainage basin being considered, but excluding extremely rare combination.

Maximum Probable Flood (MPF)

This differs from the SPF in that it includes the extremely rare and catastrophic floods and is usually confined to spillway design of very high dams. The SPF is usually around 80% of the MPF for the basin.

FLOOD ESTIMATION &ROUTING

ESTIMATION OF PEAK FLOOD

(*i*) Physical indications of past floods—flood marks and local enquiry

(*ii*) Empirical formulae and curves

(*iii*) Concentration time method

(*iv*) Overland flow hydrograph

(*v*) Rational method

(*vi*) Unit hydrograph

(*vii*) Flood frequency studies

FLOOD ESTIMATION &ROUTING

ESTIMATION OF PEAK FLOOD (Empirical formula)

(ii) Empirical Flood Formulae

1. Dickens formula for moderate size basins of north and central India

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

the coefficient C = 11–14, where the *aar* is 60–120 cm

= 14–19 in Madhya Pradesh

= 32 in western Ghats

up to 35, maximum value

2. Ryves formula derived from a study of rivers in south India

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

FLOOD ESTIMATION &ROUTING

ESTIMATION OF PEAK FLOOD

Coefficient C = 6.8 within 80 km of coast

= 8.3 for areas between 80 and 2400 km from the coast

= 10.0 for limited area near the hills

up to 40, actual observed values

3. Inglis formula for fan-shaped catchments of Bombay state (Maharashtra)

$$Q = \frac{124A}{\sqrt{A + 10.4}}$$

4. Myers formula $\quad Q = 175\sqrt{A}$

5. Ali Nawab Jang Bahadur formula for the old Hyderabad state

$$Q = CA^{(0.993 - 1/14 \log A)}$$

the coefficient C varies from 48 to 60

FLOOD ESTIMATION &ROUTING

ESTIMATION OF PEAK FLOOD

6. Fuller's formula (1914)

$$Q = CA^{0.8} (1 + 0.8 \log T_T)(1 + 2.67 A^{-0.3}) \quad ...(8.6)$$

constants derived from the basins in USA 10 years data is required for sufficient reliability. The coefficient C varies from 0.026 to 2.77; T = recurrence interval in years. Fuller was the first to suggest that frequency should be considered as a factor in estimating floods.

7. Greager's formula for USA

$$Q = C(0.386\, A)^{0.894(0.386\, A)^{-0.048}} \quad ...(8.7)$$

the coefficient $C \approx 130$ (140.5 for areas most favourable to large floods)

8. Burkli Ziegler formula for USA

$$Q = 412\, A^{3/4} \quad ...(8.8)$$

FLOOD ESTIMATION &ROUTING

Return period

The return period or recurrence interval (*T*) is the average number of years during which a flood of given magnitude will be equalled or exceeded once.

Return period

The return period or recurrence interval (*T*) is the average number of years during which a flood of given magnitude will be equalled or exceeded once.

METHODS OF FLOOD CONTROL

(*i*) by confining the flow between high banks by constructing levees (flood banks) , dykes, or flood walls.

(*ii*) by channel improvement by cutting, straightening or deepening and following river training works.

(*iii*) by diversion of a portion of the flood through bypasses or flood ways. In some cases a fuse plug levee is provided. It is a low section of levee, which when once over topped, will

FLOOD ESTIMATION &ROUTING

METHODS OF FLOOD CONTROL

(*iv*) by providing a temporary storage of the peak floods by constructing upstream reservoirs and retarding basins (detention basins).

(*v*) by adopting soil conservation measures (land management) in the catchment area.

(*vi*) by temporary and permanent evacuation of the flood plain, and flood plain zoning by enacting legislation.

(*vii*) by flood proofing of specific properties by constructing a ring levee or flood wall around the property.

(*viii*) by setting up flood forecasting—short term, long term, rhythm signals and radar, and warning centres at vulnerable areas.

