Q. 22. Describe the adequacy of rain gauge stations.

Ans. If there are already some rain gauge stations in a catchments, the optimal number of stations that should exist to have an assigned percentage of error in the estimation of mean rainfall is obtained by statistical analysis as

$$N = \left(\frac{C_V}{\varepsilon}\right)^2$$

where, N = Optimal number of stations, ε = Allowable degree of error in the estimate of the mean rainfall and C_V = Coefficient of variation of the rainfall values at the existing m stations.

$$C_V = \frac{100 \times \sigma_m - 1}{\overline{p}}$$

where,

$$\sigma_{m-1} = \sqrt{\left[\frac{\sum_{1}^{m}(p_i - \overline{p})^2}{m-1}\right]} = \text{Standard deviation}$$

$$\overline{P} = \frac{1}{m}\left(\sum_{1}^{m} p_i\right) = \text{Mean precipitation.}$$

Q. 23. Analysis of data on maximum one-day rainfall depth at Madras indicated that a depth of 280 mm had a return period of 50 years. Determine the probability of a one-day rainfall depth equal to or greater than 280 mm at Madras occurring (a) Once in 20 successive years (b) Two times in is successive years and (c) At least once in 20 successive years.

Sol. Here $P = \frac{1}{50} = 0 \cdot 002$

(a) $n = 20, r = 1$

$$P_{1,20} = \frac{20!}{19!1!} \times 0 \cdot 002 \times (0 \cdot 98)^{19}$$

$$= 20 \times 0 \cdot 02 \times 0 \cdot 68123 = 0 \cdot 272$$

(b) $n = 15, r = 2$

$$P_{2,15} = \frac{15!}{13!\,2!} \times (0 \cdot 02)^2 \times (0 \cdot 98)^{13}$$

$$= 0 \cdot 323$$

(c)

$$P_1 = 1 - (1 - 0 \cdot 02)^{20}$$

$$= 0 \cdot 332.$$

Ans.

●●

Unit III

INFILTRATION AND RUNOFF

Syllabus : Introduction, Factors affecting in filtration, Measurement of infiltration, infiltrometers, infiltration equations, infiltration indices, Effect of infiltration on runoff and recharge of ground water, Runoff, Components of runoff, Estimation of runoff, Calculation by infiltration method, Rainfall-runoff relationship, Rational method of estimating runoff, Basin yield.

Introduction : As described in the hydrologic cycle, infiltration is one of the ways through which the precipitation reaching the earth's surface is disposed of. The other ways include evaporation and evapotranspiration, overland flow, and surface runoff. It is the only source for groundwater replenishment and thus forms an important arc of the hydrologic cycle.

Infiltration may be defined as the process by which water enters the surface strata of the earth.

A soil under given conditions has an upper limit on its absorbing capacity. The infiltration capacity of a soil under given condition is defined as the maximum rate at which it is capable of absorbing water and is denoted by f.

$$f_a = f, \text{ if } i \geq f \text{ and}$$
$$f_a = i, \text{ if } i < f.$$

Q. 1. Define Infiltration ?

(C.S.V.T.U. Nov.-Dec., 2007, Nov.-Dec., 2009, April-May, 2010)

Ans. Infiltration may be defined as the process by which water enters the surface strata of the earth. The infiltrated water first meets the soil moisture deficiency, and there after the excess water moves vertically downwards to reach the ground water table. This vertical movement is called percolation.

Q. 2. What are the factors affecting infiltration ?

Ans. The variations in the infiltration capacity are large. The filtration capacity is influenced by many factors. Some factors contribute to special variation while the others to temporal variation.

Depth of surface detention and thickness of saturated layer : Infiltration takes place due to combined influences of gravity and capillary forces. The infiltration of water through a soil surface may be visualised as a flow through a large number of tiny pipes. As the infiltration continues the wet front will be travelling downwards. At any instant of time the resistance to flow is proportional to time thickness of the saturated layer up to wet front L, while the driving head is proportional to $(L + d)$ d being the depth of detention.

Soil Moisture : If a soil is completely dry at the beginning of rain there is a capillary attraction for moisture in the subsurface layers that acts in the same direction as gravity and gives high initial value of infiltration.

Compaction : The clay surfaced soils are compacted even by the impact of rain drops which reduce f. This effect is negligible on sandy soils. Compaction not only reduces the porosity but also the pore sizes. When the compaction is aritificial due to man-made effects the initial infiltration capacity is very low and it is further reduced during the storm. Overgrazed pastures, playgrounds and areas subjected to heavy vehicular traffic will have less infiltration capacities.

Surface cover conditions : The nature of surface cover has also an important influence on the infiltration. The presence of surface cover has also an important influence on the infiltration. The presence of a dense cover of vegetation on the surface increases f. The vegetative cover retards the movement of overland flow and causes high depths of detention. It reduces the effect of rain drop compaction.

Temperature : The effect of temperature on infiltration is explained through viscosity. The flow through soil pores is by and large laminar for which the resistance is directly proportional to viscosity. At high temperatures since viscosity of water is low, high infiltration capacities are expected.

Q. 3. A storm with 10 cm of precipitation produced a direct runoff 5·8 cm. The duration of rainfall was 16 hours and its time distribution is given below. Estimate the ϕ-index of the storm.

Time From Start (h)	0	2	4	6	8	10	12	14	16
Cumulative rainfall (cm)	0	0·4	1·3	2·8	5·1	6·9	8·5	9·5	10

(C.S.V.T.U. Nov.-Dec., 2007)

Sol : Pulses of uniform time duration $\Delta t = 2h$ are considered.

Pulse number (h)	1	2	3	4	5	6	7	8
Cumulative rainfall	0·4	1·3	2·8	5·1	6·9	8·5	9·5	10
Incremental rain (cm)	0·40	0·90	1·50	2·30	1·80	1·60	1	0·50
Intensity of rain (I_i) in cm/h	0·20	0·45	0·75	1·15	0·90	0·80	0·50	0·25

Hence duration of rainfall $D = 16$, $\Delta t = 2h$, $N = 8$

Assume $M = 8$, $\Delta t = 2h$

Hence $t_e = M \cdot \Delta t = 16$ hours

Since $M = N$, all the pules are included.

$$\text{Runoff } R_d = 5 \cdot 8 \text{ cm} = \sum_1^8 (I_i - \phi)\Delta t = \sum_1^8 I_i \times \Delta t - \phi(8 \times 2)$$

$$5 \cdot 8 = \{(0 \cdot 20 \times 2) + (0 \cdot 45 \times 2) + (0 \cdot 75 \times 2) + (1 \cdot 15 \times 2) + (0 \cdot 90 \times 2) + (0 \cdot 80 \times 2) + (0 \cdot 50 \times 2) + (0 \cdot 25 \times 2)\} - 16\,\phi = 10 - 14\,\phi$$

$$\phi = \frac{4 \cdot 2}{14} = 0 \cdot 263 \text{ cm/h}$$

Q. 4. Describe the different components of runoff ?

(C.S.V.T.U. Nov.-Dec., 2007, Nov.-Dec., 2009, April-May, 2010)

Ans. According to the source from which the flow is derived, the total runoff is visualised to consist of surface runoff, subsurface runoff and groundwater runoff. Before reaching the ground a small portion of precipitation evaporates and joins back the atmosphere while another small portion is intercepted which also eventually becomes atmospheric moisture through evaporation. This portion is usually small and insignificant in the runoff analysis. The remaining precipitation reaching the ground is called the through-fall.

It may fall either on land surface or directly on to the water surfaces of streams, lakes and reservoirs. The precipitation falling on water surfaces is called channel precipitation and it immediately becomes the stream-flow. A very small fraction of the precipitation. Falling on the land surface may be absorbed in the storage like small ponds, swamps etc., before it becomes evaporation and infiltration. This is called the depression storage. The rest of the precipitation falling on land surface, after satisfying the infiltration demand, is temporarily detained on the ground surface and when sufficient depth is built-up it travels over the ground surface towards the stream channels either as quasi-laminar sheet flow. This is called the overland flow. The overland flow ceases shortly after the rainfall stops.

Water which infiltrates the soil surface and then moves laterally through the upper soil horizons towards the stream channels above the main groundwater table is known as the inter flow. It is also known as subsurface runoff, subsurface storm flow, storm seepage and secondary base flow.

The infiltrated water which percolates deeply becomes groundwater and when groundwater table rises and intersects the stream channels of the basin it discharges into streams as the groundwater runoff.

For the practical purpose of analysis total runoff in stream channels is generally classified as direct runoff and base flow. The direct runoff is that part of runoff which enters the stream promptly and is equal to the sum of surface runoff and rapid inter flow.

The precipitation excess is that part of total precipitation which contributes directly to the surface runoff. When the precipitation is in the form of rainfall only it is known as rainfall excess.

Q. 5. Explain the different empirical equations for runoff calculation.

(C.S.V.T.U. Nov.-Dec., 2007)

Ans. With a keen sense of observation in the region of their activity many engineers of the past have developed empirical runoff estimation formulae. Some of the important formulae used in various parts of India are given below.

Binnie's Percentages : Sir Alexander Binnie measured the runoff from a small catchment near Nagpur during 1869 and 1872 and developed curves of cumulative runoff against cumulative rainfall. The two curves were found to be similar. From these he established the percentages of runoff from rainfall. These percentages have been used in Madhya Pradesh and Vidrabha region of Maharashtra for the estimation of yield.

Barlow's tables : Barlow, the first chief Engineer of the Hydro-Electric Survey of India (1915) on the basis of his study in small catchments (area ~ 130 km^2) in Uttar Pradesh expressed runoff R as

$$R = K_b\, P$$

where K_b = runoff coefficient with depend upon the type of catchment and nature of monsoon rainfall.

