

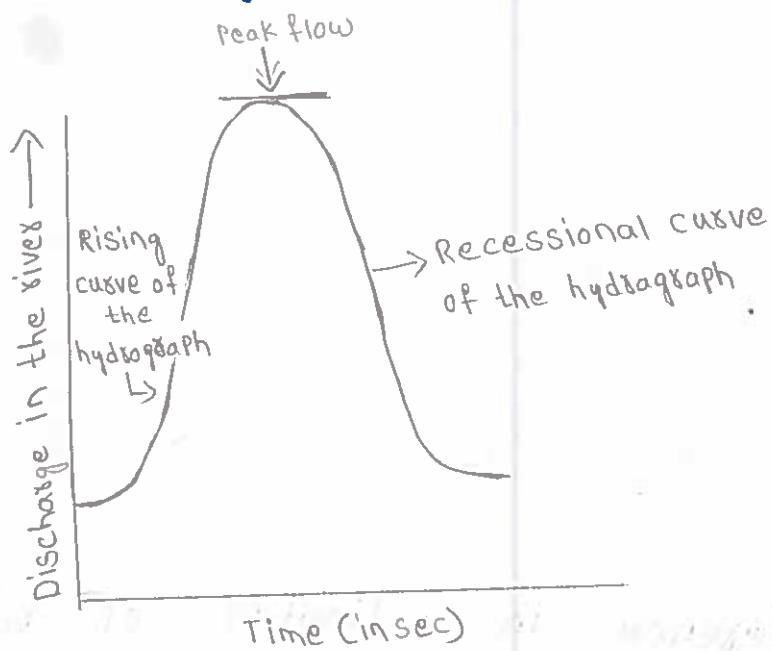
## UNIT-III Hydrographs

Ref Text book

saya Qamri azddy

Hydrograph:

- \* A hydrograph is the graphical representation of the discharge flowing in a river at the given location with specific time.
- \* A hydrograph is capable of representing discharge fluctuation in the river at a given site over given time period.
- \* Hydrograph gives us the peak flow, which is important for design of hydraulic structure.

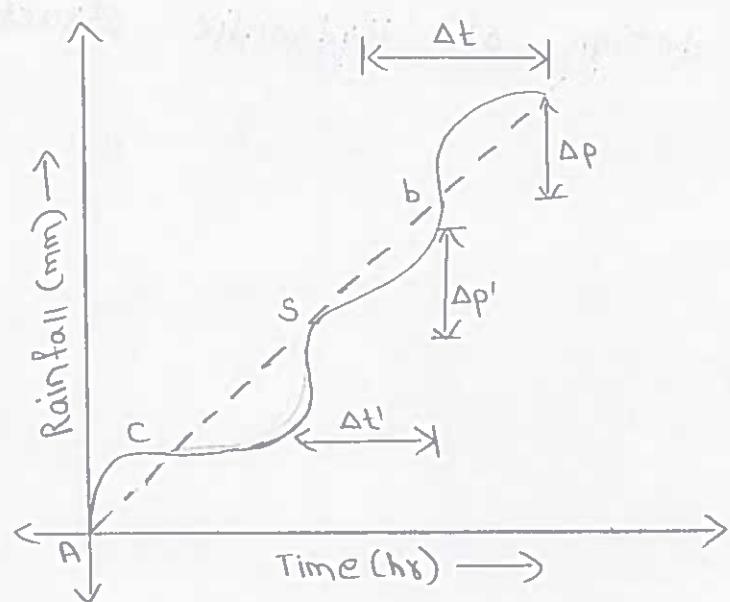


Components of Hydrograph:

- i. Rising limb
- ii. Falling limb
- iii. crest segment
- iv. Inflection point
- v. crest

## Rainfall hyetograph:

- \* A graph showing the variation of rainfall intensity against time is called rainfall hyetograph.
- \* A graph showing the cumulative depth of rainfall against time is called as rainfall mass curve.
- \* The data on the rainfall mass curve corresponds to the values obtained from the float type recording rain gauge.



- \* The difference in ordinates of rainfall mass curve are:

$$\Delta p = (p_2 - p_1) \text{ and } \Delta t = (t_2 - t_1)$$

The slope of tangent drawn to the rainfall mass curve at any particular point provides the instantaneous rainfall intensity at that particular time.

$$\therefore L = \lim_{\Delta t \rightarrow 0} \frac{\Delta P}{\Delta E} = \frac{dp}{dt}$$

Factors affecting flood hydrograph:

Flood hydrograph shows stream flow due to a storm over a catchment.

The factors that affects the shape of the hydrograph are:

1. Shape and size of basin
2. Nature of the Valley
3. Density of drainage
4. Infiltration characteristic
5. Channel characteristic
6. Climatic factors

Generally the rising limb is affected by the climatic factors and recession limb is affected by the physiographic factor.

Flood hydrograph:

The hydrograph which results due to an isolated storm is typically single-peaked skew distribution of discharge and is known as flood hydrograph.

Describe how the recession constants of direct runoff and base flow curves are obtained from a semilogarithmic plot.

\* The runoff hydrograph is a smooth curve known as the base flow recession curve.

\* In a semilogarithmic plot of the recession curve with time on x-axis and discharge on y-axis and it takes the form of a straight line.

