31/12/18.

3. RUN-OFF

Runoff means the draining of precipitation from a catchement area through the surface channels. It is normally expressed as volume per unit time for a given area, represents the output from the catchment in a given unit of time.

* Characteristics of Runoff: / catchment

The total runoff from a typical catchement area may be divided into 4 parts

1. Direct precipitation / stream channels.
2. Surface runoff
3. Interflow
4. Groundwater flow.

* Direct precipitation / stream channels:

The precipitation on the water surface & into the stream channels will normally represent only a small percentage of total volume of water flowing in the stream

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* surface runoff

The precipitation over the land surface move as sheet flow, this portion of runoff is called over land flow. Normally the length & depth of over land flow is small and flow is laminar after travelling this small length over the ground they join a channel and become

turbulent due to high velocity in channel. The flow from several small channels join to make bigger channel and these bigger channel join to form large stream till the overall flow reaches the catchment outlet.

* Interflow

The part of precipitation that infiltrate into the soil moves gradually laterally and return to the surface at some location away from the point of entry to the soil is called "Interflow."

* Ground Water flow

Sometime infiltrated water is to undergo deep percolation and reach the ground water storage in the soil. The ground water follow a complicated path until finally reaches the surface.

* Classification of Runoff.

Based on the time delay blw the precipitation & the runoff, the runoff is classified as

1. Direct runoff
2. Base flow.

* Direct runoff

It is the part of runoff which enters the stream immediately just after the rainfall.

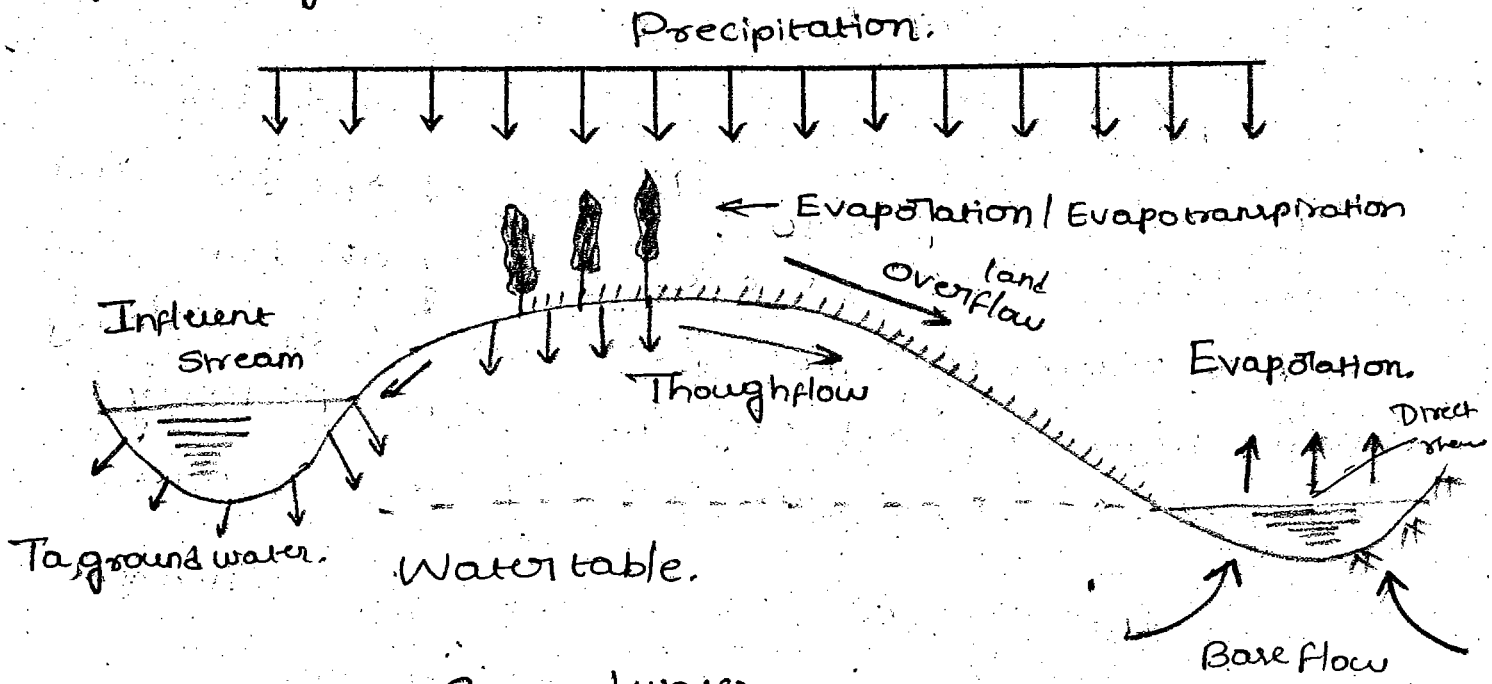
It includes

1. Surface runoff
2. Prompt inflow
3. Rainfall on surface of stream

- Resulting inflow due to snow melt into strom is called "Direct runoff."

* Baseflow

The delayed flow that reaches a stream generally as groundwater is called "Baseflow."



05/01/19.