Strange's table : The available rainfall and runoff in the border areas of present-day Maharashtra and Karnataka and has obtained yield ratios as functions of indicators representing catchment characteristics. Catchments are classified as good, average and bad according to the relative magnitudes of yield they give. For example, catchments with good forest and having soils of high permeability would be classified as bad, while catchments having soils of low permeability and having little or no vegetal cover is termed good.

Q. 6. Discuss the infiltration Indices ? **(C.S.V.T.U. April-May 2008; Nov.-Dec., 2008)**

Ans. The infiltration capacity curves which are developed either from infiltrometer tests or the hydrograph analyses methods can be used to estimate the runoff from a given storm. The infiltration rate curve existing at the time of occurrence of storm is superimposed on the rainfall hyetograph with base lines coincident. The area of the rainfall hyetograph above the infiltration curve would then represent the runoff volume whose time distribution may be obtained through the application of unit hydrograph principle. The rainfall volume below the infiltration curve represents the total depth of infiltration during the storm lies in selecting the appropriate infiltration curve representive of the conditions existing at the start of the storm.

Though this approach appears to be simple there are some difficulties. If the rainfall intensity is always more than the infiltration capacity the results are satisfactory. If the rainfall intensity fluctuates above and below the infiltration capacity rate curve the problem is complicated. The intensity of rainfall is rarely uniform both in time and space. If the rainfall is less than infiltration capacity the contribution to soil moisture is less than assumed and drop in infiltration curve is correspondingly less.

Q. 7. Discuss the rational method of estimating runoff ?
(C.S.V.T.U. April-May, 2008; Nov.-Dec., 2008)

Ans. Consider a rainfall of uniform intensity and very long duration occurring over a basin. The runoff rate gradually increases from zero to a constant value as indicated. The runoff increases as more and more flow from remote areas of the catchment reach the outlet. Designing the time taken for a drop of water from the farthest part of the catchment to reach the outlet as t_c = time of concentration, it is obvious that if the rainfall continues beyond t_c, the runoff will be constant and at the peak value. The peak value of the runoff is given by

$$Q_P = CA_i \text{ for } t \geq t_c$$

where C = coefficient of runoff,
A = Area of the catchment and i = intensity of rainfall. This is the basic equation of the rational method.

$$Q_P = \frac{1}{3 \cdot 6} = C(i_{tc,p})A$$

Q_P = peak discharge (m^3/s)
C = coefficient of runoff
A = drainage area in km^2

The use of this method to compute Q_P requires three parameters : t_c, $(i_{tc,\ p})$ and C.

Q. 8. A 6 *h* storm produced rainfall intensities of 7, 18, 25, 12, 10 and 3 mm/h in successive one hour intervals over a basin of 800 sq. km. The resulting runoff is observed to be 2640 hectare-metres. Determine ϕ-index for the basin. **(C.S.V.T.U. Nov.-Dec., 2008)**

Solution : Total Vol. of Runoff

$$= 2640 \text{ hectare-metres}$$
$$= 2640 \times 10000$$
$$= 264 \times 10^5 \text{ m}^3$$

Area of the basin $= 800 \text{ km}^2 = 800 \times 10^6 \text{ M}^2$

$\therefore$ The depth of runoff $= \dfrac{264 \times 10^5}{800 \times 10^6} = 0 \cdot 033 \text{ m}$
$= 33 \text{ mm}$

By trial and error if ϕ-index is chosen to be 8 mm/h, the rainfall volume above the ϕ-index line to equal to

$$0 + (18-8) + (25-8) + (12-8) + (10-8) + 0$$
$$= 0 + 10 + 17 + 4 + 2 + 0$$
$$= 33 \text{ mm}$$

This is exactly equal to the observed runoff. Therefore ϕ = 8 mm/h.

Q. 9. What do you understand by Infiltration Capacity ?
(C.S.V.T.U. April-May, 2009; Nov.-Dec., 2010; April-May, 2011)

Ans. The maximum rate at which a given soil at a given time can absorb water is defined as the infiltration capacity. It is designated as f_P and is expressed in units of cm/h.

The actual rate of infiltration f can be expressed as :

$$f = f_P \text{ when } i \geq f_P$$
$$f = i \text{ when } i < f_P$$

where i = intensity of rainfall. The infiltration capacity of a soil is high at the beginning of a storm and has an exponential decay as the time elapes.

The infiltration capacity of an area is dependent on a large number of factors, chief of them are :

- Characteristics of soils
- Condition of the soil surface
- Current moisture content
- Vegetative cover
- Soil temperature.

Q. 10. Explain briefly :
(i) ϕ index
(ii) *W* index. **(C.S.V.T.U. April-May, 2009; Nov.-Dec., 2010; April-May, 2011)**

Ans. (i) ϕ index : The ϕ-index is an average rainfall intensity above which the rainfall volume equals the runoff volume. The rainfall hyetograph is plotted on a time base and a horizontal line is drawn such that the shaded area above the line exactly equals the measured runoff. Since the unshaded area below the line is also the line is also measured rainfall but did not appear as runoff it represents all the losses including depression storage, evaporation, interception as well as infiltration. Infiltration is the largest loss compared to the other losses. The ϕ-index can be determined for each flood event for which the runoff measurement are available. Then probably a relationship between the size of the flood, antecedent soil moisture and the ϕ-index could be developed. Since the data required to drive a precise infiltration rate curve for large watersheds is very large, the ϕ-index will be very useful in predicting the infiltration from a storm on large water-sheds. The ϕ-index is used in unit hydrograph studies to define the pattern of rainfall excess.

(ii) W-index : The W-index is a refined version of ϕ-index. It excludes the depression storage and interception from the total losses. It is the average infiltration rate during the time rainfall intensity exceeds the capacity rate.

That is $$W = \frac{F}{t} = \frac{(P-Q-S)}{t}$$

where F is the total infiltration, t is time during which rainfall intensity exceeds infiltration capacity, P is total precipitation corresponding to t, Q is the total storm runoff and S is the volume of depression storage and interception. Thus W-index is essentially equal to ϕ-index minus the depression and interception storage.

Q. 11. What is the factor affecting runoff ? **(C.S.V.T.U. April-May, 2008)**

Ans. The runoff from a drainage basin is influenced by various factors which may be put under two groups, namely the climatic factors and the physiographic factors.

The climatic factors include :

(i) Type of precipitation.
(ii) Intensity of rainfall.
(iii) Duration of rainfall.
(iv) Areal distribution of rainfall.
(v) Direction of storm movement.
(vi) Antecedent precipitation.
(vii) Other climatic factors that affect evaporation and transpiration.

The physiographic factors are :

(i) Land use.
(ii) Type of soil.
(iii) Area of the basin.
(iv) Shape of the basin.
(v) Elevation.
(vi) Slope.

(vii) Orientation.

(viii) Type of drainage network.

(ix) Indirect drainage.

(x) Artificial drainage.

Type of Precipitation : If the precipitation falls in the form of rain its effect on runoff is almost immediately felt provided its intensity is sufficiently large. The resulting runoff, of course, will also depend upon the interaction of the other factors.

Intensity of precipitation : For rainfall intensities exceeding the infiltration capacity, the runoff increases with increase in intensity. Owing to the storage effects of the basin, the increase in the runoff rate is not same as the increase in rainfall intensity.

Duration of rainfall : If rainfall is of sufficiently prolonged duration, infiltration capacity rate is greatly reduced resulting in high runoff rates. Under favourable conditions the infiltrated water may even raise the watertable to the ground surface reducing the infiltration to zero leading to serious flood. As a consequence, rains of long duration may produce high rates of runoff even though the intensity is relatively mild. It is pertinent here to consider the duration of rainfall in conjunction with critical concentration time of the basin t_c, which is defined as the time taken by a rain drop falling on the remotest point of the basin to reach the basin outlet.

Antecedent precipitation : The soil moisture conditions of the basin existing at the time of occurrence of storm would greatly influence the runoff peak resulting from that storm. Even very intense rains falling in late summer, when the soil moisture is at its least, rarely produce high discharges because most of the water enters the soil moisture under the existing high infiltration capacity rates and is held there. In the winter and rainly seasons, since the precipitation occurred in the earlier periods would have raised the soil moisture to high level, one can expect very low infiltration capacity rates.

The Antecedent Precipitation Index (API) as given below

$$I_t = KI_{t-1}$$

If there is no rainfall in the previous t days then,

$$I_t = K^t I_o$$

where I_o is the initial value of API.

Land use : Land use affects the runoff through its influence on interception, evapotranspiration and soil moisture movement. In urban areas there is little scope for infiltration and transpiration and all the rainfall immediately becomes direct runoff producing high discharges.

Type of Soil : The type of soil had direct influence on its infiltration capacity rate and consequently it also affects the runoff. Open textured sandy soils will tend to have higher infiltration rates and therefore tend to produce less peak discharges.

Elevation : The variation in elevation and also the mean elevation of a basin may influence runoff in as much as they decide the proportion of precipitation falling in the form of snow and the evaporation and transpiration losses. For large basins the mean elevation is determined by the intersections method.

Orientation : The orientation of the basin decides the amount of solar radiation received from the sun. Thus it may affect the runoff through its influence on evaporation, transpiration and snow melt processes.

Artificial drainage : Conditions of articifial drainage exist in areas provided with a system of open ditches or tile drains and also in urban areas provided with storm sewers and where considerable portions of the area are covered by buildings or paved surfaces. Runoff from such areas would naturally be accelerated, but the effect would be purely local and no significant increases in peak flow of large streams can result in general.

Q. 12. Explain the following :

(i) Infiltrometer

(ii) Basin yield. **(C.S.V.T.U. Nov.-Dec., 2009, 2010; April-May, 2011)**

Ans. (i) Infiltrometer : Infiltrometers are of two types. They are (i) Flooding type infiltrometers (ii) rainfall simulators. In the flooding type of infiltrometers water is applied in the form of a sheet usually with a constant depth of flooding. They may use a single ring or two rings to delineate the sample area. In former case it is known as a simple infiltrometer or a tube infiltrometer. In the latter case it is called a double ring infiltrometer. In the rainfall simulations water is applied by sprinkling at a uniform rate that is in excess of infiltration capacity.