\* Base flow is given by

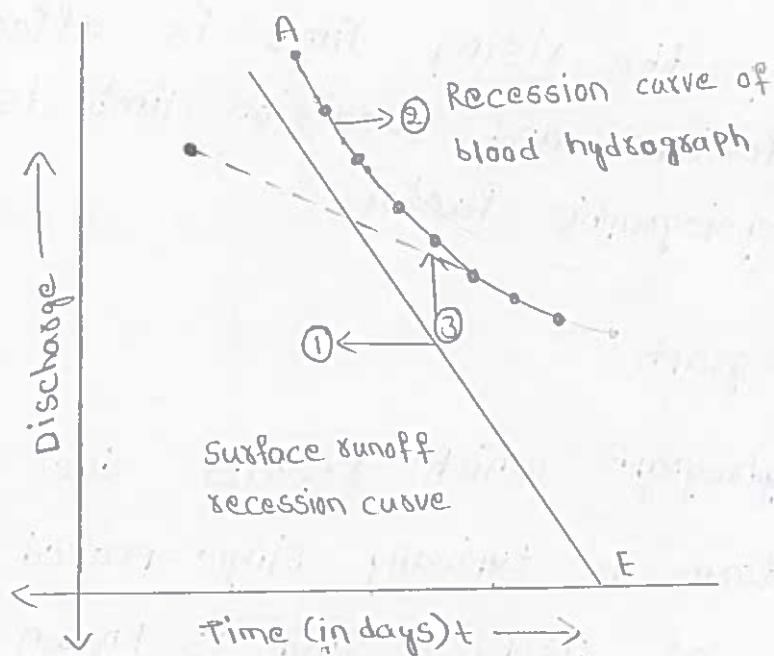
$$Q = Q_0 e^{-\alpha t}$$

where,

$Q_0$  = Base flow at time  $t=0$

$Q$  = Base flow at any later time ' $t$ '

$\alpha$  = A recession constant

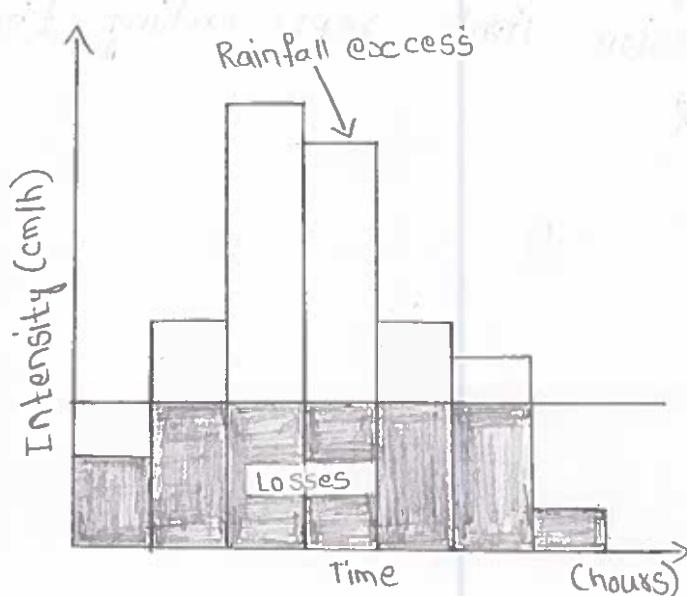


\* The recession curve of direct runoff may be estimated from the equation

$$Q(t + \Delta t) = (K)_{IS}^{\Delta t} \cdot q_t$$

## Effective Rainfall:

- \* It is that part of the rainfall which becomes the direct runoff at the outlet of the catchment.
- \* It can be defined as that rainfall which is neither retained on the land surface nor infiltrated into the soil.
- \* There is hyetograph of a storm, the initial loss and infiltration loss are subtracted from it.



Effective Rainfall Hyetograph (ERH)

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

$$\text{Effective rainfall} = \frac{\text{Direct runoff volume}}{\text{Area of catchment}}$$

## Base Flow separation:

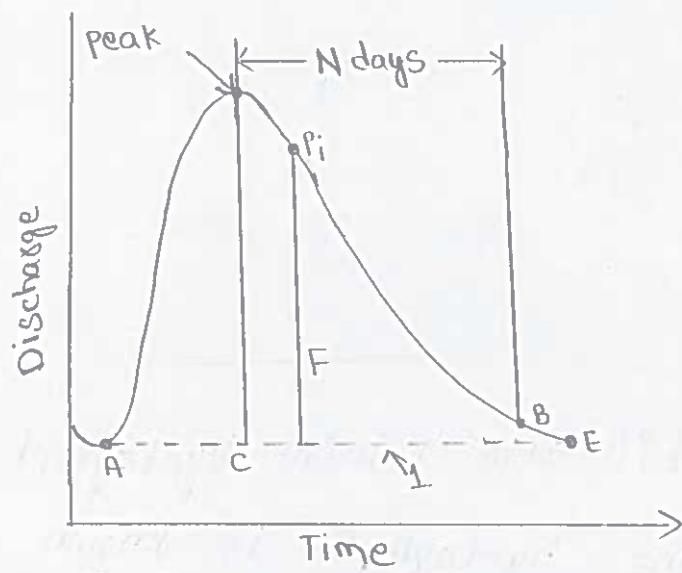
- \* In many hydrograph analysis a relationship between the surface flow and effective rainfall

is to be established so that base flow is to be deducted from the total storm hydrograph to obtain the surface flow hydrograph.

\* There are many method of base flow separation three of them are commonly used.

Method - 1: Straight line method

\* In this technique the separation of the base flow is achieved by joining a straight line from the beginning of the surface runoff of a point on the recession limb representing the end of direct runoff.



Base flow separation method

\* Point B, marking the end of direct runoff is difficult to locate in comparison to point A, which is the marking of beginning of surface runoff.