* Factors effecting Runoff

The principal factors affecting the flow from a catchment area are

1. Precipitation characteristics.

This is the most important factor on which runoff depends. Important precipitation characteristics are

1. Intensity 2. duration 3. Areal distribution
4. Direction of strom movement 5. form of precipitation
6. Evapotranspiration

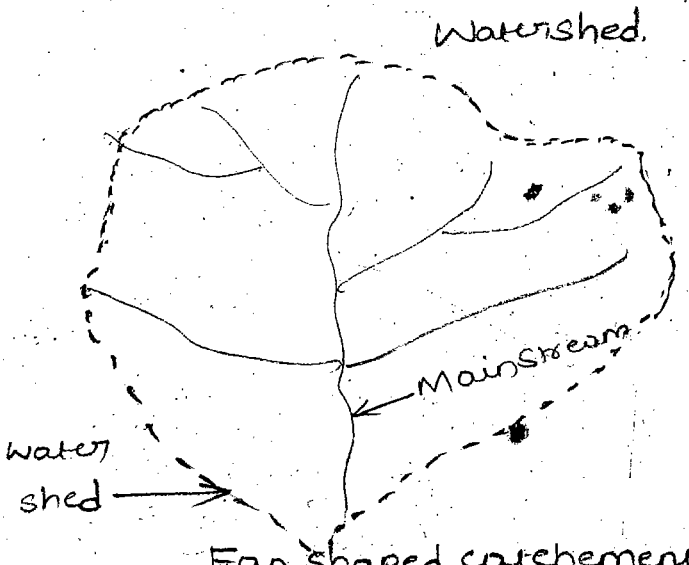
The runoff depends on the type of the strom causing precipitation and also upon it's duration. Runoff also increases with the intensity of rainfall.

2. Shape and Size of the catchement:

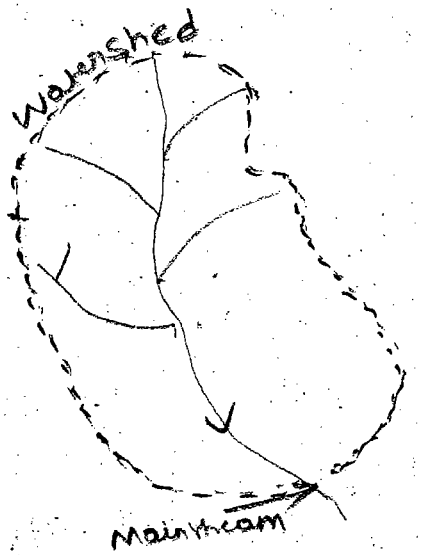
The runoff from a catchment also depends upon the size, shape and location of the catchement more intense rainfalls are generally distributed over a relatively smaller area. A stream collecting water from a small catchement area is likely to give greater runoff intensity per unit area.

In the case of fan (or) sector shape catchment all the tributaries are approximately of the same size. Such catchement gives greater runoff since the peak flood from the tributaries is likely to reach the mainstream approximately at the same time.

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Fan shaped catchement



Fern leaf catchement.

* Topography of catchment.

The runoff depends upon wheater the surface of the catchement is smooth (or) ruggle. If the surface slope is steep, water will flow quicky, and absorption, evaporation losses will be less. Resulting in greater runoff. If catchment is mountains and is on the windward side of the mountains the intensity of rainfall will be more. and hence runoff will also be more be more.

* Orentation of watershead

In orientation of watershead effects the evaporation and transpiration loss by influencing the amount of heat recieved from the sun. The N-S orientation of watershed effects the melting time of collected snow and hence the runoff. Similarly in mountains watershed the windward side of the mountain receives comparitively higher interse rainfall than the ~~leeward~~ Side leeward side.

* Geological characteristics of ~~building~~ basin

This is an important factor effecting the runoff these include the type of surface soil and subsoil, type of rock and their permeability characteristics. If the soil and subsoil is pervious seepage will be more. and this is term reduces the peak flood.. If the surface is rocky and the absorption will be practically nill. so the runoff will be more.

* Materological characteristics

Temperature, wind and humidity also effects the runoff. If the temperature is low the ground is saturated & Froozen, It gives rise to greater runoff However if the whole of the steel freezes the peak floods will be reduced.

On the other hand high temperature and greater wind velocity give rise to greater evapolation loss. and reduce the runoff

* The peak flood depends upon the direction of movement of the strom causig rainfall with relation to the direction of the stream

* Character of the catchement surface

The runoff depends upon the surface condition weather the surface is drained (or) undrained, natural (or) cultivated (or) it is covered with vegetation etc..... If the surface has known natural drainage, absorption loss will be more. If more area of a catchment is cultivated surface runoff will be less.

* Storage characteristics of cate

The artifical storage such as dams, reservoirs etc.... and natural storage such as lakes, ponds etc... tend to reduce the peak flow. They also give rise to greater evaporation losses.

04/01/2019.

Important definitions:

Stream density.

If N is the no. of streams in the basin and A is the total area of the basin. then

Stream density

$$D_s = \frac{N}{A} \cdot \left[\frac{\text{No. of streams}}{Km^2}\right]$$

Drainage Density:

It is defined as length of streams per unit area.

$$\text{Drainage density } (D_d) = \frac{L}{A} \left[\frac{L}{Km^2}\right]$$

* Time of Concentration

It is a drainage basin time required by water to reach the outlet from the remote point on the basin.

* Time of overland flow

Excess rainfall fines it's weight overland to the rivers stream and appears as surface run but only after some delay.

Another words there exist a lag b/w time and when excess rainfall occurs and the time when it appears as runoff at the outlet.

This lag is time for which water has flow through the basin before entering into a definete drain known as "Time of overland flow."

* Isochrome:

It is the line joining points of equal total time overland flow on a drainage basin

* Competation of Runoff

The using methods are

1. Using runoff coefficents
2. Using infilltration capacity curves
3. Using infilltration indices
4. Using emperical equations
5. Using tables and curves.
6. Using unit hydrograph method.