(ii) Basin Yield : Yield refers to the quantity of any product resulting from the exploitation of natural resources basin yield refers to the quantity of water available from a stream at a given point over a specified duration of time. The duration of time in the definition of yield would normally be a month or longer. The emphasis is on water volumes rather than instantaneous discharges. Therefore yield from a basin is the summation of the continuous hydrograph of flow at its outlet over the specified time period. It is the consequence of all hydrologic events causing flow, including storms of all durations and intensities and the climatic, geologic and land use environment.

The hydrologic water balance equation for any basin under consideration may be written as

$$(S_1 + S_{s_1} + S_{g_1} + S_{sm_1} + P)$$

$$= E + \int_{t_1}^{t_2} Q \cdot dt + (S_2 + S_{s_2} + S_{g_2} + S_{sm_2})$$

where S = volume of water in storage in channels and reservoirs of the basin.

Q. 13. The mean monthly temperatures over a basin for a 12 month period from June to May are 25·8, 24·4, 23·8, 23·5, 23·6, 20·2, 17·1, 16·6, 18·5, 23·3, 27·6 and 28·4° respectively. The observed rainfalls in mm in corresponding months are 86, 229, 208, 115, 15, 182, 10, 24, 24, 12, 0 and 0. Determine the annual runoff from the basin using Khosla's formula.

Solution : It may be noted that when L_m exceeds P_m resulting in a negative value for R_m, then R_m is set equal to zero.

Month	M	T_m	P_m (mm)	$L_m = 5\,T_m$	$R_m = P_m - L_m$ (mm)
June	1	25·8	86	129	0
July	2	24·4	229	122	107
August	3	23·8	208	119	89
September	4	23·5	115	117·5	0
October	5	23·6	15	118	0
November	6	20·2	182	101	81
December	7	17·1	10	85·5	0
January	8	16·6	24	83	0
February	9	18·5	24	92·5	0
March	10	23·3	12	116·5	0
April	11	27·6	0	138·0	0
May	12	28·4	0	142	0
					R_A = 277 mm

Q. 14. The cumulative depth of infiltration in an experiment on a tube infiltrometer is observed to follow the equation $F = 0{\cdot}165\, t^{0{\cdot}65}$, where F is in cm and t is in minutes. Determine the equation for infiltration rate and the average infiltration rate.

Solution :

$$F = 0{\cdot}165\, t^{0{\cdot}65}$$

$$f = \frac{dF}{dt} = 0{\cdot}165 \times 0{\cdot}65 \times t^{-0{\cdot}35}$$

$$= 0{\cdot}10725\, t^{-0{\cdot}35} \text{ cm/minute}$$

$$f = 6{\cdot}435\, t^{-0{\cdot}35} \text{ cm/h, where } t \text{ is in minutes.}$$

$$f = 1{\cdot}5353\, t^{-0{\cdot}35} \text{ cm/h, where } t \text{ is in hours}$$

$$f_{av} = \frac{F}{t} = 0{\cdot}165 t^{-0{\cdot}35} \text{ cm/minute}$$

$$= 9{\cdot}9\, t^{-0{\cdot}35} \text{ cm/h, where } t \text{ is in min.}$$

$$= 2{\cdot}362\, t^{-0{\cdot}35} \text{ cm/h, where } t \text{ is in hours.}$$

Q. 15. The Horton's infiltration equation for a basin is given by $f = 6 + 16\, e^{-2t}$ where f is in mm/h t is in hours. What are the values of f_o, f_c and K ? If a storm occurs on this basin with an intensity of more than 22 mm/h determine the depth of infiltration for the first 45 minutes and the average infiltration rate for first 75 minutes.

Solution : On comparison with the Horton's equation in the standard form one can observe that $f_c = 6$ mm/h, $f_o = 22$ mm/h and $k = 2$/h.

Since the rainfall intensity is more than f_o, the infiltration takes place at the capacity rate throughout the storm. Hence the cumulative depth of infiltration for the first 45 minutes is given by

$$F = \int_0^{3/4} f \cdot dt = \int_0^{0{\cdot}75} (6 + 16e^{-2t})\, dt$$

$$= \left[6_t - 8_e^{-2t}\right]_0^{0{\cdot}75}$$

$$= [6 \times 0{\cdot}75 - 8 \times e^{-1{\cdot}5}] - [0 - 8]$$

$$= 12{\cdot}5 - 8e^{-1{\cdot}5} = 12{\cdot}5 - 1{\cdot}785$$

$$= 10{\cdot}715 \text{ mm}$$

The cumulative depth of infiltration for the first 75 minutes is given by

$$F = \int_0^{1{\cdot}25} f \cdot dt = \left[6t - 8_e^{-2t}\right]_0^{1{\cdot}25}$$

$$= [6 \times 1{\cdot}25 - 8 \times e^{-2{\cdot}5}] - [0 - 8]$$

$$= 15{\cdot}5 - 0{\cdot}657 = 14{\cdot}843 \text{ mm}$$

The average infiltration rate for the first 75 minutes is given by

$$f_{av} = \frac{F}{t} = \frac{14{\cdot}843}{1{\cdot}25}$$

$$f_{av} = 11{\cdot}874$$

Q. 16. What are the initial losses ? How does the interception loss vary with the magnitude of storm rainfall ?

Ans. Much of the rain falling during the initial period of the storm is stored on the vegetal cover as interception. Some more precipitation is requiring to fill up all the depression before the overland flow commences. The interception and depression storage are together called the initial abstractions or the initial losses.

Interception : The amount of precipitation intercepted by the vegetal cover depends on many factors such as density and compaction of vegetation, storm characteristics and prevailing wind at the time of storm. It is very difficult to exactly measure the interception. It is estimated that the annual interception by a well-developed forest may be anything between 10 to 20% of the rainfall. If the area experiences a large number of small storms it can be even greater than 25%.

Depression storage : The water which goes to fill up the surface depressions is not available to runoff as it is eventually lost as either infiltration. Thus depression storage is considered as loss from rainfall. The depression storage depends again on many factors such as the type and the nature of catchment, slope of the catchment and the antecedent precipitation that reflects the soil moisture. It is observed that the depression storage for most basins lie between 10 and 50 mm.

Q. 17. A 500 sq. km watershed received a 8 h storm which produced hourly intensities of 6, 9, 20, 16, 4, 14, 12 and 2 mm/h. If the initial abstractions are estimated to be 15 mm and ϕ-index is 5 mm/h, what would be the runoff volume produced by the storm ?

(C.S.V.T.U. Nov.-Dec., 2008)

Solution : The rainfall occurring in the first two hours is 15 mm which is same as the initial abstractions. Therefore no runoff is produced in this period. In the remaining 6 h period the rainfall excess is given by

$(20–5) + (16–5) + 0\ (14–5) + (12–5) + 0 = 42$ mm

$\therefore$ The runoff volume = Area of the basin × Runoff depth

$$= 500 \times 10^6 \times \frac{42}{1000}$$

$$= 21 \times 10^6 \text{ m}^3$$

If the initial abstractions are neglected and ϕ-index is applied throughout the storm the runoff is over-estimated by 5 mm resulting in an error of about 12%. The basin produces surfaces runoff from the end of 2nd hour.

Q. 18. Rainfall of 12, 30, 40, 44 and 17 mm were recorded on 3rd, 9th, 10th, 16th and 17th days of a particular month. Compute the antecedent precipitation index for the first 20 days of the month and assume that *API* of the last day in the previous month is 85 mm and the value of the recession factor K is 0·90. **(C.S.V.T.U. April-May, 2009)**

Solution : The *API* of any day t, denoted by I_t is obtained from the equation.

$$I_t = K\, I_{t-1} + P_t$$

where P_t is the precipitation on t^{th} day. The computations to obtain the *API* for the first 20 days in the month are set out in Table, with $I_o = 85$ and $K = 0{\cdot}90$

Day	Precipitation in (mm) P_t	I_{t-1}	$K \cdot I_{t-1}$	$I_t = KI_{t-1} + P_t$
1	0	85	76·50	76·50
2	0	76·50	68·85	68·85
3	12	68·85	61·97	73·97
4	0	73·97	66·57	66·57
5	0	66·57	59·91	59·91
6	0	59·91	53·92	53·92
7	0	53·92	48·53	48·53
8	0	48·53	43·68	69·31
9	30	43·68	39·31	102·38
10	40	69·31	62·38	92·14
11	0	102·38	92·14	82·93
12	0	92·14	82·93	74·64
13	0	82·93	74·64	67·18

14	0	74·64	67·18	60·46
15	0	67·18	60·46	98·41
16	44	60·46	54·41	105·57
17	17	98·41	88·57	95·01
18	0	105·57	95·01	85·51
19	0	95·01	85·51	76·96
20	0	85·51	76·96	76·96

Q. 19. The following table gives values of measured discharges at a stream gauging site in a year. Upstream of the gauging site a weir built across the stream diverts 3 Mm^3 and 0·50 Mm^3 of water per month for irrigation and for use in an industry respectively. The return flows from the irrigation is estimated as 0·8 Mm^3 and from the industry at 0·30 Mm^3 reaching the stream upstream of the gauging site. Estimate the natural flow. If the catchment area is 180 km^2 and the average annual rainfall is 185 cm. Determine the runoff-rainfall ratio.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Gauged flow	2	1·5	0·8	0·6	2·1	8	18	22	14	9	7	3

Solution : $R_N = (R_o - V_r) + V_d + E + E_x + \Delta S$

Here E, E_x and ΔS are assumed to be insignificant and of zero value.