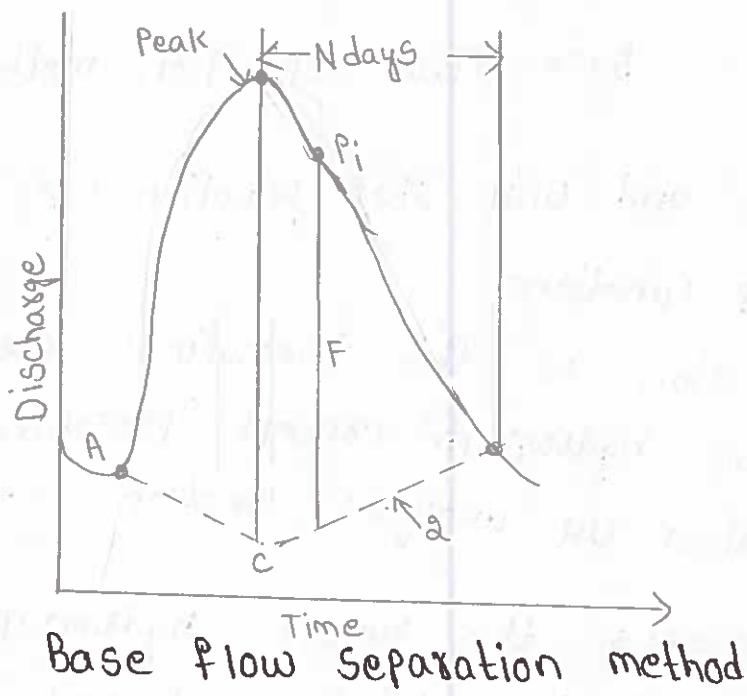
$$N = 0.83A^{0.2}$$

$N$  = Time interval in between peak and B.  
(in days)

$A$  = Drainage area (in  $\text{km}^2$ )

### Method - 2:

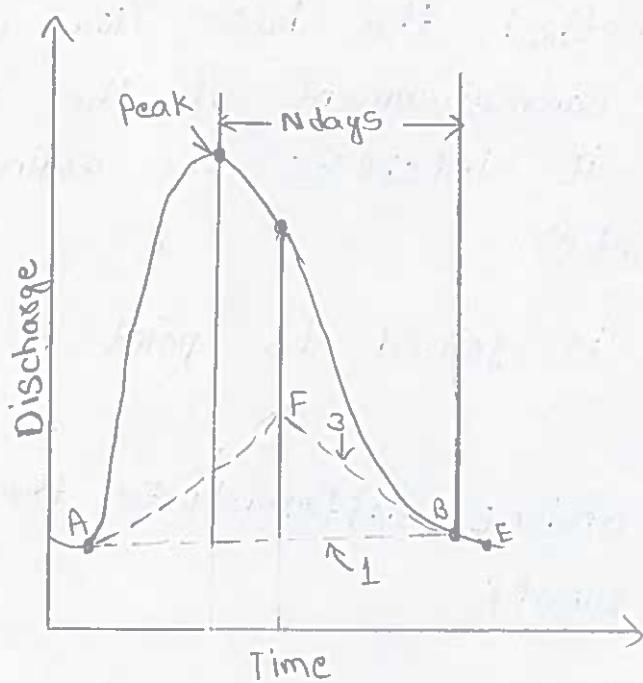
- \* In this method the base flow curve existing prior to the commencement of the surface runoff extended till it intersects the ordinate drawn at the peak (Point C).
- \* This point is joined to point B by a straight line.
- \* Segment AC and CB differentiate the base flow and surface runoff.



### Method 3:

- \* The base flow recession curve after the depletion of the flood water is extended backward till it cuts the ordinate at the point of inflection (ordinate at P line EF).
- \* Point A and F are joined by an arbitrary smooth curve.
- \* This method is realistic in these situations where the ground water contribution are significant.

and reach the stream quickly.



Base flow separation method

### Unit pulse and unit step Function

#### 1. Unit step function:

\* This function is the theoretical counterpart to the S-curve hydrograph concept presented earlier in the empirical UH analysis section.

\* It represents the runoff hydrographs from a continuous effective rainfall of unit intensity.

\* As can be seen from its definition. It is the convolution of I and  $u(t)$ . and obtained as,

$$g(t) = \int_0^t u(t') dt'$$

#### 2. Unit pulse function:

\* This is the theoretical counter part to the UH concept presented earlier.

\* It represents the runoff hydrograph from a constant effective rainfall of intensity  $\frac{I}{\Delta t}$  and of

duration  $\Delta t$ .

$$h(t) = \frac{1}{\Delta t} [q(t) - q(t - \Delta t)]$$

$$= \frac{1}{\Delta t} \int_{t-\Delta t}^t u(i) di$$

\* From its definition, the unit pulse function can be seen as the normalized difference between two lagged unit function. Lagged by an amount  $\Delta t$ .

### Unit Hydrograph

Unit hydrograph with its applications and limitations:

Definition:

- \* The concept of a unit hydrograph initially called unit graph.
- \* A unit hydrograph is defined as the hydrograph of direct runoff resulting from one unit depth of rainfall excess occurring uniformly over the basin and a uniform rate for a specified duration.

The term unit here refers to a unit depth of rainfall excess which is usually taken as 1cm.

Applications of unit hydrographs:

It is useful in study of hydrology of a catchment as,

- \* In the development of flood hydrograph for extreme rainfall magnitude.

- \* In extension of flood-flow records based on rainfall records.

\* In development of flood forecasting and warning system based on rainfall.

Limitations of unit hydrograph:

\* Unit hydrograph assumes uniform distribution of rainfall over the catchment and the intensity of rainfall is assumed constant for the duration of rainfall excess. In practice these two conditions are never strictly satisfied.

\* Unit hydrograph method cannot be used for a catchment area greater than  $5000 \text{ km}^2$  and less than  $2 \text{ km}^2$ .

\* Snowmelt runoff cannot be satisfactorily represented by unit hydrograph.

\* The catchment should not have large storage which affects the linear relationship between storage and discharge.

Derivation of unit Hydrograph:

For finding the unit hydrograph from the given flood hydrograph following steps are to be taken.

Step 1: From the given flood hydrograph, separate the base flow from it and make it direct runoff hydrograph.

Total storm hydrographs ordinate

$$\begin{aligned} &= \text{Direct runoff hydrographs ordinate} \\ &\quad + \text{Base flow's ordinate.} \end{aligned}$$

Step 2: Determine the volume of direct runoff hydrograph [value of DRH = Area under DRH]

Step 3: Divide the value of direct runoff by the catchment area, this gives us the rainfall.