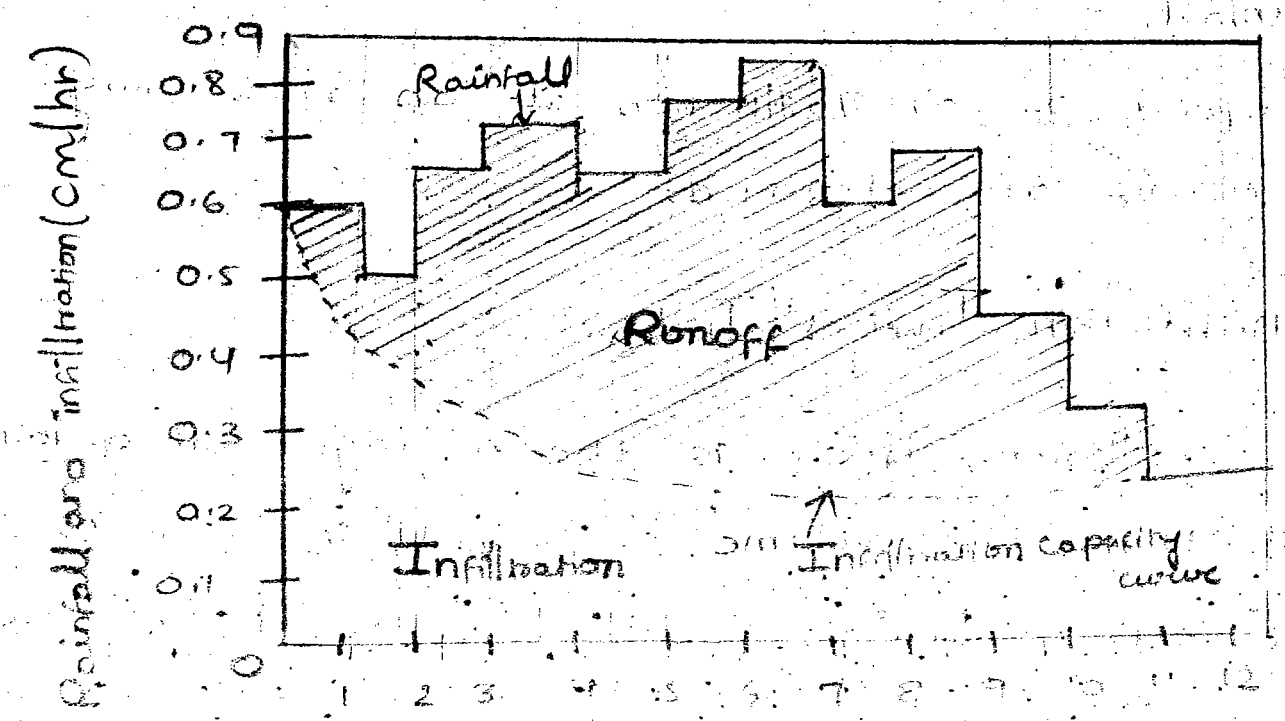
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* Runoff coefficents

$R = K.P$

K = Coefficent, P = Preciptation, R = Runoff.
in cm in cm in cm

Runoff by Infilltration capacity curve Method.



The infiltration is defined as the movement of water to the soil surface and into the soil.

The capacity of any soil to absorb water from rainfall falling continously at an excessive rate goes on decreasing with time until a minimum rate infiltration is reached.

The infiltration rate is the rate at which water actually enters the soil during a strom and is equal to the infiltration capacity (or) the rainfall rate whichever is less.

IC curve limitations

It is applicable for small areas with homogenous soil condition and uniform rainfall

→ and it cannot be applicable for large areas because the soil having heterogenous conditions & non-uniform rainfall.

→ Some part of an infiltration at an area may be runoff at other area.

* Infiltration Indices / Index:

Infiltration Index is the average rate of loss such that the volume of rainfall in excess of that rate will be equal to the direct runoff

Estimate of runoff volume from large areas having heterogenous infiltration loss and rainfall characterics are made by use of infiltration Indices.

* Average Infiltration Rate (ϕi) W-Index & ϕ-Index

ϕ-Index

It is defined as the average rate of rainfall above which the rainfall volume equal to the runoff volume. Alternatively it is defined as the average rate of loss such that the volume of rainfall in excess of that rate will be equal to direct runoff. The ϕ index is usually known as excess of rainfall (or) effective rainfall.

$$\phi_i = \frac{P-R}{t_{DR}}$$

Thus we find that W-index is esentially equal to ϕ-index minus average rate of retenston by intercepHon and depresion stōlage.

$$\phi_i = \frac{\text{Total infiltration during excess rainfall}}{\text{Duration of excess rainfall}}$$

ϕ index equal to $\frac{A_2+A_3+A_4+A_5}{P}$

$$\phi_i = \frac{A_2+A_3+A_4+A_5}{t_{re_1}+t_{re_2}+t_{re_3}}$$

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Where.

A_2, A_3, A_4, A_5 = Infiltration during excess rainfall

$t_{re_1}, t_{re_2}, t_{re_3}$ = Individual periods of excess rainfall;

* W-index.

$$W_i = \frac{A_2+A_3+A_4+A_5}{t_{r_1}+t_{r_2}+t_{r_3}}$$

Where t_r = Total period of Rainfall.

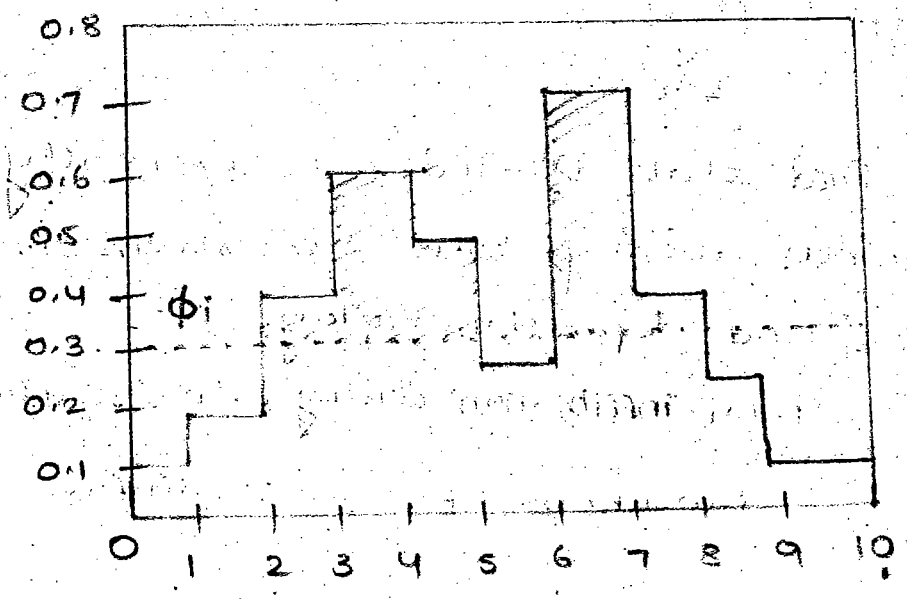
The W-index is calculated from the expression is

$$W_i = \frac{P-R-S_R}{t_r} \text{ cm/hr.}$$

Where S_R = Surface Retention

t_r = Duration of rainfall in hours.