FLOOD ESTIMATION &ROUTING

METHODS OF FLOOD CONTROL

- Flood Control by Reservoirs
- Retarding Basins
- Construction of Levees
- Channel Improvement

FLOOD ESTIMATION &ROUTING

Example 8.6 (b) *Determine the percentage chance that a 25-yr storm may occur*

(a) In the next 10 years *(b) In the next year itself*

(c) May not occur in another 15 years

Solution (*a*) $T = 25, \quad P_{Ex} = 1 - (1-P)^N, \quad P = \dfrac{1}{T}$

$$= 1 - \left(1 - \frac{1}{25}\right)^{10} = 0.335 \text{ or } \mathbf{33.5\%}$$

(*b*) $P_{Ex} = 1 - \left(1 - \dfrac{1}{25}\right)^{1} = 0.04$ or **4%, i.e., 1 in 25 chance**

(*c*) $P_{(N,\,0)} = (1-P)^N = \left(1 - \dfrac{1}{25}\right)^{15} = 0.542$ or **54.2%**

Example 8.6 (c) *Determine the return period (recurrence interval T) of a flood, which has a 10% risk of being flooded (a) in the next 100 years, (b) in the next 50 years.*

Solution $P_{Ex} = 1 - (1 - P)^N$, for risk of being exceeded

i.e., $P_{Ex} = 10\% = 0.1$

(*a*) $0.1 = 1 - (1 - P)^{100}$, $(1 - P)^{100} = 1 - 0.1 = 0.9$

$$1 - P = 0.9^{0.01} = 0.99895, \quad P = 0.00105 = 1.05 \times 10^{-3}$$

$$T = \frac{1}{P} = \frac{1}{1.05 \times 10^{-3}} = \mathbf{950\ yr}, \text{ say 1000-yr flood}$$

(*b*) $0.1 = 1 - (1 - P)^{50}$, $(1 - P)^{50} = 1 - 0.1 = 0.9$

$$1 - P = 0.9^{0.02} = 0.9979$$

$$P = 0.0021 = 2.1 \times 10^{-3}$$

$$T = \frac{1}{P} = \frac{1}{2.1 \times 10^{-3}} = \mathbf{476\ Yr}, \text{ say 500-yr flood.}$$

Groundwater

Aquifer

A water bearing geologic formation or stratum capable of transmitting water through its pores at a rate sufficient for economic extraction by wells is called 'aquifer'.

Aquiclude

A geologic formation, which can absorb water but can not transmit significant amounts is called an 'aquiclude'. Examples are clays, shales, etc.

Groundwater

Aquifuge

A geologic formation with no interconnected pores and hence can neither absorb nor transmit water is called an ‘aquifuge’. Examples are basalts, granites, etc.

Aquitard

A geologic formation of rather impervious nature, which transmits water at a slow rate compared to an aquifer (insufficient for pumping from wells) is called an ‘aquitard’. Examples are clay lenses interbedded with sand.

Groundwater

Specific yield

The volume of water expressed as a percentage of the total volume of the saturated aquifer, that will drain by gravity when the water table (Ground Water Table (GWT) drops due to pumping or drainage, is called the ‘specific yield (*Sy*)’ and that percentage volume of water, which will not drain by gravity is called ‘specific retention (*Sr*)’.

porosity = specific yield + specific retention

$$n = S_y + S_r$$

Groundwater

Unconfined Aquifer

If there is homogeneous porous formation extending from the ground surface up to an impervious bed underneath (Fig. 7.1), rainwater percolating down in the soil saturates the formation and builds up the ground water table (GWT). This aquifer under water table conditions is called an *unconfined aquifer* (water-table aquifer) and well drilled into this aquifer is called a *water table well*.

Artesian/confined Aquifer

On the other hand, if a porous formation underneath is sandwiched between two impervious strata (aquicludes) and is recharged by a natural source (by rain water when the formation outcrops at the ground surface—recharge area, or outcrops into a river-bed or bank) at a higher elevation so that the water is under pressure in the aquifer (like pipe flow), *i.e.,* artesian condition. Such an aquifer is called an artesian aquifer or confined aquifer

Groundwater

Perched water table

Sometimes a small band of impervious strata lying above the main ground water table (GWT) holds part of the water percolating from above. Such small water bodies of local nature can be exhausted quickly and are deceptive. The water level in them is called ‘perched water table’.