V_r = Volume of return flow from irrigation, domestic water supply and industrial use = 0·80 + 0·30 = 1·10 Mm^3

V_d = Volume diverted out of the stream for irrigation, domestic water supply and industrial use = 3 + 0·5 = 3·5 Mm^3

Month	1	2	3	4	5	6	7	8	9	10	11	12
R_o (Mm^3)	2	1·5	0·8	0·6	2·1	8	18	22	14	9	7	3
V_d (Mm^3)	3·5	3·5	3·5	3·5	3·5	3·5	3·5	3·5	3·5	3·5	3·5	3·5
V_r (Mm^3)	1·1	1·1	1·1	1·1	1·1	1·1	1·1	1·1	1·1	1·1	1·1	1·1
R_N (Mm^3)	4·4	3·5	3·2	3	4·5	10·4	20·4	24·4	16·4	11·4	9·4	5·4

Total R_N = 116·8 Mm^3

Annual natural flow volume = Annual runoff volume = 116·8 Mm^3

Annual natural flow volume = Annual runoff volume = 116·8 Mm^3

Area of the catchment = 180 km^2 = $1·80 \times 10^8$

$$\text{Annual runoff depth} = \frac{1·168\times10^8}{1·80\times10^8} = 0·649 \text{ m} = 64·9 \text{ cm}$$

Annual rainfall = 185 cm

(Runoff/Rainfall) = 64·9/185

= 0·35

Q. 20. Monthly rainfall values of the 50% dependable year at a site selected for construction of an irrigation tank is given below. Estimate the monthly and annual runoff volume of this catchment of area 1500 ha.

Month	June	July	August	September	October
Monthly rainfall (mm) rainfall (mm)	90	160	145	22	240

Solution :

No.	Month	June	July	August	September	October
1.	Monthly rainfall (mm)	90	160	145	22	240
2.	Cumulative monthly rainfall (mm)	90	250	395	417	657
3.	Runoff/Rainfall as %	0·56	4·17	10·01	11·08	21·69
4.	Cumulative Runoff	0·50	10·43	39·54	46·20	142·50
5.	Monthly Runoff	0·50	9·92	29·11	6·66	96·30

Row 4 is obtained by using table. Note that cumulative monthly rainfall is used to get cumulative runoff-ratio percentage at any month

Total monsoon runoff = 142·50 mm

= $(142·5/1000) \times (1500 \times 10^4) / 16^6$ Mm^3

= 2·1375 Mm^3

Annual Runoff is taken as equal to monsoon runoff.

Q. 21. The observed mean monthly flows of a stream for a one year period from June to May in m^3/s are 18, 20, 46, 42, 37, 30, 33, 23, 26, 21, 19 and 8.

(a) Determine the flow which can be expected 80 percent of time.

(b) What is the dependability of the flow of magnitude 40 m^3/s ?

Sol.

Month	Observed flow m^3/s	Flow arranged in descending order m^3/s	Rank m	Percent of time flow equalled or exceeded $= \frac{m}{n} \times 100(\%)$
June	18	46	1	8·33
July	20	42	2	16·67
Aug.	46	37	3	25
Sept.	42	33	4	33·33
Oct.	37	30	5	41·67
Nov.	30	26	6	50
Dec.	33	23	7	58·33
Jan.	23	21	8	66·67
Feb.	26	20	9	75
Mar.	21	19	10	83·33
Apr.	19	18	11	91·67
May	8	8	12	100

(a) Flow expected 80 percent of the time = 18·5 m^3/s

(b) Dependability of flow of magnitude 40 m^3/s = 18·4%. **Ans.**

●●

Unit IV

HYDROGRAPH ANALYSIS

Syllabus : Introduction, Characteristics of the hydrograph, Effect of rainfall distribution on the shape of hydrograph, Hydrograph separation, Unit hydrograph, Deviation of the unit hydrograph, Unit hydrograph from the complex storms-hydrograph, Applications of unit hydrograph.

Introduction : The time distribution of runoff produced by a given precipitation on a basin is analysed. The runoff measured at the basin outlet, when plotted against time gives the hydrograph. As the runoff includes the contributions from surface runoff, interflow and groundwater runoff, the hydrograph can be regarded as an integral expression of the physiographic and climatic characteristics that govern the relations between rainfall and runoff. It shows the time distribution of runoff at the basin outlet defining the complexities of the basin characteristics by a single empirical curve. Thus it forms a basis to relate rainfall and the time distribution of runoff produced by it.

Q. 1. Define unit hydrograph ?

(C.S.V.T.U. Nov.-Dec., 2007; April-May, 2009; Nov.-Dec., 2009)

Ans. The Unit hydrograph of a drainage basin is defined as a hydrograph of direct runoff resulting from 1 cm of effective rainfall applied uniformly over the basin area at a uniform rate during a specified period of time.

Q. 2. Discuss the characteristics of the hydrograph. **(C.S.V.T.U. April-May, 2008)**

Ans. It has three characteristic regions :

(i) The rising limb AB, joining point A, the starting point of the rising curve and point B, the point of inflection.

(ii) The crest segment BC between the two points of inflection with a peak P in between.

(iii) The falling limb or depletion curve CD starting from the second point of inflection C.

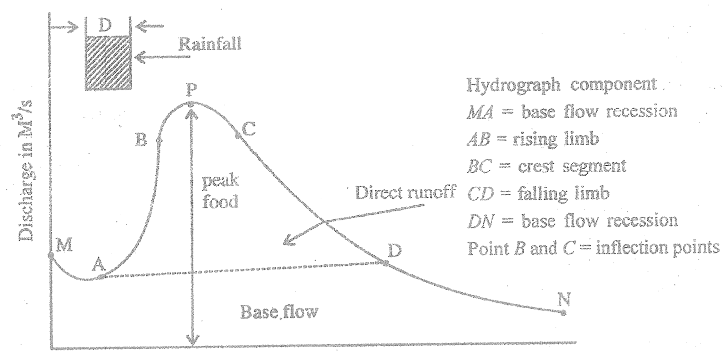

Fig.

Q. 3. Discuss the definition of a unit hydrograph implies ? (C.S.V.T.U. April-May, 2008)

Ans. (i) The unit hydrograph represents the lumped response of the catchment to a unit rainfall excess of *D-h* duration to produce a direct-runoff hydrograph. It relates only the direct runoff to the rainfall excess. A 1 cm depth of rainfall excess is considered the area of the unit hydrograph is equal to a volume given by 1 cm over the catchment.

(ii) The rainfall is considered to have an average intensity of excess rainfall (*ER*) of 1/D cm/*h* for the duration *D-h* of the storm.

(iii) The distribution of the storm is considered to be uniform all over the catchment.

Q. 4. Write limitation of unit hydrograph. **(C.S.V.T.U. April-May, 2009)**

Ans. Since uniform intensity over long duration is less likely the storms selected for unit hydrograph analysis should be of short duration. The uniform aerial distribution of rainfall over large areas is less likely, the unit hydrographs can be applied only to drainage basins with small areas. In case of large basins, the basin has to be divided into small sub-basins and each sub-basin is subjected to analysis for storms covering the whole sub-basin. The unit hydrograph is also not suitable for areas less than 200 hectares. Basins with odd shapes, particularly those which are long and narrow, will commonly have uneven rainfall distribution and hence unit hydrographs are not well adopted to such basins. The assumption of constant base period for storms of same duration may not produce excessive error since the recession curve approaches zero asymptotically. The unit hydrographs derived from two storms of same duration but with different runoff volumes will not be same. The peak discharge in the unit hydrograph derived from ordinary floods is often increased by 5 to 20 per cent before using it for predicting the extreme flood peaks with the belief that channel-flow time shortens as flood magnitude increases. If extreme floods overflow into flood plains, the opposite effect might result.

Q. 5. What are the assumptions of unit hydrograph theory ?(C.S.V.T.U. Nov.-Dec., 2009)

Ans. The following basic assumptions constitute the so-called unit hydrograph theory.

(a) The effective rainfall is uniformly distributed within its duration.

(b) The effective rainfall is uniformly distributed throughout the whole area of the basin.

(c) The base periods of the direct runoff hydrographs produced by effective rainfall of same duration are also same.

(d) The ordinates of the direct runoff hydrograph of a common base period are directly proportional to the total volume of direct runoff represented by the respective hydrographs.

(e) For a given drainage basin the hydrograph of runoff due to a given period of rainfall reflects the unchanging characteristics of the basin.

Q. 6. Explain briefly :

(i) Hydrograph Separation,

(ii) S-curve hydrograph. **(C.S.V.T.U. April-May, 2009; April-May-2011)**

Ans. (i) Hydrograph Separation : It is necessary to separate to observed hydrograph into its component parts namely the surface runoff, interflow and groundwater runoff for subsequent analysis. However, in many engineering applications it is the standard practice to separate the hydrograph into two parts only direct runoff and base flow.

If a continuous record of discharge in the stream over a period of few year is available a master depletion curve also called a type curve or a composite recession curve is constructed and used for separating the baseflow. The construction of the master depletion curve is as follows. Recession segments which represent only base flow contribution at their respective tails are selected. These segments should be selected at as many different stages in the river as possible.

They are then plotted on transparent papers with coincident time axis and are adjusted such that all of them will have a common overlapping portion.

While the procedure described above is perhaps the best available, it requires previously observed data on stream flow for a long period which may not be available in all cases. In such situations a point on the recession limb of the hydrograph to mark the end of direct runoff may be fixed N days after the peak of the hydrograph where N is calculated from the empirical equation.

$$N = 0{\cdot}827\ A^{0{\cdot}2} \qquad ...(1)$$

in, A is the area of the drainage basin in km^2. N as given by eq. (1) may be taken as a rule of thumb and need not strictly adhered to, if it is giving either too long or too short base flow separation line.