Rainfall excess =  $\frac{\text{Volume of direct runoff}}{\text{catchment area}}$

Step 4: divide the ordinate of DRH by the depth of rainfall, gives us the ordinate of unit hydrograph.

#### S-Hydrograph:

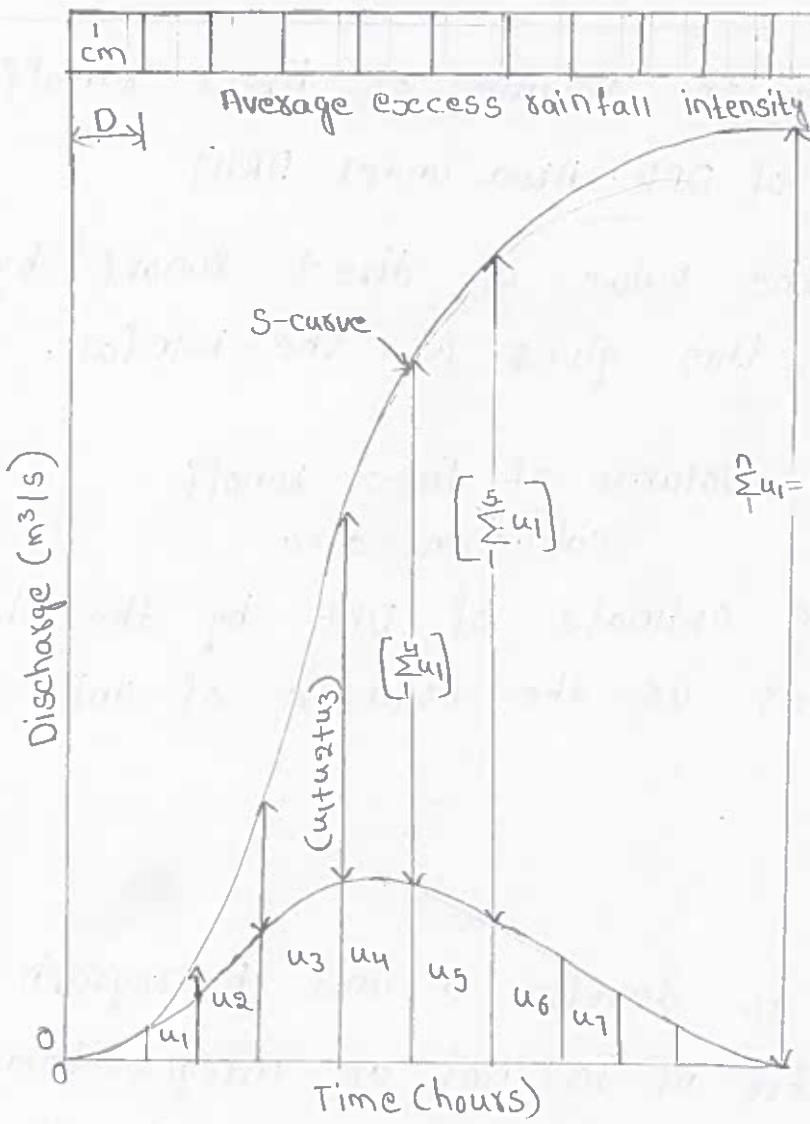
- \* If we want to develop a unit hydrograph of duration  $mD$ , here  $m$  is not an integer, then we can't apply the method of super position. Here we use S-curve technique.

- \* The S-curve is a hydrograph produced by a continuous rainfall at a constant rate for an infinite period. It is also known as s-hydrograph.

- \* It is a curve obtained by summation of an infinite series of D-h unit hydrographs spaced D-h apart.

- \* The S-curve due to a D-h unit hydrograph, has an initial step portion and reaches a maximum equilibrium discharge as a time equal to the base period of first unit hydrograph.

- \* So the number of unit hydrograph required to produce S-curve is  $= \frac{T_B}{D}$



Where,

$T_B$  = Base period of first unit hydrograph

$O$  = Time period of first storm.

\* The equilibrium discharge from the S-curve is

$$Q_s = \left[ \frac{A}{D} \times 10^4 \right] m^3/h$$

$Q_s$  = Equilibrium discharge ( $m^3/h$ )

$A$  = Area of catchment ( $km^2$ )

$D$  = Duration of storm (hrs)

Alternatively.

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

## Synthetic Unit Hydrograph

Synthetic unit hydrograph - Synder's method:

- \* To develop unit hydrograph for a catchment, we need detailed information about the rainfall and resulting flood hydrograph.
- \* Majority of location in world, specially those which are at remote location, the data would normally be very scanty.
- \* For those area we construct the unit hydrograph with the help of empirical equation, such a unit hydrograph is called synthetic unit hydrograph.
- \* Synder developed a set of empirical equation for construction of synthetic unit hydrograph. Which is known as Synder's synthetic unit hydrograph. Synder selected three important parameters for construction of SUH.