Groundwater

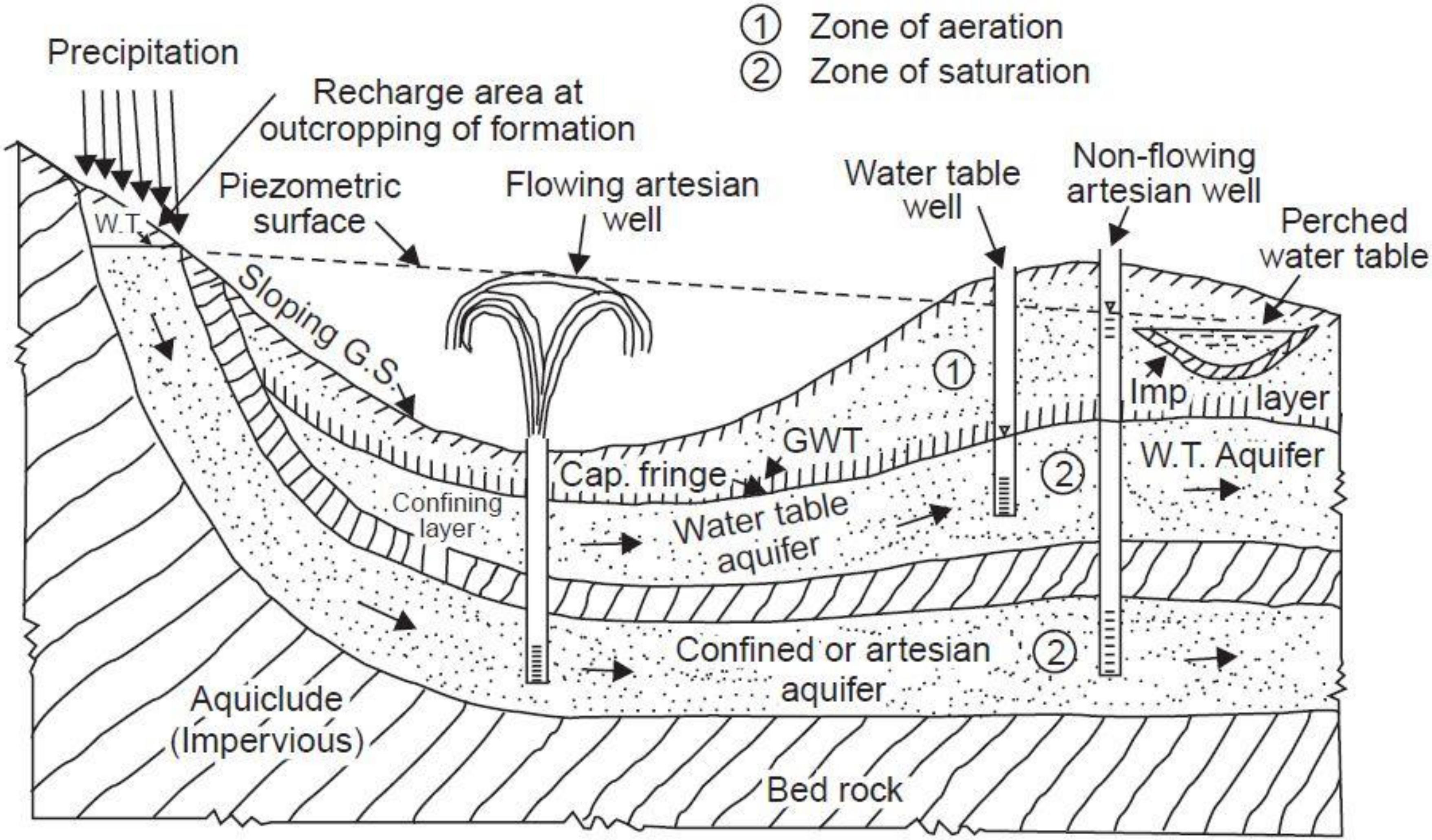


Fig. 7.1 Types of aquifers and location of wells

Storage coefficient

The volume of water given out by a unit prism of aquifer (*i.e.,* a column of aquifer standing on a unit horizontal area) when the piezometric surface (confined aquifers) or the water table (unconfined aquifers) drops by unit depth is called the *storage coefficient* of the aquifer (*S*) and is dimensionless (fraction).

Groundwater

Example 7.2 An artesian aquifer, 30 m thick has a porosity of 25% and bulk modulus of compression 2000 kg/cm^2. Estimate the storage coefficient of the aquifer. What fraction of this is attributable to the expansibility of water?