ϕ curve:



24/01/16

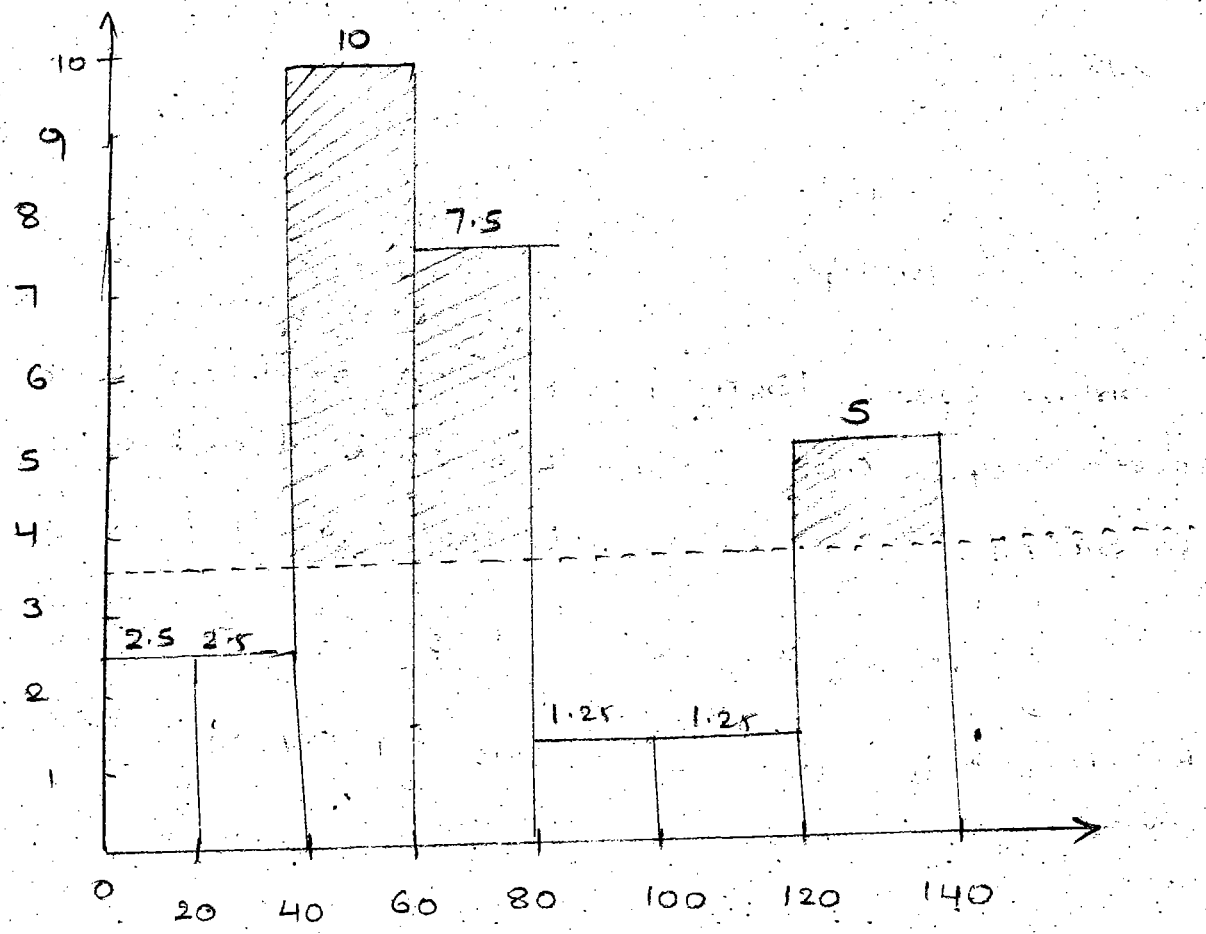
1. The following are the rate of rainfall for successive 20min period for a rainfall of 140minutes duration.

Time	20	40	60	80	100	120
Duration (Rate of rain fall)	2.5	2.5	10	7.5	1.25	1.25

Time	140
Duration	5.0.

Taking ϕ i as 3.2cm/hr
Find out net ronoff in cm
Total ronoff & value of W-index.

Sol:



Step 1:

Net runoff $R = \Sigma (i - \phi i) t$

$$= \left[(10-3.2)\frac{20}{60} + (7.5-3.2)\frac{20}{60} + (5-3.2)\frac{20}{60} \right]$$

$$= 4.8 \text{ cm/hr}$$

Step 2

Total Rainfall $= (2.5+2.5+10+7.5+1.25+1.25+5.)\frac{20}{60}$

$$= 30 \text{ cm/hr}$$

Step : 3.

Windex

$$W_i = \frac{P - R - S_r}{t_r}$$

$$= \frac{10 - 4.3 - 0}{140/60} = 2.44 \text{ cm/hr.}$$

2. A Strom with 15cm precipitation produces a direct runoff of 8.7cm. the time distribution of Strom is as follows. Estimate ϕ index of a shr

Time	1	2	3	4	5	6	7	8
Excess Rainfall in each hour (cm)	0.6	1.35	2.25	3.45	2.7	2.4	1.5	0.75

28101119.