(ii) *S*-curve hydrograph : A *S*-curve hydrograph may be defined as the hydrograph of direct runoff resulting from a continuous effective rainfall of uniform intensity $\frac{1}{D}$ cm/h. The *S*-curve is constructed by adding together a series of D *h* unit hydrographs, each lagged by D *h* with respect to the previous one. The *S*-curve hydrograph attains a constant ordinate called the equilibrium discharge denoted by Q_e, approximately at the end of the base period T of the unit hydrograph. Thus the number of unit hydrographs needed to produce the *S*-curve is $\frac{T}{D}$. The *S*-curve ordinates are sometimes found to oscillate in the top portion at and around the equilibrium discharge. This is called the hunting of *S*-curve.

Q. 7. Write a use and Applications of unit hydrograph ? **(C.S.V.T.U. April-May, 2009)**

Ans. The unit hydrographs are used in many hydrological problems such as :–

(i) In the development of flood hydrograph corresponding to design of hydraulic structures.

(ii) In the watershed simulation models.

(iii) In the studies of flood forecasting and flood warning systems, and

(v) In extending the flood flow records based on rainfall records.

Application of unit hydrograph :

(i) The rainfall hyetograph is constructed for the storm under consideration and the effective rainfall is determined by drawing an appropriate ϕ-index line.

(ii) The effective rainfall hyetograph is split into periods of approximately uniform intensity and durations that meet the requirements of the unit hydrograph available.

(iii) The direct runoff hydrograph resulting from each rainfall periods obtained by multiplying the ordinates of the appropriate U.H. by the depth of effective rainfall in that period.

(iv) These direct runoff hydrographs are plotted and graphically added with appropriate time lag to yield the composite direct runoff hydrograph.

(v) The estimated baseflow is then added to the composite direct runoff hydrograph to give the total runoff hydrograph.

Q. 8. Two storms each of 6 hours duration and having rainfall excess values of 3 and 2 cm respectively. The 2 cm *ER* rain follows the 3 cm rain. The 6 h unit hydrograph for the catchment is given, calculate the resulting *DRH*.

Time (h)	UH ordinates (m^3/s)
0	0
3	25
6	50
9	85
12	125
15	160
18	185
24	160
30	110
36	60
42	36
48	25
54	16
60	8
69	0

(C.S.V.T.U. Nov.-Dec., 2007)

Sol : First, the DRH_s due to 3 and 2 cm *ER* are calculated, by multiplying the ordinates of unit hydrograph by 3 and 2 respectively. Noting that the 2 cm *DRH* occurs after the 3 cm *DRH*, the ordinates of the 2 cm *DRH* are lagged by 6 hrs as shown column 4 of table. Column 3 and 4 give the proper sequence of the two DRH_s. Using the method of superposition, the ordinates of the resulting *DRH* are obtained by combining the ordinates of the 3 and 2 cm DRH_s at any instant. By this process the ordinates of the 5 cm *DRH* are obtained in column 5.

Time (h)	Ordinate of 6-h *UH* (m^3/s)	Ordinate of 3-cm *DRH* (col. 2) × 3	Ordinate of 2-cm *DRH* (col. 2 lagged by 6h) × 2	Ordinate of 5 cm *DRH* (col. 3 + col. 4) (m^3/s)	Remarks
1	2	3	4	5	6
0	0	0	0	0	
3	25	75	0	75	
6	50	150	0	150	
9	85	255	50	305	
12	125	375	100	475	
15	160	480	170	650	
18	185	555	250	805	
(21)	(172·5)	(517·5)	(320)	(837·5)	Interpolated value
24	160	480	370	850	
30	110	330	320	650	
36	60	180	220	400	
42	36	108	120	228	
48	25	75	72	147	
54	16	48	50	98	
60	8	24	32	56	
(66)	(2·7)	(8·1)	(16)	(24·1)	Interpolated value
69	0	0	(10·6)	(10·6)	Interpolated value
75	0	0	0	0	

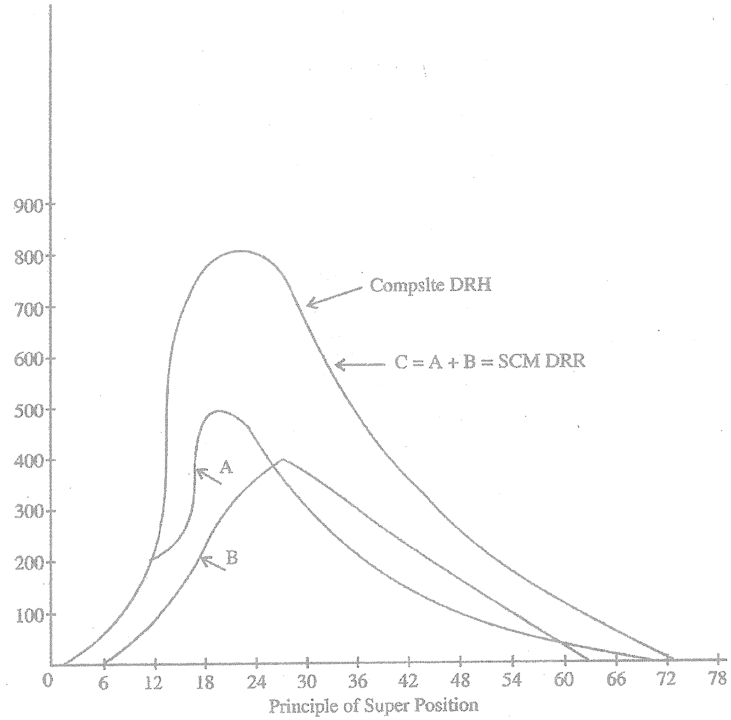

Fig.

Q. 9. Following are the ordinates of a storm hydrograph of a river during a catchment area of 423 km^2 due to a 6 h isolated storm. Derive the ordinates of 6 h unit hydrograph for the catchment.

Time from start of storm (*h*)	Discharge (m^3/s)
– 6	10
0	10
6	30
12	87·5
18	115·5
24	102·5
30	85
36	71
42	59
48	47·5
54	39
60	31·5
66	26
72	21·5
78	17·5
84	15
90	12·5
96	12
102	12

(C.S.V.T.U. Nov.-Dec., 2007)

Solution :

$$\text{Hence } N = (90 - 20) = 70 \text{ h} = 2{\cdot}91 \text{ days}$$
$$N' = 0{\cdot}83\,(423)^{0{\cdot}2}$$
$$= 2{\cdot}78 \text{ days}$$

however, $N = 2{\cdot}91$ days is adopted for convenience. A straight line joining A and B is taken as divide line for base flow separation. The ordinates of *DRH* are obtained by substracting the base flow from the ordinates of the storm hydrograph. The calculation are :

$$\text{Volume of } DRH = 60 \times 60 \times 6 \times (\text{sum of } DRH \text{ ordinates})$$
$$= 60 \times 60 \times 6 \times 587$$
$$= 12{\cdot}68 \text{ Mm}^3$$
$$\text{Drainage area} = 423 \text{ km}^2 = 423 \text{ Mm}^2$$
$$\text{Runoff depth} = ER = \frac{12{\cdot}68}{423}$$
$$= 0{\cdot}03 \text{ m} = 3 \text{ cm.}$$

The ordinates of *DRH* (col. *u*) are divided by 3 to obtain the ordinates of the 6-h unit hydrograph.

Time from beginning of storm (h)	Ordinate of flood hydrograph (m^3/s)	Base flow (m^3/s)	Ordinate of DRH	Ordinate of 6 H unit hydrograph
1	2	3	4	5
– 6	10	10	0	0
0	10	10	0	0
6	30	10	20	6·7
12	87·5	10·5	77	25·7
18	111·5	10·5	101	33·7
24	102·5	10·5	101	33·7
30	85	11	74	24·7
36	71	11	60	20
42	59	11	48	16
48	47·5	11·5	36	12
54	39	11·5	27·5	9·2
60	31·5	11·5	20	
66	26	12	14	
72	21·5	12	9·5	

Time from beginning of storm (h)	Ordinate of flood hydrograph	Base flow	Ordinate of *DRH*	Ordinate of 6 H unit hydrograph
1	2	3	4	5
78	17·5	12	5·5	
84	15	12·5	2·5	
90	12·5	12·5	0	
96	12	12	0	
102	12	12	0	

Q. 10. The ordinates of a 4*h* U.H. of a basin of are 300 km^2 measured at 1h intervals are 6, 36, 66, 91, 106, 93, 79, 68, 58, 49, 41, 34, 27, 23, 17, 13, 9, 6, 3 and 1·5 m^3/s respectively obtain the ordinates of 3*h* U.H for the basin using the *S*-curve technique.

(C.S.V.T.U. Nov., Dec., 2008)

Solution :

Column (1) = The time axis at a uniform interval of 1*h*.
Column (2) = The given ordinates of 4*h* *U.H*
Column (3) = The *S*-curve additions
Column (4) = Col. (2) + Col. (3) = The *S*-curve ordinates
Column (5) = S-curve lagged by 3 h (since $D^1 = 3$ h)
Column (6) = Col. (4) – Col. (5) = The difference graph.

$$\text{Column (7)} = \text{Col. (6)} \times \frac{4}{3}\left(\text{since}\ \frac{D}{D^1} = \frac{4}{3}\right)$$

= The ordinates of 3h U.H.