Bulk modulus of elasticity of water = 2.4 × 104 kg/cm^2.

Solution $S = \gamma_w nb \left(\frac{1}{K_w} + \frac{1}{nK_s}\right) = 1000 \times 0.25 \times 30 \left(\frac{1}{2.14 \times 10^8} + \frac{1}{0.25 \times 2 \times 10^7}\right)$

$= 7500\,(0.467 \times 10^{-8} + 20 \times 10^{-8}) = \mathbf{1.54 \times 10^{-3}}$

Storage coefficient due to the expansibility of water as a percentage of S above

$= \frac{7500 \times 0.467 \times 10^{-8}}{7500 \times 20.467 \times 10^{-8}} \times 100 = \mathbf{2.28\%}$, which is negligibe

Note In less compressible formations like limestones for which $E_s \approx 2 \times 10^5$ kg/cm^2, $S = 5 \times 10^{-5}$ and the fractions of this attributable to water and aquifer skeleton are 70% and 30%, respectively.

Groundwater

7.3 DARCY'S LAW

Flow of ground water except through coarse gravels and rockfills is laminar and the velocity of flow is given by Darcy's law (1856), which states that 'the velocity of flow in a porous medium is proportional to the hydraulic gradient', Fig. 7.2, *i.e.*,

$$V = Ki, \quad \text{...(7.4)}$$

$$i = \frac{\Delta h}{L} \quad \text{...(7.4 } a\text{)}$$

$$Q = AV = AKi, \quad A = Wb, \quad T = Kb \quad \text{...(7.4 } b\text{)}$$

$$\therefore \quad Q = WbKi \quad \text{...(7.4 } c\text{)}$$

$$\therefore \quad Q = T\,iw \quad \text{...(7.5)}$$

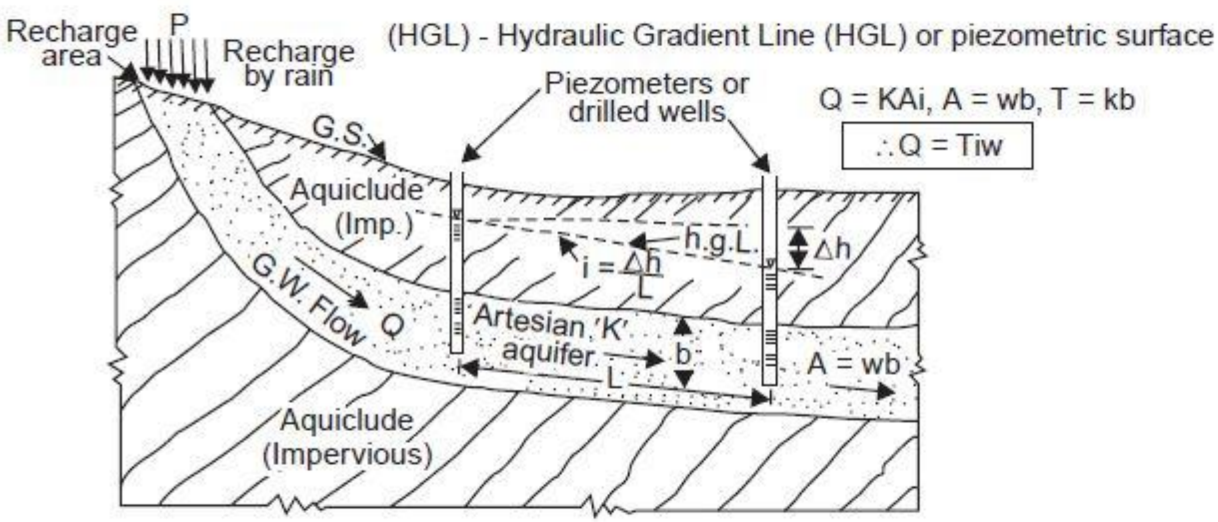


Fig. 7.2 Flow of ground water

TRANSMISSIBILITY

Transmissibility is the flow capacity of an aquifer per unit width under unit hydraulic gradient and is equal to the product of permeability times the saturated thickness of the aquifer. In a confined aquifer, $T = Kb$ and is independent of the piezometric surface. In a water table aquifer, $T = KH$, where H is the saturated thickness.