2 Sol: Given data:

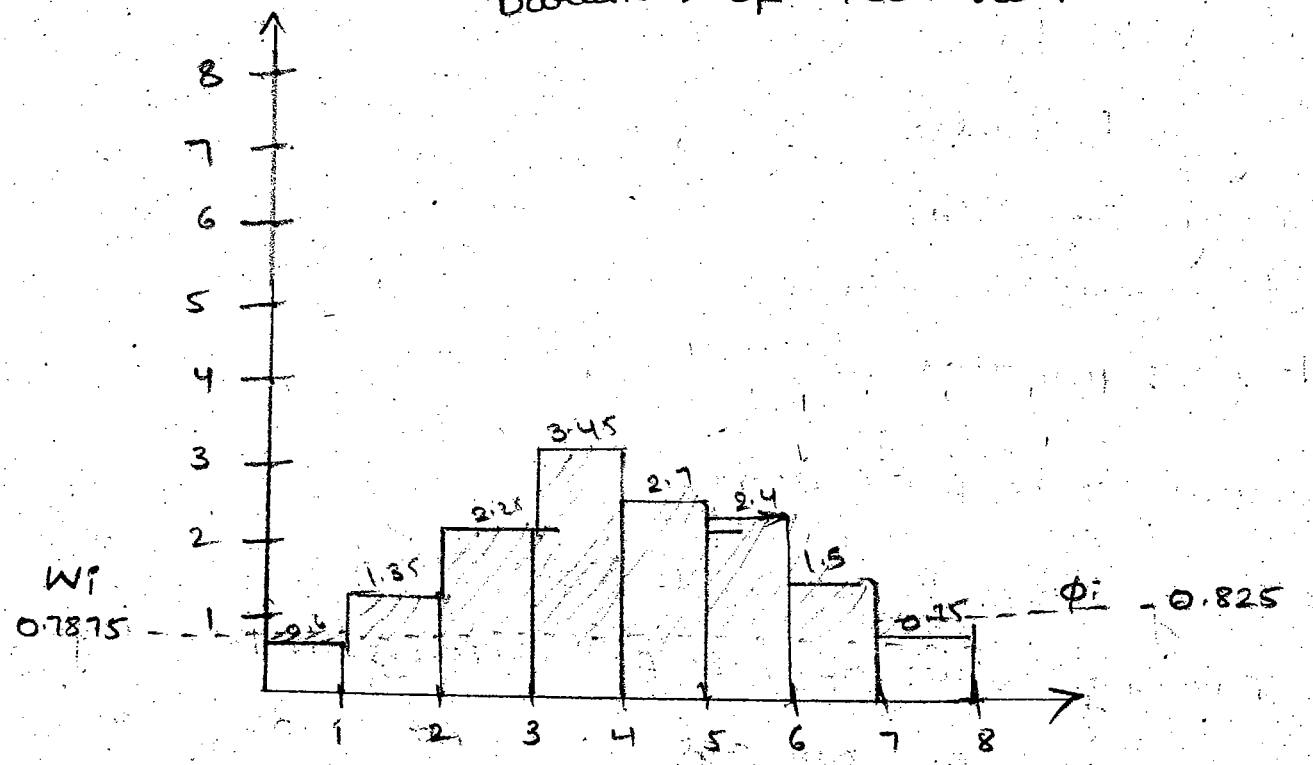
Precipitation (P) = 15cm

Direct Runoff (R) = 8.7cm

As we know that ϕ index $\geq W_i$

$$W_i = \frac{P-R-S_1}{t_{S_1}} = \frac{15-8.7-0}{8} = 0.7875 \text{ cm/hr}$$

$$\phi_i = \frac{\text{Total infiltration during excess rainfall} - (\text{Infiltration}_{1\text{st ord}}) - (\text{Infiltration}_{\text{last ord}})}{\text{Duration of excess rainfall.}}$$



As 1st and last hour rainfall is less than W-index so they donot give any excess rainfall i.e Runoff.

∴ The excess rainfall may be occur in b/w

$$\phi_i = \frac{\text{Total infiltration during excess rainfall} - (\text{Infiltration}_{\text{1st value}} + \text{Infiltration}_{\text{of last ordinate}})}{\text{Duration of excess rainfall.}}$$

$$= \frac{(15-8.7) - (0.6) - (0.75)}{6} = 0.825$$

Check:

$$\text{Runoff} = (1.35 - 0.825) + (2.25 - 0.825) + (3.45 - 0.825) + (2.7 - 0.825) + (2.4 - 0.825) + (1.8 - 0.825)$$

$$= 8.7\text{cm}$$

29/01/19.

* Emprical Formulae and Charts.

1. Burlow's runoff coefficent
2. Stranger's charts and tables
3. Ingli's Formulea
4. Lacey's Formulas
5. Khos Laws formulas
6. Pakers formulas.

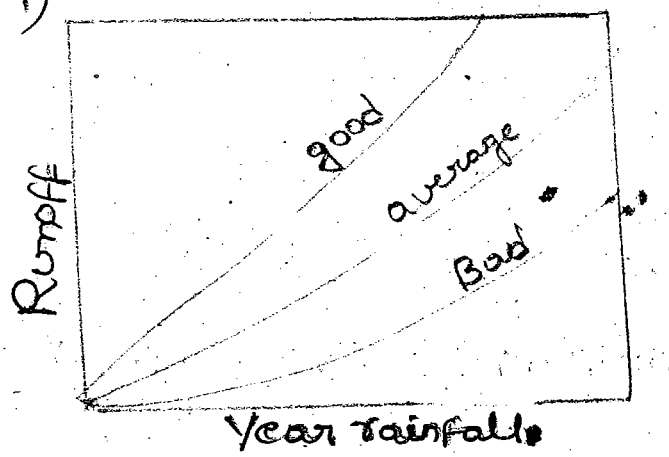
* Burlow's runoff coefficent:

This is Study 140 km^2 catchment in united province and give following values of runoff coefficents in percentages. The values are for average coefficent and to be multiplied with constants according to seasons