Time (t) hours	Ordinates of of 4-*h* *UH* *U* (*t*) (m^3/s)	S-curve additions *S* (*t*–4)	S-curve ordinates *S*(*t*)	S-curve lagged by 3*h*, *S*(*t*–3)	Difference graph	Ordinates of 3*h* *UH*
1	2	3	(4) = (2) + (3)	(5)	(6) = (4) – (5)	7 = (6) × (3)
0	0		0		0	0
1	6		6		6	8
2	36		36		36	48
3	66		66	0	66	88
4	91	0	91	6	85	113·3
5	106	6	112	36	76	101·3
6	93	36	129	66	63	84
7	79	66	145	91	54	72
8	68	91	159	112	47	62·7
9	58	112	170	129	41	54·7
10	49	129	178	145	33	44
11	41	145	186	159	27	36
12	34	159	193	170	23	30·7
13	27	170	197	178	19	25·3
14	23	178	201	186	15	20
15	17	186	203	193	10	13·3
16	13	193	206 *	197	9	12
17	9	197	206·5	201	5·5	7·3
18	6	201	207	203	4	5·3
19	3	203	207·5 *	206	1·5	2
20	1·5	206	208	206·5	0 **	0
21	0	206·5	208·5 *	207	0 **	

Q. 11. The effective rainfall hyetograph of a complex storm has a duration of 12*h*, with rainfall intensity of 2, 0·75 and 4 cm/h respectively in successive 4*h* periods. The ordinates of the corresponding direct runoff hydrograph read at 4*h* intervals are 160, 300, 570, 636, 404, 234, 105 and 48 m^3/s respectively. Determine the ordinates of the 4*h* unit hydrograph using the deconvolution method. (C.S.V.T.U. Nov.-Dec., 2008; April-May, 2009)

Solution : From the given data, we have

$D = 4h$

$I_1 = 2{\cdot}0$ cm/h, $I_2 = 0{\cdot}75$ cm/h

$I_3 = 4$ cm/h

$P_1 = I_1 \cdot D = 2 \times 4 = 8$ cm

$P_2 = I_2 \cdot D = 0{\cdot}75 \times 4 = 3$ cm

$P_3 = I_3 \cdot D = 4 \times 4 = 16$ cm

$Q_1 = 160, Q_2 = 300........\text{and } Q_8 = 48$

Also $M = 3$, and $R = 8$. Therefore the 4*h* U.H. will have ($N = R + 1 - M = 8 + 1 - 3 = 6$) 6 ordinates which are computed as given below.

$$Q = P_1U_1 \text{ or } U_1 = \frac{Q_1}{P_1} = \frac{160}{8} = 20\,\text{m}^3/\text{s}$$

$$Q_2 = P_1U_2 \text{ or } P_2U_1 = 8U_2 + 3 \times 20 = 8U_2 + 60$$

$$U_2 = \frac{Q_2 - 60}{8} = \frac{300-60}{8} = 30\,\text{m}^3/\text{s}$$

$$Q_3 = P_1U_3 + P_2U_2 + P_3U_1 = 8U_3 + 3 \times 30 + 16 \times 20$$
$$= 8U_3 + 410$$

$$U_3 = \frac{Q_3 - 410}{8} = \frac{570-410}{8} = 20\ \text{m}^3/\text{s}$$

$$Q_4 = P_1U_4 + P_2U_3 + P_3U_2 = 8U_4 + 3 \times 20 + 16 \times 30$$
$$= 8U_4 + 540$$

$$U_4 = \frac{Q_4 - 540}{8} = \frac{636-540}{8} = 12\,\text{m}^3/\text{s}$$

$$Q_5 = P_1U_5 + P_2U_4 + P_3U_3 = 8U_5 + 3 \times 12 + 16 \times 20$$
$$= 8U_5 + 356$$

$$U_5 = \frac{Q_5 - 356}{8} = \frac{404-356}{8} = 6\ \text{m}^3/\text{s}$$

$$Q_6 = P_1U_6 + P_2U_5 + P_3U_4 = 8U_6 + 3 \times 6 + 16 \times 12$$
$$= 8U_6 + 210$$

$$U_6 = \frac{Q_6 - 210}{8} = \frac{234-210}{8} = 3\ \text{m}^3/\text{s}$$

Thus the ordinates of the 4 h unit hydrograph at 4 h intervals are 20, 30, 20, 12, 6 and 3 m^3/s respectively.

Q. 12. The ordinates of 4 h unit hydrograph of a basin are tabulated below. Derive 2 h unit hydrograph ordinate from the 4 h unit hydrograph.

Time (h)	0	4	8	12	16	20	24	28	32	36	40	44
Ordinate or 4–h U.H.	0	20	80	130	150	130	90	52	27	15	5	0

(C.S.V.T.U. Nov.-Dec., 2009)

Solution : In this case the time interval of the ordinates of the given unit hydrograph should be at least 2 h. As the given ordinates are at 4 h intervals, the unit hydrograph is plotted and its ordinates at 2 h intervals determined. The ordinates are shown in column 2 of table. The S-curve additions and S-curve ordinates are shown in column 3 and 4 respectively. First, the S-curve ordinates corresponding to the time intervals equal to successive durations of the given unit hydrograph (in this case at 0, 4, 8, 12.....h) are determined by following the method. Next the ordinates at intermediate intervals (at, t = 2, 6, 10, 14......h) are determind by having another series of S-curve additions. To obtain a 2 h unit hydrograph the S-curve is lagged by 2 h (column 5) and this is subtracted from column 4 and the results listed in column 6. The ordinates in column 6 are now divided by $T/D = 2/4 = 0{\cdot}5$, to obtain the required 2 h unit hydrograph ordinates, shown in column 7.

Time (h)	Ordinates of 4-h UH (m^3/s)	S-curve additions (m^3/s)	S-curve (Col. 2 + 3) (m^3/s)	S-curve lagged by 2h	Col. 4 – Col. 5 DRH of $\left(\frac{2}{4}\right) = 0{\cdot}5$ cm	2 h UH ordinate $\frac{\text{Col. 6}}{(2/4)}$
1	2	3	4	5	6	7
0	0	—	0	—	0	0
2	8	—	8	0	8	16
4	20	0	20	8	12	24
6	43	8	51	20	31	62
8	80	20	100	51	49	98
10	110	51	161	100	61	122
12	130	100	230	161	69	138
14	146	161	307	230	77	154
16	150	230	380	307	73	146
18	142	307	449	380	69	138
20	130	380	510	449	61	122
22	112	449	561	510	51	102
24	90	510	600	561	39	78
26	70	561	631	600	31	62
28	52	600	652	631	21	42
30	38	631	669	652	17	34
32	27	652	679	669	10	20
34	20	669	689	679	10	(20) 15
36	15	679	694	689	5	(10) 10
38	10	689	699	694	5	(10) 6
40	5	694	699	699	(0)	(0) 3
42	2	699	701	699	(2)	(4) 0
44	0	699	699	701	(–2)	(–4) 0

Q. 13. The ordinates of 4 h unit hydrograph of a basin are tabulated below. Derives 8 h unit hydrograph from the 4 h unit hydrograph. Time (hour) 4 h UH ordinates m^3/sec.

Time (h)	Ordinates
0	0
2	12·52
4	21·32
6	23·54
8	17·84
10	14·79
12	12·18
14	10·04
16	8·26
18	6·51
20	4·98
22	3·95
24	3·05
26	2·26
28	1·60
30	1·07
32	0·53

(C.S.V.T.U. April-May, 2010)

Solution : The necessary computations required to obtained the ordinates of 8 h unit hydrograph are given in Table :

Time (h) (1)	Ordinates of without lage (2)	4h UH in (m^3/s) lagged by 4 h (3)	Combined hydrograph m^3/s (4) = (2) + (3)	Ordinate of 8 h $U.H.$ m^3/s (5) = (4)/2
0	0		0	0
2	12·52		12·52	6·26
4	21·32	0	21·32	10·66
6	23·54	12·52	36·06	18·03
8	17·84	21·32	39·16	19·58
10	14·79	23·54	38·33	19·17
12	12·18	17·84	30·02	15·01
14	10·04	14·79	24·83	12·42
16	8·26	12·18	20·44	10·22
18	6·51	10·04	16·59	8·30
20	4·98	8·26	13·24	6·62
22	3·95	6·51	10·46	5·23
24	3·05	4·98	8·03	4·02
26	2·26	3·95	6·21	3·11

28	1·60	3·05	4·65	2·33
30	1·07	2·26	3·33	1·67
32	0·53	1·60	2·13	1·07

Q. 14. Rainfall of magnitude 3·8 cm and 2·8 cm occurring on two consecutive 4-*h* durations on a catchment of area 27 km² produced the following hydrograph of flow at the outlet of the catchment. Estimate the rainfall excess and φ index.

Time from start of rainfall (h)	– 6	0	6	12	18	24	30	36	42	48	54	60	66
Observed flow (m³/s)	6	5	13	26	21	16	12	9	7	5	5	4·5	4·5

Solution : For using the simple straight line method of base flow separation by eqn.

$$N = 0{\cdot}83 \times (27)^{0{\cdot}2} = 1{\cdot}6 \text{ days} = 38{\cdot}5\ h$$

however, by inspecstion, DRH starts at $t = 0$, has the peak at $t = 12\ h$ and ends at $t = 48\ h$. As $N = 36\ h$ appears to be more satisfactory than $N = 38{\cdot}5\ h$, in the present case *DRH* is assumed to exist from $t = 0$ to $48\ h$. A straight line base flow separation gives a constant value of 5 m³/s for the base flow.

$$\text{Area of } DRH = (6\times60\times60)\left[\frac{1}{2}(8)+\frac{1}{2}(8+21)+\frac{1}{2}(21+16)+\frac{1}{2}(16+11) + \frac{1}{2}(11+7)+\frac{1}{2}(7+4)+\frac{1}{2}(4+2)+\frac{1}{2}(2)\right]$$

$$= 3600 \times 6\,(8 + 21 + 16 + 11 + 7 + 4 + 2)$$

$$= 1{\cdot}4904 \times 10^6 \text{ m}^3$$

$$\text{Runoff depth} = \frac{\text{runoff volume}}{\text{catchment area}} = \frac{1{\cdot}4904\times10^6}{27\times10^6}$$

$$= 0{\cdot}0552 \text{ m}$$

$$= 5{\cdot}52 \text{ cm} = \text{rainfall excess}$$

$$\text{Total rainfall} = 3{\cdot}8 + 2{\cdot}8$$

$$= 6{\cdot}6 \text{ cm}$$

$$\text{Duration} = 8\ h$$

$$\phi \text{ index} = \frac{6{\cdot}6 - 5{\cdot}52}{8}$$

$$= 0{\cdot}135 \text{ cm}/h$$

Q. 15. Describe the analysis of the recession limb of a flood hydrograph ?

Ans. The recession limb, which extends from the point of inflection at the end of the crest segment to the commencement of the natural groundwater flow represents the withdrawal of water from the storage built up in the basin during the earlier phases of the hydrograph. The starting point of the recession limb, the point of inflection represents the condition of maximum storage. Since the depletion of storage takes place after the cessation of rainfall, the shape of this part of the hydrograph is independent of storm characteristics and depend entirely on the basin characteristics.