Groundwater

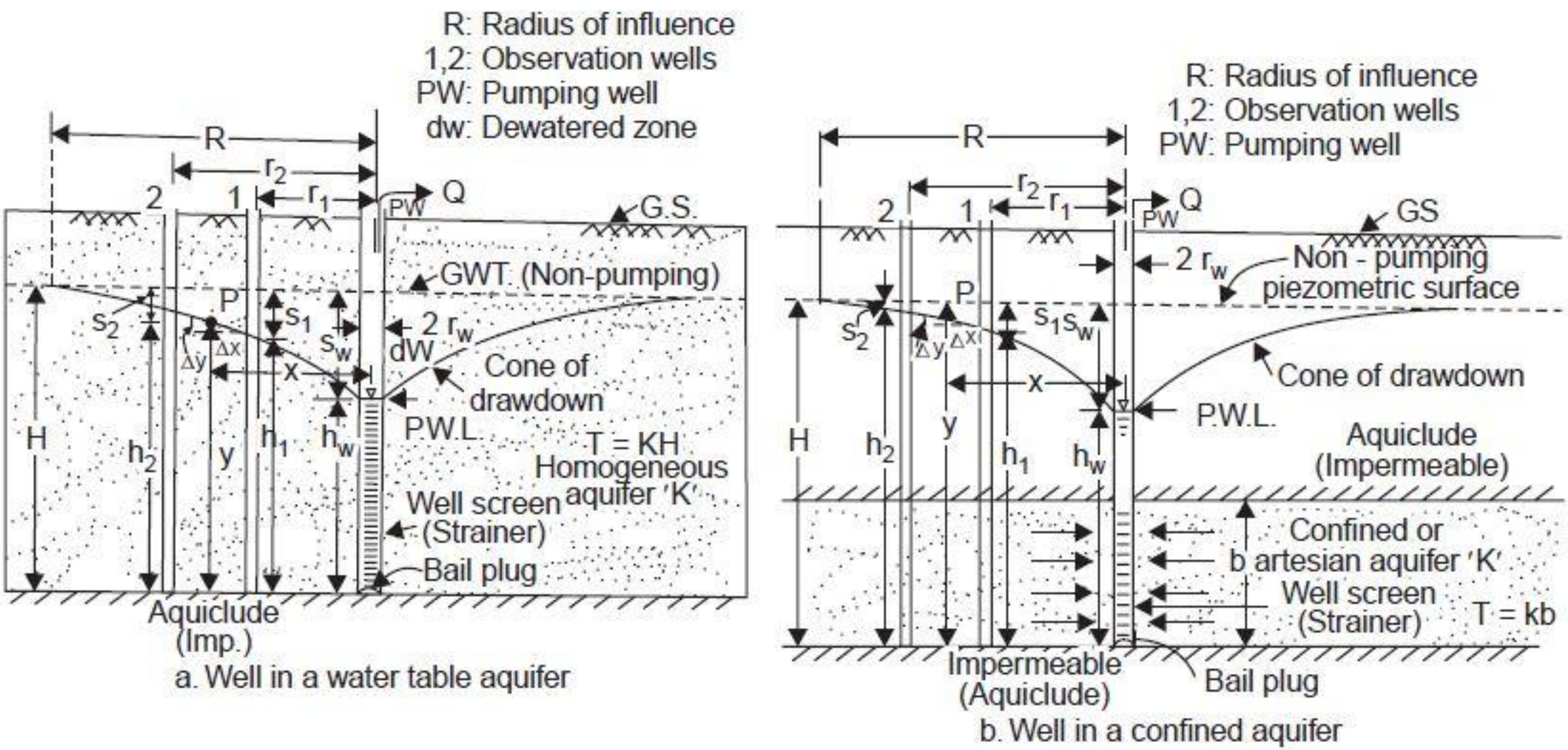


Fig. 7.3 Steady radial flow into a well

Groundwater

7.5 WELL HYDRAULICS

Steady radial flow into a well (Dupuit 1863, Thiem 1906)

(a) Water table conditions (unconfined aquifer)

Assuming that the well is pumped at a constant rate Q for a long time and the water levels in the observation wells have stabilised, *i.e.*, equilibrium conditions have been reached, Fig. 7.3 (a).