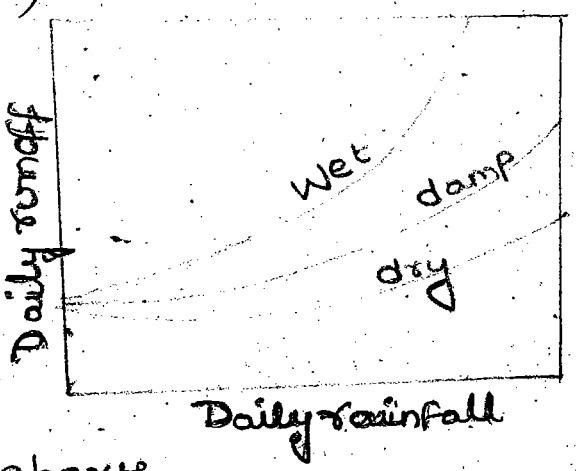
	Burlow's catchments	K(%)
A	Flat, cultivated, Blackcottonsoils	10%
B	Flat partly cultivated variousoils	15%
C	Average soils	20%
D	Hills and planes with cultivation	35%
E	Very hilly and steep area with hardly cultivation	45%

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1)



2)



* Stranger's Tables and charts

He proposed tables & charts for competation of ronoff in plaines of southIndia. There charts & tables gives information about yearly and daily ronoff based on correponding rainfalls and take into account of 3 types of catchements.

1. Good 2. Average 3. Bad (Rainfalls
2. Dry, Damp, Wet → (surface conditions)

* Inglis Formula:

For Bombay presidency, Western Ghats and plains of Maharastra

Ghats : $R = 0.85P - 30.5.$

Non Ghats: $R = \left(\frac{P-17.8}{2.54}\right)P$ [P, R in cm]

Indogangetic plain:

$$R = \frac{1}{1 + \frac{304.8F}{P.S}} \quad (P, R \text{ in cm})$$

F → Type of Monson for certain period.

F — 0.5 Short
F — 1.0 Standard
F — 1.5 Long

'S value' Depending upon classification of catchement by Burdow

A → 0.125
B → 0.6
C → 1.0
D → 1.7
E → 345

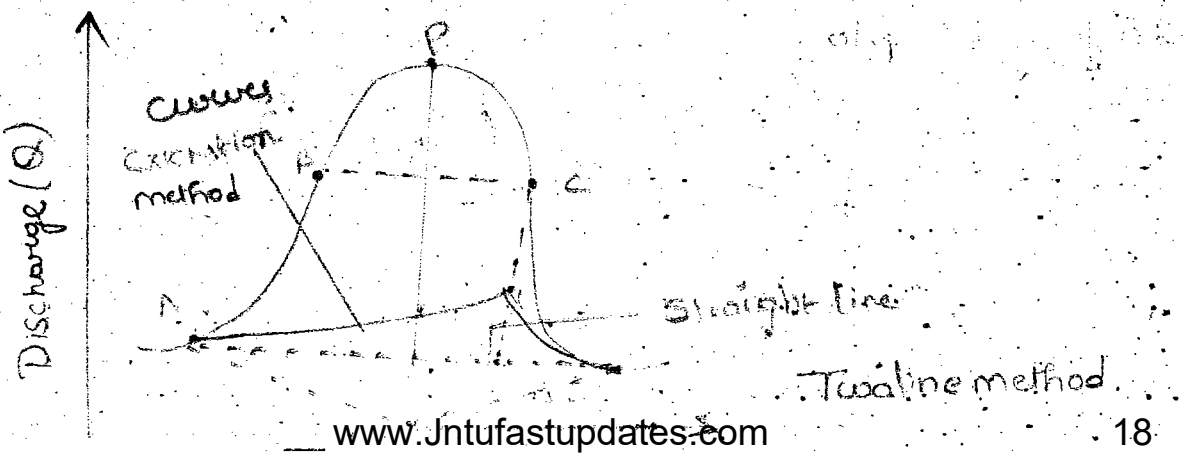
4. Khosla's Formula:

Runoff $R = P - \frac{T-32}{3.74}$

5. Parker's Formula:

$R = 0.94P - 1.4$ → British
$= 0.94P - 1.6$ → Germany
$= 0.84P - 16.5$ → East U.S.A.

Base flow Graph

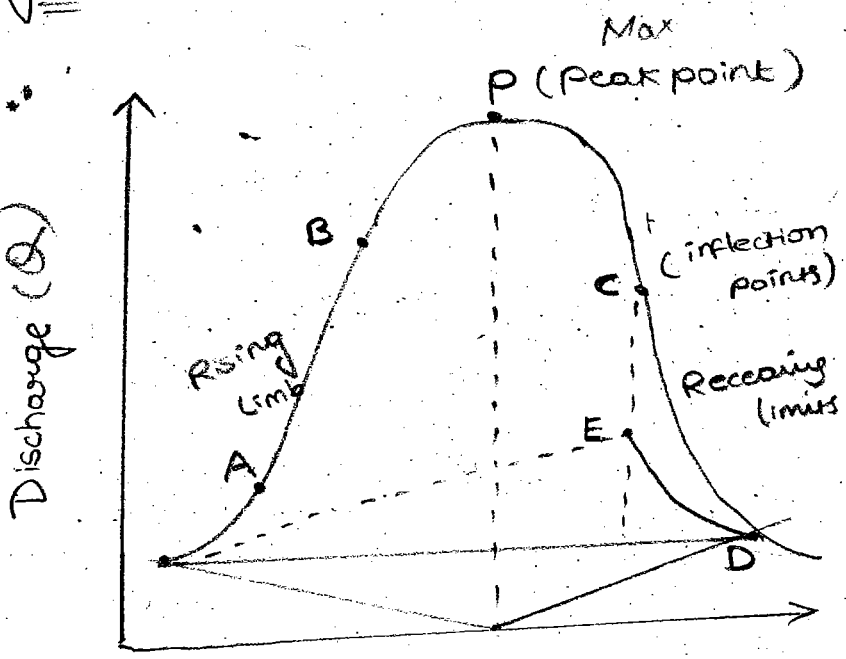


08/02/19:

* Hydrograph Analysis:

Components:

1. Rising Limb
2. Peak point
3. Inflection point
4. Receiving limits



Base flow Seperation

1. Straight line method
2. Two line method
3. Curves extension method.

1. The following are the ordinates of a runoff hydrograph 3 hours storms runoff readings are measured at 3hour intervals

(Time) Hour	0	3	6	9	12	15	18	21	24
Ordinate	10	25	40	60	75	35	20	15	10

Assume Baseflow $10 m^3$ per second. uniformly Findout ordinates of direct runoff hydrograph & runoff depth in cm if area of catchment is $20 km^2$.