1. Base width ( $T$ )

$$T = 0.32 + 3t_p \text{ (in hours)}$$

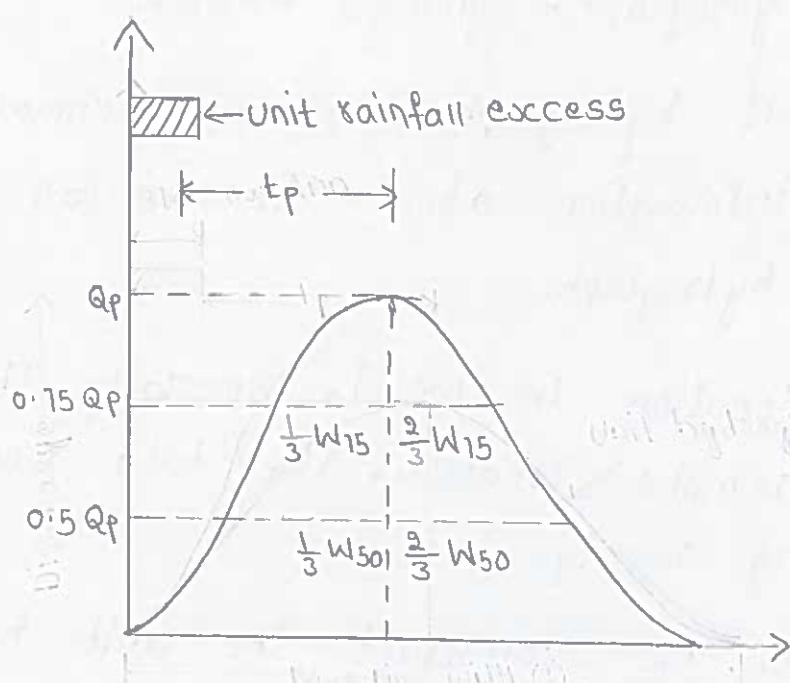
2. Peak discharge ( $Q_p$ )

$$Q_p = 2.78 C_p \frac{A}{t_p}$$

3. Lag time ( $t_p$ )

- \* It represent the mean time of travel of water from all parts of catchment of the outlet during given storm.

$$t_p = C_f (L \cdot L_c)^{0.3}$$



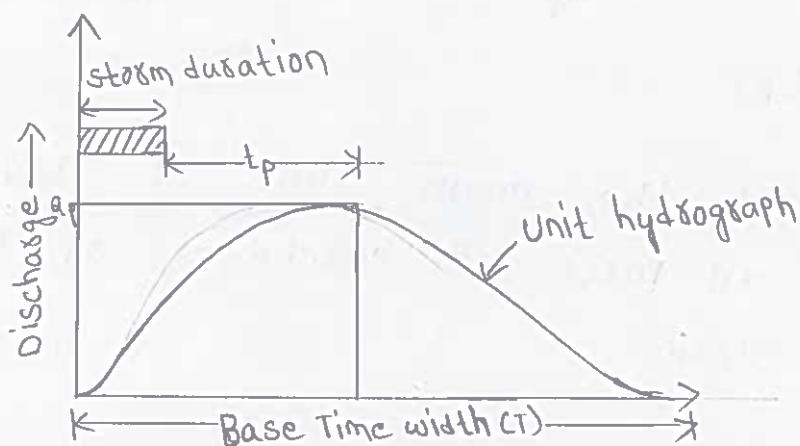
Where

$L$  = Length of main stream in the catchment upto gauging site (in km)

$L_c$  = The distance along the main stream from the gauging site to a point on the stream which is nearest to the centroid of the basin (in km).

$C_f$  = Regional constant representing the watershed slope and storage ( $C_f$  varies from 0.3 to 6)

$W_{75}$  = Width of graph in hours at 75% of peak discharge.



## Numericals

The 3h unit hydrograph of a basin with an area of  $20 \text{ km}^2$  at one hour interval are as below 0, 0.41, 1.38, 4, 7.72, 10.06, 9.24, 6.62, 4.57, 3.86, 2.76, 2.07, 1.38, 0.83, 0.41, 0.

If the rainfall excess with intensity of  $2 \text{ cm/h}$  for a period of 4h followed immediately by another 3h storm with an intensity of  $1 \text{ cm/h}$  occurs on the basin, what is the peak flow produced by this rainfall and at which time after the commencement of rainfall would this peak flow occurs? Assume base flow is negligible.

Intensity of rainfall,  $I_1 = 2 \text{ cm/hr}$  and  $I_2 = 1 \text{ cm/hr}$

Durations,  $D_1 = 4 \text{ hrs}$  and  $D_2 = 3 \text{ hrs}$

Effective rainfall in 1st time interval is given by

$$P_1 = I_1 D_1 [\text{in-cm}]$$

$$P_1 = 2 \times 4 = 8 \text{ cm}$$

Effective rainfall 2nd time interval is given by,

$$P_2 = I_2 D_2 = 1 \times 3 = 3 \text{ cm}$$

Time h(1)	ordinates of $Q_H$ in $m^3/s$		Combined Hydrograph $Q$ ( $m^3/s$ ) (4)	$U = P/Q$ substituting value 'U' $Q_n = P_n U_n$
	Without lag (2)	Lagged by 3h (3)		
0	0		0	$U_1 = 0$
1	0.41		0.41	$U_2 = 0.0512$
2	1.38		1.38	$U_3 = 0.153$
3	4	0	4	$U_4 = 0.442$
4	7.72	0.41	8.13	$U_5 = 0.851$
5	10.06	1.38	11.44	$U_6 = 1.111$
6	9.24	4	13.24	$U_7 = 1.238$
7	6.62	7.72	14.34	$U_8 = 1.328$
8	4.51	10.06	14.63	$U_9 = 1.331$
9	3.86	9.24	13	$U_{10} = 1.126$
10	2.76	6.62	9.38	$U_{11} = 0.751$
11	2.07	4.51	6.64	$U_{12} = 0.548$
12	1.38	3.86	5.24	$U_{13} = 0.449$
13	0.83	2.76	3.59	$U_{14} = 0.280$
14	0.41	2.07	2.48	$U_{15} = 0.205$
15	0	1.38	1.38	$U_{16} = 0.095$
16		0.83	0.83	$U_{17} = 0.068$
17		0.41	0.41	$U_{18} = 0.026$

Note: Direct runoff  $Q_1 = P_1 U_1$  and further calculated by,

$$Q_2 = P_1 U_2 + P_2 U_2$$

$$Q_3 = P_1 U_3 + P_2 U_2$$

$$Q_4 = P_1 U_4 + P_3 U_3$$

$$\text{upto } Q_{18} = P_1 U_{18} + P_2 U_{17}$$

the peak discharge and time to peak in a 3h unit hydrograph derived for a basin of area  $250 \text{ km}^2$  with  $L = 30 \text{ km}$  and  $L_c = 14 \text{ km}$  are  $50 \text{ m}^3/\text{s}$  and 9h respectively. Assuming that Synder's synthetic unit hydrograph applies determine the coefficient  $c_f$  and  $c_p$ . Determine the 2h unit hydrograph for the upper  $180 \text{ km}^2$  of the same water shed which has  $L = 20 \text{ km}$  and  $L_c = 11.8 \text{ km}$ .