The storage of water in the basin exists as :

(i) surface storage, which includes both surface detention and channel storage,

(ii) interflow storage and,

(iii) groundwater storage, base-flow storage.

The recession of a storage can be expressed as :

$$Q_t = Q_0\, K_r^{\,t} \qquad ...(1)$$

in which Q_t is the discharge at a time t and Q_0 is the discharge at $t = 0$, K_r is a recession of value less than unity. Equation (1) can also be expressed in an alternative form of the exponential decay as

$$Q_t = Q_0\, e^{-at} \qquad ...(2)$$

where $a = -1_n\, K_r$

The recession constant K_r, can be considered to be made up the three components to account for the three types of storages as

$$K_r = K_{rs}{\cdot}K_{ri}{\cdot}K_{rb}$$

where K_{rs} = recession constant for surface storage,

K_{ri} = recession constant for interflow and

K_{rb} = recession constant for base flow. Typically the value of these recession constants, when time t is in days, are

K_{rs} = 0·05 to 0·20 $\qquad K_{ri}$ = 0·50 to 0·85

K_{rb} = 0·85 to 0·99

when the interflow is not significant, K_{ri} can be assumed to be unity.

If suffixes 1 and 2 denote the conditions at two time instances t_1 and t_2.

From eqn. (1)
$$\frac{Q_1}{Q_2} = K_r^{(t_1-t_2)} \qquad ...(3)$$

or From eqn. (2)
$$\frac{Q_1}{Q_2} = e^{-a(t_1-t_2)} \qquad ...(4)$$

The storage S_t remaining at any time t is obtained as

$$S_t = \int_t^\infty Q_t\,dt = \int_t^\infty Q_0 e^{-at}\,dt = \frac{Q_t}{a} \qquad ...(5)$$

Q. 16. Explain the term Rainfall Excess (*ER*). How is *ERH* of a storm obtained ?

Ans. Effective rainfall (also known as Excess Rainfall) (*ER*) is that part of the rainfall that becomes direct runoff at the outlet of the watershed. It is thus the total rainfall in a given duration from which abstractions such as infiltration and initial losses are subtracted. *ER* could be defined as that rainfall that is neither retained on the land surface nor infiltrated into the soil.

For purposes of correlating *DRH* with the rainfall which produced the flow, the hyetograph of the rainfall is also pruned by deducting the losses. The initial loss and infiltration losses are subtracted form it. .

The resulting hyetograph is know as effective rainfall hyetograph (*ERH*). It is also known as excess rainfall hyetograph.

Both *DRH* and *ERH* represent the same total quantity but in different units. Since *ERH* is usually in cm/h plotted against time, the area of *ERH* multiplied by the catchment area gives the total volume of direct runoff which is the same as the area of *DRH*. The initial loss and infiltration losses are estimated based on the available data of the catchment.

Q. 17. Given below are the ordinates of a 6 *h* unit hydrograph for a catchment. Calculate the ordinates of the *DRH* due to a rainfall excess of 3·5 cm occurring in 6 *h*.

Time (h)	0	3	6	9	12	15	18	24	30	36	42	48	54	60	69
UH ordinate (m³/s)	0	25	50	85	125	160	185	160	110	60	36	25	16	8	0

Solution : The desired ordinates of the *DRH* are obtained by multiplying the ordinates of the unit hydrograph by a factor of 3·5 as in table. The resulting *DRH* are also the unit hydrograph. The intervals of coordinates of the unit hydrograph are not in any way related to the duration of the rainfall excess and can be any convenient value.

Time (h) (1)	Ordinate of 6 h Unit hydrograph (m^3/s) (2)	Ordinate of 3·5 cm (3) *DRH* (m^3/s)
0	0	0
3	25	87·5
6	50	175
9	85	297·5
12	125	437·5
15	160	560
18	185	647·5
24	160	560
30	110	385
36	60	210
42	36	126
48	25	87·5
54	16	56
60	8	28
69	0	0

Q. 18. Derive the *S*-curve for the 4 h unit hydrograph given below :

Time (h)	0	4	8	12	16	20	24	28
Ordinate of 4-*h* UH (m^3/s)	0	10	30	25	18	10	5	0

Solution : Computations are shown in table. In this table Col. 2 shows the ordinates of the 4-*h* unit hydrograph. Col. 3 gives the *S*-curve additions and Col. 4 gives the ordinates of the *S*-curve. The sequence of entry in Col. 3 is shown by arrows. Values of entries in Col. 4 is obtained by using eqn. $S(t) = U(t) + S(t-D)$, by summing up of entries in Col. 2 and Col. 4 along each row.

Time in hours 1	Ordinate of 4-h 2	S-curve addition (m^3/s) 3	Su-curve ordinate (m^3/s) · (col. 2 + col. 3) 4
0	0	–	0
4	10	0	10
8	30	10	40
12	25	40	65
16	18	65	83
20	10	83	93
24	5	93	98
28	0	98	98

At $i = 4$ hours, ordinate of 4-*h* $UH = 10$ m^3/s

S-curve addition = ordinate of 4-*h* *UH* @

$\{t = (4-4) \neq 0 \text{ hours}\} = 0$

Hence *S*-curve ordinate Eqn.

$S(t) = U(t) + S(t-D) = 10 + 0 = 10$ m^3/s

At t = 8 hours, ordinate of 4-*h* $UH = 30$ m^3/s.

S-curve addition = ordinate of 4-*h* *UH* @

$\{t = (8-4) = 4 \text{ hours}\} = 10$ m^3/s

Hence *S*-curve ordinate eqn. = 30 + 10 = 40 m^3/s

At t = 12 hours, ordinate of 4-*h* $UH = 25$ m^3/s.

S-curve addition = ordinate of 4-*h* *UH* @

$\{t = (12-4) = 48 \text{ hours}\} = 40$ m^3/s

Hence *S*-curve ordinate eqn. = 25 + 40 = 65 m^3/s.

This calculations is repeated for all time intervals till t = base with of UH = 28 hours.

Q. 19. A catchment of 200 hectares area has rainfalls of 7·5 cm, 2 cm and 5 cm in three consecutive days. The average ϕ index can be assumed to be 2·5 cm/day. Distribution-graph percentages of the surface runoff which extended over 6 days for every rainfall of 1-day duration are 5, 15, 40, 25, 10 and 5. Determine the ordinates of the discharge hydrograph by neglecting the base flow.

Solution :

Time interval (days)	Rainfall (cm)	Infiltration loss (cm)	Effective rainfall (cm)	Aveg. distribution ratio (percent)	Distribution runoff for (rainfall excess) of 5 cm 0·25			Runoff cm $m^3/s \times 10^{-2}$	
0–1	7·5	2·5	5	5	0·250	0		0·250	5·79
1–2	2	2·5	0	15	0·750	0	0	0·75	17·3
2–3	5	2·5	2·5	40	2	0	0·125	2·75	49·1
3–4				25	1·250	0	0·375	2·125	37·62
4–5				10	0·500	0	1·00	1·625	34·7
5–6				5	0·250	0	0·625	1·50	20·2
6–7				0	0	0	0·250	0·87	5·79
7–8						0	1·25	0·250	2·89
8–9							0	1·25	0

[Runoff of 1 cm in 1 day = $\dfrac{200 \times 100 \times 100}{86400 \times 100}$ m^3/s for 1 day = 0·23148 m^3/s for 1 day.]

Q. 20. Explain a procedure of deriving a *D-h* unit hydrograph from the *IUH* of the catchment.

Ans. Consider an S-curve, designated as S_1, derived from a *D-h* unit hydrograph. In this the intensity of rainfall excess, $i = 1/D$ cm/h. Let S_2 be another S-curve of intensity i cm/h. If S_2 is separated from S_1 by a time interval dt and the ordinates are subtracted, a *DRH* due to a rainfall excess of duration dt and magnitude $idt = dt/Dh$ is obtained. A unit hydrograph of dt hours is obtained from this by dividing the above *DRH* by idt.

Thus the *dt-h* unit hydrograph will have ordinates equal to $\left(\dfrac{S_2 - S_1}{idt}\right)$. As dt is made smaller, as $dt \to o$, an *IUH* results. Thus for an *IUH*, the ordinate at any time t is

$$u(t) = \lim_{dt \to o} \left(\frac{S_2 - S_1}{idt}\right) = \frac{1}{i}\frac{dS}{dt} \qquad ...(1)$$

If $i = 1$, then $u(t) = dS'/dt$. ...(2)

where S' represents a S-curve of intenstity 1 cm/h. Thus the ordinate of an IUH at any time t is the slope of the S-curve of intensity 1 cm/h at the corresponding time. Equation (1) can be used in deriving IUH approximately.

IUH_S can be derived in many other ways notably by (i) harmonic analysis (ii) Laplace transform (iii) Conceptual models.

Derivation of D-hour Unit hydrograph From IUH : For simple geometric forms of IUH, equation $Q(t) = \int_0^{t'} u(t-\tau)\, I(\tau)\, d\tau$ can be used to derive a D-hour unit hydrograph.