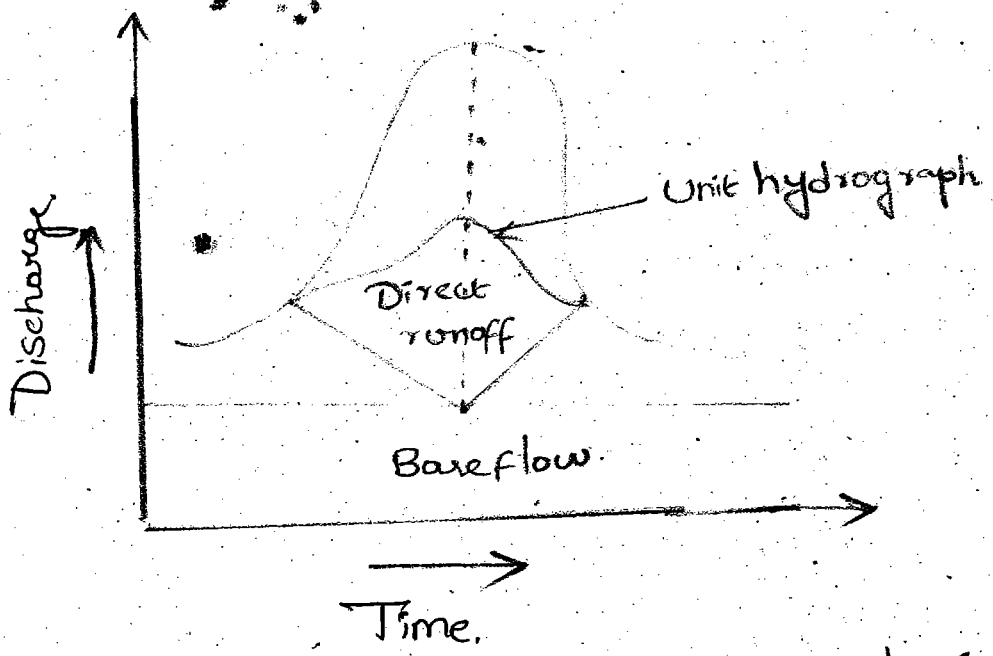
Sol: Direct runoff $= \frac{0.36(\Sigma O)t}{A}$

$$D.R = \frac{0.36(10+25+40+60+75+35+20+15+10)\,23}{20}$$

$$= 15.66 cm$$

14/02/19.

Unit Hydrograph Method



* The following Runoff values are available for outlet for 4 hour rainfall over a catchment. Derive 4 hour unit hydrograph for a catchment Assuming base flow is uniform at 20m³/s. Area of catchment is 200KM².

Time (hours)	Ordinates of flood Hydrograph	Baseflow.
0	20	20
4	35	20
8	60	20
12	220	20
16	430	20
20	450	20
24	250	20
28	180	20
32	80	20
36	20	20

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Time (hours)	ordinates of flood hydrograph	Baseflow	ordinates of DRH	unit hydrograph
0	20	20	0	0
4	35	20	15	1.348
8	60	20	40	3.595
12	220	20	200	17.979
16	430	20	410	36.853
20	450	20	430	38.665
24	250	20	230	20.676
28	180	20	160	14.313
32	80	20	60	5.393
36	20	20	0	0

$$\text{Depth of runoff} = \frac{0.36(1545)4}{200}$$

$$= 11.124 \text{ cm}$$

Ordinates of unit hydrograph $\left(\frac{\text{DRH ord}}{\text{Runoff}}\right)$

$$\frac{15}{11.124} = 1.348$$

$$\frac{40}{11.124} = 3.595$$

$$\frac{200}{11.124} = 17.979$$

$$\frac{410}{11.124} = 36.853$$

$$\frac{430}{11.124} = 38.655$$

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$$\frac{230}{11.124} = 20.676$$

$$\frac{160}{11.124} = 14.383$$

$$\frac{60}{11.124} = 5.393$$

$\Sigma O = 138.882$.

Check: Depth of runoff for U.H = 1cm

$$\Rightarrow \frac{(0.36 \times 138.82) \times 4}{200} = 1\text{cm}.$$

* Exp

Derive a 2-hr unit hydrograph from following total runoff hydrograph resulting from rainfall of effective duration 2hrs. Drainage basin area is 104 km².

Date	Time(hr)	Runoff (m^3/s)	Baseflow(m^3/s)
July 10	06	14.2	14.2
	08	958.5	14.7
	10	260	15.2
	12	286	15.7
	14	221	16.2
	16	186.5	16.7
	18	157	17.2
	20	133	17.3
	22	113	17.7

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July 11	2	76.4	19.2
	4	65.0	19.7
	6	55.2	20.2
	8	46.7	20.7
	10	39.6	21.2
	12	34	21.7
	14	28.3	22.2
	16	22.7	22.7

Sol: Depth of run off $= \frac{0.36(\Sigma O) \times t}{A}$

$= \frac{0.36(159.3) \times 2}{104}$

$= 11.480\text{m}$.