From Darcy's law, $Q = K\, i\, A$

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

$$Q \int_{r_1}^{r_2} \frac{dx}{x} = 2\,\pi\, K \int_{h_1}^{h_2} y\, dy$$

$$\therefore \qquad Q = \frac{\pi\, K(h_2^2 - h_1^2)}{2.303 \log_{10}\left(\dfrac{r_2}{r_1}\right)} \qquad \text{...(7.7)}$$

$\left(r_w\right)$

(b) Artesian conditions (confined aquifer)

If the well is pumped at constant pumping rate Q for a long time and the equilibrium conditions have reached, Fig. 7.3 (b).

From Darcy's law, $Q = K\,i\,A$

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

$$Q \int_{r_1}^{r_2} \frac{dx}{x} = 2\pi\, Kb \int_{h_1}^{h_2} dy$$

$$\therefore \quad Q = \frac{2\pi\,(kb)\,(h_2 - h_1)}{2.303 \log_{10}\left(\dfrac{r_2}{r_1}\right)} \qquad \text{...(7.9)}$$

Applying Eq. (7.9) between the face of the well ($r = r_w$, $h = h_w$) and the point of zero-drawdown ($r = R$, $h = H$), simplifying and putting $T = Kb$,

$$Q = \frac{2.72\,T\,(H - h_w)}{\log_{10}\left(\dfrac{R}{r_w}\right)} \qquad \text{...(7.10)}$$

Groundwater

Dupuit's Equations Assumptions

(*i*) Stabilised drawdown—*i.e.,* the pumping has been continued for a sufficiently long time at a constant rate, so that the equilibrium stage of steady flow conditions have been reached.

(*ii*) The aquifer is homogeneous, isotropic, of infinite areal extent and of constant thickness, *i.e.,* constant permeability.

(*iii*) Complete penetration of the well (with complete screening of the aquifer thickness) with 100% well efficiency.

(*iv*) Flow lines are radial and horizontal and the flow is laminar, *i.e.,* Darcy's law is applicable.

(*v*) The well is infinitely small with negligible storage and all the pumped water comes from the aquifer.

SPECIFIC CAPACITY

The specific capacity *Q/Sw* of a well is the discharge per unit drawdown in the well and is usually expressed as lpm/m.

Example 7.3

A 20-cm well penetrates 30 m below static water level (GWT). After a long period of pumping at a rate of 1800 lpm, the drawdowns in the observation wells at 12 m and 36 m from the pumped well are 1.2 m and 0.5 m, respectively. Determine: (*i*) *the transmissibility of the aquifer.* (*ii*) *the drawdown in the pumped well*

Groundwater

Solution Dupuit's Eq. (7.7): $Q = \dfrac{\pi K(h_2^2 - h_1^2)}{2.303 \log_{10} r_2/r_1}$

$$h_2 = H - s_2 = 30 - 0.5 = 29.5 \text{ m};\ h_1 = H - s_1 = 30 - 1.2 = 28.8 \text{ m}$$

$$\frac{1.800}{60} = \frac{\pi K(29.5^2 - 28.8^2)}{2.303 \log_{10} 36/12}$$

$\therefore$ $K = 2.62 \times 10^{-4}$ m/sec or **22.7 m/day**

(*i*) Transmissibility $T = KH = (2.62 \times 10^{-4})\ 30 = 78.6 \times 10^{-4}$ m^2/sec,

or $= 22.7 \times 30 =$ **681 m^2/day**

(*ii*) Eq. (7.8): $Q = \dfrac{2.72\, T\, (H - h_w)}{\log_{10} R/r_w}$

$$\frac{1.800}{60} \equiv \frac{2.72(78.6 \times 10^{-4})\, S_w}{\log_{10} 300/0.10}$$

$\therefore$ drawdown in the well, S_w = **4.88 m**

(*iii*) The specific capacity of the well

$$= \frac{Q}{S_w} = \frac{1.800}{60 \times 4.88} = 0.0062\ (\text{m}^3\,\text{sec}^{-1}/\text{m})$$

or **372 Ipm/m**

$$\frac{Q}{S_w} \approx \frac{T}{1.2} = \frac{78.6 \times 10^{-4}}{1.2} = 0.00655\ (\text{m}^2\,\text{sec}^{-1}/\text{m})$$

or **393 lpm/m**