Given: Peak discharge,  $Q_p = 50 \text{ m}^3/\text{s}$

Base width,  $T_b = 3 \text{ hours}$

Basin lag in hours,  $t_p = 9 \text{ hours}$

Distance from station to catchment,  $L = 30 \text{ km}$  and  $L_c = 14 \text{ km}$ .

i. peak discharge,

$$Q_p = \frac{2.778 \times c_p A}{t_p}$$

$$50 = \frac{2.778 \times 250 c_p}{9}$$

$$C_p = 0.6479$$

$$\text{ii. } t_p = C_f (L_c \cdot L)^{0.3}$$

$$q = C_f (14 \times 30)^{0.3}$$

$$C_f = 1.47$$

Now,  $T_b = 2 \text{ hours}$ ,  $A = 180 \text{ km}^2$

$$L = 20 \text{ kN}, L_c = 11.8 \text{ km}$$

For second drainage basin,

$$t_p = C_f (L \cdot L_c)^{0.3}$$

$$t_p = 1.47 (20 \times 11.8)^{0.3}$$

$$t_p = 7.571$$

Standard duration:

$$t_s = \frac{t_p}{5.5} = \frac{7.571}{5.5} = 1.37 \text{ h}$$

Non-standard duration of rainfall of 2 hours.

$$t_{ps} = \frac{21}{22} t_p + \frac{t_s}{4}$$

$$t_{ps} = \frac{21}{22} \times 7.571 + \frac{2}{4}$$

$$t_{ps} = 7.727 \text{ h}$$

Peak discharge for  $t_s = 2 \text{ h}$  is given by,

$$\begin{aligned} Q_{ps} &= 2.778 C_p \frac{A}{t_{ps}} \\ &= 2.778 \times 0.648 \times \frac{180}{7.727} \end{aligned}$$

$$Q_{p8} = 41.93 \text{ m}^3/\text{s}$$

$$\text{Peak time} = t_{\text{peak}} = t_{p8} + \frac{t_k}{2} = 7.727 + \frac{2}{2} = 8.727 \text{ h}$$

A drainage basin has an area of  $3800 \text{ km}^2$ .

Determine

- Lag period
- peak discharge
- base period

of a 9 hour unit hydrograph from the following data:

$$L = 320 \text{ km}, L_{ca} = 200 \text{ km}, C_f = 0.9, C_p = 4$$

$$\text{Given: Area } A = 3800 \text{ km}^2,$$

$$\text{Length of the main stream} = L = 320 \text{ km}$$

Distance from basin outlet to the centroids

$$L_{ca} = 200 \text{ km}$$

$$C_f = 0.9, C_p = 4.0$$

i. Lag period :

$$t_p = C_f (L L_{ca})^{0.3}$$

$$t_p = 0.9 (320 \times 200)^{0.3}$$

$$\therefore t_p = 24.89 \text{ hrs}$$

ii. peak discharge :

$$Q_p = \frac{2.78 C_p \cdot A}{t_p} = \frac{2.78 \times 4 \times 380}{24.89}$$

$$= 1697.70 \text{ cumecs}$$

$$q_p = \frac{Q_p}{A} = \frac{1697.70}{3800}$$

$$= 0.447 \text{ cumecs/km}^2$$

iii. Base period:

$$T = 3 + 3 (t_p/24)$$

$$T = 3 + 3 (24.89/24)$$

$$T = 6.11 \text{ days}$$

A drainage basin has an area of  $1700 \text{ km}^2$ . construct a 6 hours unit hydrograph, the data is given below,

Length of the longest water course =  $82 \text{ km}$  from another catchment, which is meteorologically homogeneous, the constant obtained  $C_f = 1.2$ ,  $C_p = 5$ .

Length along the main water course from the gauging station to a point opposite the centroid of the basin =  $48 \text{ km}$ .

Given: Area,  $A = 1700 \text{ km}^2$

Length of the main stream,  $L = 82 \text{ km}$

Distance from basin outlet to the centroid,  $L_c = 48 \text{ km}$

$C_f = 1.2$ ,  $C_p = 5$ ,  $t_x = 6 \text{ hours}$

i. Lag period,

$$t_p = C_f (L \cdot L_c)^{0.3}$$

$$t_p = 1.2 (82 \times 48)^{0.3}$$

$$t_p = 14.37 \text{ hours}$$

$$t_8 = \frac{t_p}{5.5} = \frac{14.37}{5.5} = 2.61 \text{ hours}$$

$$t_{pr} = t_p + \frac{t_8 - t_p}{4}$$

$$t_{pr} = 14.37 + \frac{6-2.61}{4}$$

$$t_{pr} = 15.225 \text{ hours}$$

ii. Peak flow:

$$Q_p = C_p \times \frac{A}{t_p}$$

$$Q_p = 5 \times \frac{1700}{14.378}$$

$$\therefore Q_p = 591.181 \text{ cumecs}$$

iii. Peak time:

$$\begin{aligned} t_{peak} &= t_{pr} + \frac{t_8}{4} \\ &= 15.225 + 6/2 \\ &= 18.225 \text{ hours} \end{aligned}$$

iv. Base time:

$$T = 3 + 3 \left[ \frac{t_p}{24} \right] = 3 + 3 \left[ \frac{14.37}{24} \right]$$

$$T = 4.78 \text{ hours}$$

v. peak discharge:

$$Q_p = q_p \times A$$

$$q_p = \frac{Q_p}{A} = \frac{591.18}{1700}$$

$$q_p = 0.348$$

$$V_i \cdot W_{50} = \frac{5.6}{(q_p)^{1.08}} = \frac{5.6}{(0.348)^{1.08}}$$

$$= 17.51 \text{ days}$$

$$W_{75} = \frac{3.21}{(q_p)^{1.08}} = \frac{3.21}{(0.348)^{1.08}}$$

$$= 10.037 \text{ days}$$

A 6h unit hydrograph of a basin has a peak ordinate of  $96 \text{ m}^3/\text{s}$  when the base flow in the stream is  $25 \text{ m}^3/\text{s}$ , and when the basin has reached its minimum infiltration capacity of  $2.5 \text{ mm/h}$ , a 6h storm with  $18.3 \text{ cm}$  of total rainfall had occurred on the basin. What is the magnitude of the peak discharge in the flood hydrograph produced by this storm?