From equation (2), $dS' = u(t)\ dt$

Integrating between two points 1 and 2

$$S'_2 - S'_1 = \int_{t_1}^{t_2} u(t)\, dt \qquad ...(3)$$

If $u(t)$ is essentially linear within the range 1–2, then for small values of $\Delta t = (t_2 - t_1)$, by taking

$$u(t) = \bar{u}(t) = \frac{1}{2}[u(t_1) + u(t_2)]$$

$$S'_2 - S'_1 = \frac{1}{2}[u(t_1) + u(t_2)](t_2 - t_1) \qquad ...(4)$$

But $(S'_2 - S'_1)/(t_2 - t_1)$ = ordinate of a unit hydrograph of duration $D_1 = (t_2 - t_1)$. Thus, in general terms, for small values of D_1, the ordinates of a D_1-hour unit hydrograph are obtained by the equation.

$$(D_1 - \text{hour } UH)_t = \frac{1}{2}[(IUH)_t + (IUH)_{t-D_1}] \qquad ...(5)$$

Thus if two IUH_S are lagged by D_1–hour where D_1 is small and their corresponding ordinates are summed up and divided by two, the resulting hydrograph will be D_1-hour UH. After obtaining the ordinates of a D-hour unit hydrograph from eqn. (5), the ordinates of any D-hour UH can be obtained by the superposition method.

From accuracy considerations, unless the limbs of IUH can be approximated as linear, it is desirable to confine D_1 to a value of 1-hour or less.

Q. 21. In a stream the base flow is observed to be 30 m^3/s on Feb. 1 and 23 m^{3}s on Feb. 10. If there is no rain during February, estimate the base flow on Feb. 28 and the volume of water in groundwater storage on Feb. 1 and Feb. 28. Assume base flow recession curve of the stream can be described by eqn. $Q_t = Q_o K_r^{(t-t_o)}$.

Solution :

$Q_o = 30$ m^3/S $\qquad t_o = 1$

$Q_t = 23$ m^3/S $\qquad t = 10$

$$\frac{Q_t}{Q_o} = K_r^{(t-t_o)}$$

$$\frac{23}{30} = K_r^{(10-1)} = K_r^{9}$$

$\therefore \qquad K_r = 0{\cdot}971$

when $\qquad t = 28, \qquad Q_t = Q_o\,(0{\cdot}971)^{(28-1)}$

$Q_1 = 30 \times 0{\cdot}971^{27} = 13{\cdot}52$ m^3/s.

$\therefore$ The flow in the stream on Feb. 28 = 13·52 m^3/s.

From eqn.

$$S_t = \frac{Q_t}{(-1_{nK_r})} = \frac{Q_t}{-1n0{\cdot}971} = 33{\cdot}98\,Q_t.$$

In the estimation of K_r a time unit of day has been used. Hence the storage computed from the above expression will be in cumec-days.

Storage on Feb. 1 $= 33{\cdot}98 \times 30 = 1019{\cdot}4$ cumec–days
$= 88{\cdot}08 \times 10^6$ m^3
$= 88{\cdot}08$ Mm^3

Storage on Feb. 28 $= 33{\cdot}98 \times 13{\cdot}52 = 459{\cdot}41$ cumec – days
$= 39{\cdot}69 \times 10^6$ m^3
$= 39{\cdot}69$ Mm^3

Q. 22. The peak of flood hydrograph due to a 3-h duration isolated storm in a catchment is 270 m^3/s. The total depth of rainfall is 5·9 cm. Assuming an average infiltration loss of 0·3 cm/h and a constant base flow of 20 m^3/s, estimate the peak of the 3-h unit hydrograph (UH) of this catchment.

If the area of the catchment is 567 km^2 determine the base width of the 3-h unit hydrograph by assuming it to be triangular in shape. (C.S.V.T.U. April-May, 2011)

Solution :

Duration of rainfall excess $= 3h$

Loss @ 0·3 cm/h for $3h$ = 0·9 cm

Total depth of rainfall = 5·9 cm

Rainfall excess = 5·9 – 0·9
= 5 cm.

Peak flow :

Peak of flood hydrograph = 270 m^3/s $\qquad$ Peak of DRH = 250 m^3/s

Base flow = 20 m^3/s

$$\text{Peak of 3-}h\text{ unit hydrograph} = \frac{\text{Peak of } DRH}{\text{rainfall excess}} = \frac{250}{5} = 50 \text{ m}^3/\text{s}$$

Let B = base width of the 3-h UH in hours.

Volume represented by the area of UH = Volume of 1 cm depth over the catchment

Area of UH = (Area of catchment × 1 cm)

$$\frac{1}{2} \times B \times 60 \times 60 \times 50 = 567 \times 10^6 \times \frac{1}{100}$$

$$B = \frac{567 \times 10^4}{9 \times 10^4}$$

$B = 63$ hours.

Q. 23. Derive a 3-h synthetic unit hydrograph of a basin with the following data : Basin area = 3000 km^2, Length of the main stream = 120 km; Distance from centroid of the basin to the outlet = 63 km. The synder's coefficients C_t and C_p may be assumed to be 1·60 and 0·64 respectively.

Solution :

$t_p = C_t\,(LL_C)^{0{\cdot}3}$
$= 1{\cdot}6\,(120 \times 63)^{0{\cdot}3}$

$t_p = 23{\cdot}32\ h$

$$D = t_p \times \frac{2}{11}$$
$$D = 4{\cdot}24\ h$$
$$D' = 3h$$
$$t'_p = t_p + \frac{D'-D}{4} = 23{\cdot}32 - 0{\cdot}31 = 23{\cdot}01\ h$$
$$q'_p = \frac{2{\cdot}778C_P}{t'_P} = \frac{2{\cdot}778\times 0{\cdot}64}{23{\cdot}01} = 0{\cdot}073\ \text{m}^3/\text{s/km}^2$$
$$Q'_P = A{\cdot}q'_P = 231{\cdot}9\ \text{m}^3/\text{s}$$
$$T' = \frac{5{\cdot}556}{q'_p} = \frac{5{\cdot}556}{0{\cdot}0773} = 71{\cdot}87\ \text{h} \approx 72h$$
$$W_{50} = \frac{2{\cdot}14}{(0{\cdot}0773)^{1{\cdot}08}} = 33{\cdot}98\ \text{h} \approx 34h$$
$$W_{75} = \frac{1{\cdot}22}{(0{\cdot}0773)^{1{\cdot}08}} = 19{\cdot}37h$$

Q. 24. From the topographical map of a drainage basin the following quantities are measured: $A = 3480$ km^2, $L = 148$ km and $L_C = 74$ km. The 12 *h* unit hydrograph derived for the basin has a peak ordinate of 155 m^3/s occurring at 40 *h*. Determine the coefficients C_t and C_p for the synthetic unit hydrograph of the basin.

Sol.

$$D' = 12h$$
$$t'_p = 40 - \frac{D'}{2} = 40 - 6 = 34h$$
$$t'_p = t_p + \frac{D'-D}{4}$$
$$D = \frac{2}{11}t_p$$
$$\therefore \quad 34 = t_p + \frac{12}{4} - \frac{1}{4}\left(\frac{2}{11}t_p\right)$$
$$t_p = 32{\cdot}48h$$
$$C_t = \frac{t_p}{(LL_C)^{0{\cdot}3}} = \frac{32{\cdot}48}{(148\times 74)^{0{\cdot}3}} = 1{\cdot}994$$
$$q'_p = \frac{Q'_p}{A} = \frac{155}{3480} = 0{\cdot}04454$$
$$C_p = \frac{q'_p t'_p}{2{\cdot}778}$$
$$C_p = \frac{0{\cdot}04454\times 34}{2{\cdot}778}$$
$$= 0{\cdot}545.$$

Ans.

Q. 25. A basin having a drainage area of 2500 km^2 with $L = 100$ km and $L_C = 50$ km is a sub-basin of the catchment of 12 *h* unit hydrograph of 155 m^3/s occurring at 40 *h*. Compute a 4 *h* synthetic unit hydrograph for this sub-basin.

Sol. The values of $C_t = 1{\cdot}994$ and $C_p = 0{\cdot}545$

$$t_p = C_t(LL_C)^{0{\cdot}3}$$
$$= 1{\cdot}994(100\times 50)^{0{\cdot}3}$$
$$= 25{\cdot}67h$$
$$D = \frac{2}{11}t_p = \frac{2}{11}\times 25{\cdot}67 = 4{\cdot}67h$$
$$D' = 4h$$
$$t'_p = t_p + \frac{D'-D}{4} = 25{\cdot}67 + \frac{4-4{\cdot}67}{4} = 25{\cdot}5h$$
$$q'_p = \frac{2{\cdot}778C_p}{t'_p}$$
$$= \frac{2{\cdot}778\times 0{\cdot}545}{25{\cdot}5} = 0{\cdot}0594\ \text{m}^3/\text{s}/\text{km}^2$$
$$Q_p = A\cdot q'_p = 2500\times 0{\cdot}0594$$
$$= 148{\cdot}5m^3/\text{s}$$
$$T' = \frac{5{\cdot}556}{q'_p} = \frac{5{\cdot}556}{0{\cdot}0594}$$
$$= 93{\cdot}5h$$
$$W_{50} = 2{\cdot}14(q'_p)^{-1{\cdot}08}$$
$$= \frac{2{\cdot}14}{(0{\cdot}0594)^{1{\cdot}08}} = 45{\cdot}2h$$
$$W_{75} = 1{\cdot}22(q'_p)^{-1{\cdot}08}$$
$$= \frac{1{\cdot}22}{(0{\cdot}0594)^{1{\cdot}08}} = 25{\cdot}7h.$$

Ans.

Q. 26. Derive a 3*h* synthetic unit hydrograph of a basin with the following data : Basin area = 3000 km^2, Length of the main stream = 120 km, Distance from centroid of the basin to the outlet = 63 km. The snyder's coefficients C_t and C_p may be assumed to be 1·60 and 0·64 respectively.

Sol.

$$t_p = C_t(LL_C)^{0{\cdot}3}$$
$$= 1{\cdot}6(120\times 63)^{0{\cdot}3} = 23{\cdot}32h$$
$$D = t_p \times \frac{2}{11} = 4{\cdot}24h$$