Given:

$$\text{Storm duration} = 6\text{h}$$

$$\text{Total rainfall depth} = 18.3\text{cm}$$

$$\text{Infiltration loss at } 0.25 \text{ cm/h for 6h}$$

$$= 0.25 \times 6$$

$$= 1.5\text{cm}$$

$$\text{Excess rainfall} = 18.3\text{cm} - 1.5\text{cm}$$

$$= 16.8\text{cm}$$

Magnitude of peak discharge:

$$1. \text{ peak ordinate} = 96 \text{ m}^3/\text{s}$$

$$2. \text{ Base flow} = 25 \text{ m}^3/\text{s}$$

$$3. \text{ Peak of DRH} = 96 - 25 = 71 \text{ m}^3/\text{s}$$

$$\therefore \text{Peak discharge for } 6\text{-UH} = \frac{\text{Peak of DRH}}{\text{Excess rainfall}}$$

$$= \frac{71}{16.8} = 4.22 \text{ m}^3/\text{s}$$

Magnitude of peak discharge of 6h-UH =  $4.22 \text{ m}^3/\text{s}$

The following are the ordinates of a 6hr UG for a basin.

Time(hs)	0	6	12	18	24	30	36	42	48
6hr.UG0	0	20	56	98	127	147	156	154	140
Time(hs)	54	60	66	72	78	84	90	96	
6hr.UG0	122	107	93	78	65	52	41	30	
Time(hs)	102	108	114	120	126	132	138	144	
6hr.UG0	20.7	14.5	10	6.7	4.5	2.2	1.1	0	

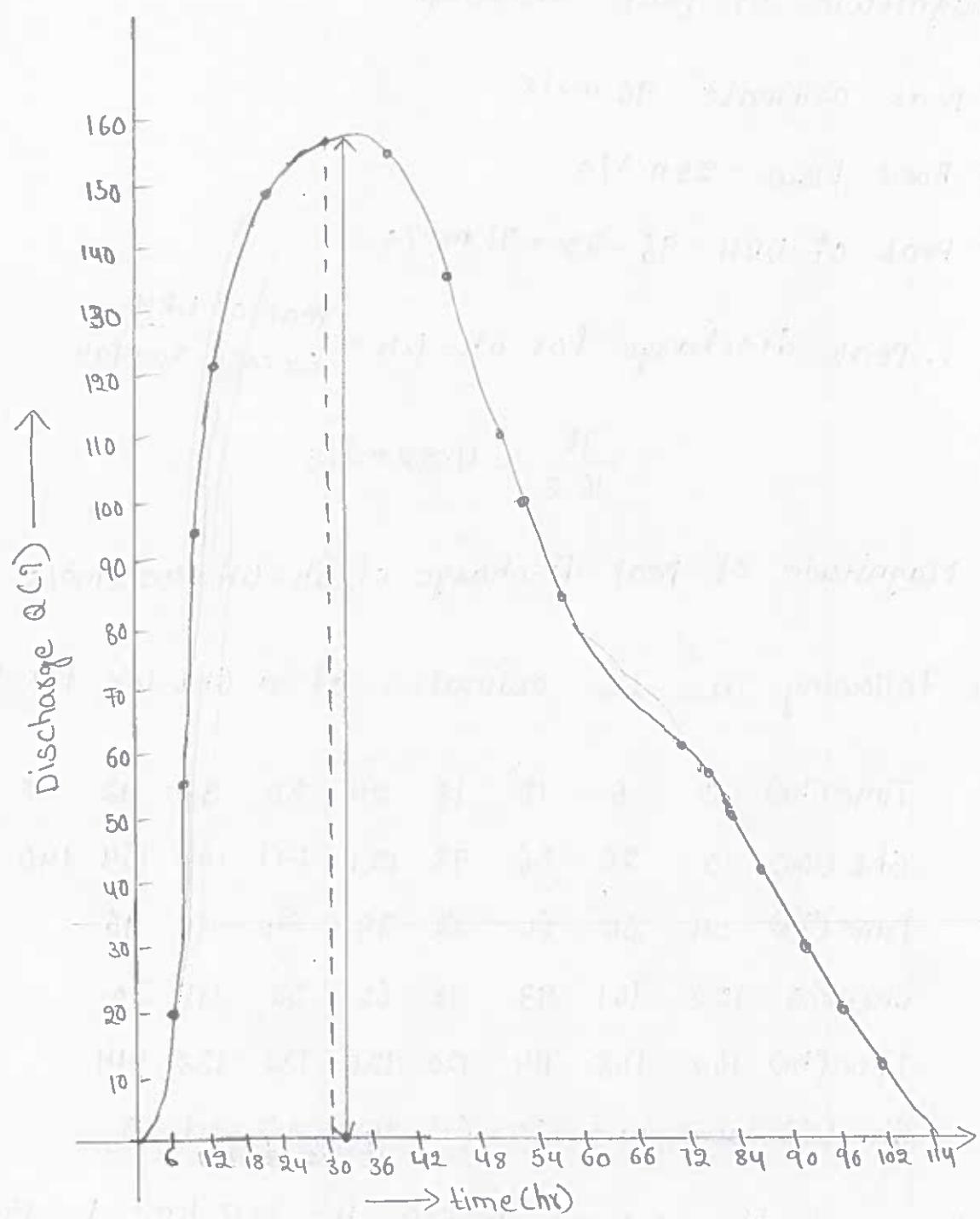
Details of the gauged basin:  $A = 3230 \text{ km}^2$ ,  $L = 150 \text{ km}$ ,  $L_{ca} = 76 \text{ km}$  another basin which is meteorologically and hydrologically similar has the following details. Derive a 6 hours synthetic-unit hydrograph for the ungauged basin.

Given:

Area of gauged basin =  $3230 \text{ km}^2$

Length of gauged basin =  $150 \text{ km}$

$L_{ca} = 76 \text{ km}$



$$1. \quad t'_{p8} = \frac{t_p}{5.5} = \frac{33}{5.5} = 6$$

$$t'_{p8} = 6 \text{ hrs}$$

$$\therefore t_{p8} = 33$$

$$2. \quad t_{p8} = t_p + \frac{t'_8 - t_8}{4}$$

$$33 = t_p + \frac{6 - t_p / 5.5}{4}$$

$$4 \times 33 = t_p + \frac{6 - t_p}{5.5}$$

$$132 = 3.818 t_p + 6$$

$$t_p = 33.002 \text{ hrs}$$

$$3. t_p = C_f (L L_{ca})^{0.3}$$

$$33.002 = C_f (150 \times 76)^{0.3}$$

$$C_f = 2.002$$

#### 4. Peak flow

$$Q = C_p \frac{A}{t_{p8}}$$

$$156 = C_p \times \frac{3230}{33}$$

$$C_p = 1.594$$

$$5. t_8 = \frac{t_p}{5.5} = \frac{33.002}{5.5} = 6$$

$t_8 = 6 \text{ hrs}$  for 6 h of unit hydrograph  $t'_8 = 6$

$$t_{p8} = t_p + \frac{t'_8 - t_8}{4} = 33.002$$

#### 6. peak flow,

$$Q = C_p \frac{A}{t_{p8}} = 1.594 \times \frac{3230}{33.002}$$

$$= 156.009 \text{ cumec}$$

Peak time from the starting of rise of limb,

$$t_{peak} = t_{p8} + \frac{t_8}{2} = 33.002 + \frac{6}{2} = 36.002 \text{ hrs}$$

Time base (in days)

$$T = 3 + 3 \left( \frac{t_{p8}}{24} \right) = 3 + 3 \left( \frac{33.002}{24} \right)$$

$$= 7.125 \text{ days and } 171 \text{ hours}$$

The width of 6hrs unit hydrograph at 50% and 75% of peak ordinates are as follows:

$$q_p = \frac{Q_p}{A} = \frac{156.009}{3230} = 0.048 \text{ cumec/cm}^2$$

$$W_{50} = \frac{5.6}{(q_p)^{1.08}} = \frac{5.6}{(0.048)^{1.08}} = 148.747 \text{ days}$$

$$W_{75} = \frac{3.21}{(q_p)^{1.08}} = \frac{3.21}{(0.048)^{1.08}} = 85.264 \text{ days}$$

The ordinate of 6hrs UH are given derive the 12hrs UH Time (hr) 0, 6, 12, 18, 24, 30, 36, 42, 48, 54, 60 12hrs (UG10) discharge (cumecs) 0, 5, 13, 30, 35, 32, 20, 14, 8, 4, 0.

Ans: Calculations:

Time (1)	12hrs (UG10) discharge (cumecs) (2)	Base flow (3)	DRH (4)	UH $\frac{\text{col}1\cdot4}{\text{DRD}}$
0	0		0	0
6	5	5	0	0
12	13	5	8.5	7.54
18	30	5	25	23.58
24	35	5	30	28.30
30	32	5	27	25.47
36	20	5	19	14.15
42	14	5	9	8.49
48	8	5	3	2.83
54	4	5	-1	-0.94
60	0	5	-5	-4.71

$$\sum O = \sum U =$$

$$111 \quad 104.71$$

Assuming base flow =  $5 \text{ m}^3/\text{s}$

$$\text{Direct runoff depth} = \frac{0.36 \times \sum Oxt}{A} = 1.06 \text{ cm}$$

$$\sum O = 111, t = 12 \text{ hrs}, A = 450 \text{ km}^2$$

$$\therefore DRD = \frac{0.36 \times \sum Uxt}{A}$$

$$= \frac{104.71 \times 0.36 \times 12}{450} = 1 \text{ cm}$$

The ordinate of 6hrs UH are given, derive the 12hrs UH

Time (hrs)	0	6	12	18	24	30	36	42	48	54	60	66	72
14hrs (UG10) discharge (cumec)	0	5	13	30	35	32	20	14	8	4	5	6	0

Ans: calculations

Time	14hrs (UG10) discharge (cumec) (2)	Base flow (3)	DRH (4) (2) - (3)	UH column (4) DRD (5)
0	0		0	0
6	5	5	0	0
12	13	5	8	5.88
18	30	5	25	18.38
24	35	5	30	22.05
30	32	5	27	19.85
36	20	5	15	11.02
42	14	5	9	6.61
48	8	5	3	2.20
54	4	5	-1	-0.73
60	5	5	0	0
66	6	5	1	0.73
72	0	5	5	3.67

$$\Sigma D = 122 \sum U = 89.66$$

Assume base flow = 5 m<sup>3</sup>/sec

$$\text{Direct runoff depth} = \frac{0.36 \times \sum o_x t}{A}$$

$$= \frac{0.36 \times 122 \times 14}{450}$$

$$= 1.36 \text{ cm}$$

$$\text{ORD} = \frac{0.36 \times \sum o_x t}{A}$$

$$= \frac{0.36 \times 89.66 \times 14}{450}$$

$$= 1.00 \text{ cm}$$