Date	Time	Runoff	Baseflow	ordinates of DRH	ordinates of 2hr hydrograph.
July 10	06	14.2	14.2	0	0
	08	158.5	14.7	143.8	12.52
	10	260	15.2	244.8	21.32
	12	286	15.7	270.8	23.54
	14	221	16.2	204.8	17.83
	18	186.5	16.7	169.8	14.79
	20	157	17.2	139.8	12.17
	22	133	17.3	115.7	10.07
	24	113	17.7	95.3	8.30
July 11	2	76.4	19.2	74.7	6.50
	4	65.0	19.7	57.2	4.98
	6	55.2	20.2	45.3	3.945
	8	46.7	20.7	35.0	3.048
	10	39.6	21.2	26.0	2.264
	12	34	21.7	18.4	1.602
	14	28.3	22.2	12.3	1.071
	16	22.7	22.7	6.1	0.531.

Σ ordinates of unit hydrograph = 144.481.

Check: $\frac{(\Sigma O) \times 36 \times 2}{104} = \frac{144.481 \times 0.36 \times 2}{104}$

$= 1.00$ cm.

14/02/19.

* Application of unit hydrograph for the construction of flood hydrograph resulting from the rainfall of unit duration.

DRH = Runoff (cm) × ordinates of unit hydrograph

2. Ordinate of flood hydrograph = ordinates of DRH + Baseflow

The following data of 2h unit hydrograph. If rainfall exceeds 8cm for an intense rainfall of 2hour on same catchment. Determine the ordinates of flood hydrograph. Base flow of ordinates are given below.

Sol:

Date	Time	Ordinates of unit hydrograph	Ordinates of D.R	Baseflow	Ordinates of flood hydrograph
	6	0	0	4.0	4
	9	0.12	0.96	3.5	4.46
	12	0.35	2.80	3.0	5.80
	15	0.88	7.04	2.5	9.54
	18	1.50	12.0	2.0	14.00
	21	2.80	22.40	1.5	23.90
	24	2.00	16	1.8	17.80
Day-2	3	1.85	14.80	2.1	16.90
	6	1.53	12.24	2.4	14.64
	9	1.26	10.08	2.7	12.78
	12	0.84	6.72	3.0	9.72
	15	0.50	4.00	3.8	7.80
	18	0.35	2.80	3.6	6.40
	21	0.12	0.96	3.8	4.76
	24.	0.00	0	4.0.	4.0.

* Application of unit hydrograph to construct flood hydrograph resulting from 2(or) more rainfalls of same duration.

Find the ordinates of a strom hydrograph resulting from a 3h with rainfalls of 2, 6.75, 3.75 cm respectively during subsequent 3hours intervals. The ordinates of unit hydrograph are given in the following table. Assume an initial loss of 5mm and ϕ index of 2.5mm/hr and a constant base flow of $10 m^3/sec$

Time	Ordinates of UH.	Rainfall Excess.	Surface Runoff during excess rainfall in 3hr dur				Base flow.
			0.75	6	3	Total	
3	0	0.75	0	0	0	0	
6	110	6	82.5	660	330	1072.5	
9	365	3	273.7	2190	1095		
12	500		375	3000	1500		
15	390		292.5	2340	1170		
18	310		232.5	1860	930		
21	250		187.5	1500	750		
24	235		176.25	1410	705		
3	175		131.25	1050	525		
6	130		97.5	780	390		
9	95		71.25	570	285		
12	65		48.75	390	195		
15	40		30	240	120		
18	22		16.5	132	66		
21	10		7.5	60	30		
24	0		0	0	0		

Rainfall excess during 1st 3 hours

$\Rightarrow$ $20 - (2.5 \times 3) = 12.5 - 5 = 7.5\text{mm} = 7.5\text{mm} = 0.75\text{cm}$.

Rainfall excess during 2nd 3 hours.

$67.5 - (2.5 \times 3) = 60\text{mm} = 6\text{cm}$.

Rainfall excess during 3rd and last 3 hours,

$37.5 - (2.5 \times 3) = 30\text{mm} = 3\text{cm}$.

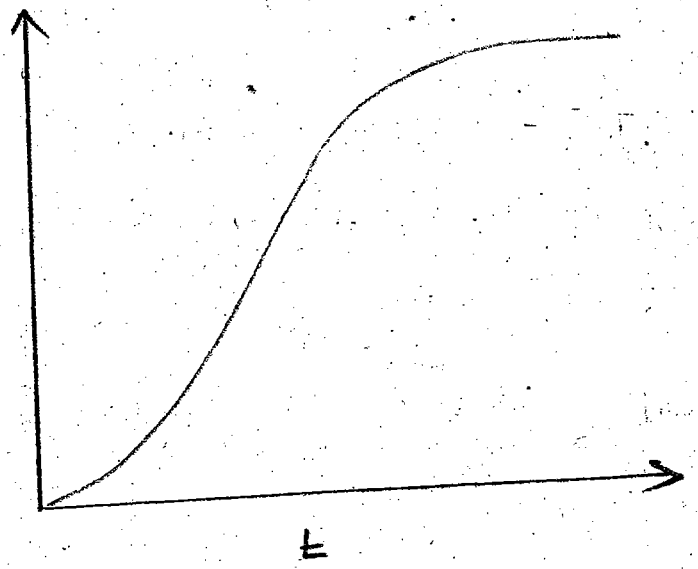
Rainfall excess.	Surface run-off from rainfall excess during successive unit periods				Baseflow	Total Discharge
	0.75	6.00	3.00	Total.		
0.75	0			0	10	10
6.00	82.5	0		82.5	10	92.5
3.00	274	660	0	934	10	944
	375	2190	330	2895.	10	2905
	292.5	3000	1095	4387.5.	10	4397.5
	232.5	2340	1500	4072.5	10	4082.5
	187.5	1860	1170	3217.5.	10	3227.5
	176.25	1500	930	2606.25.	10	2616.25
	131.25	1410	750	2291.25.	10	2301.25.
	97.5	1050	705	1852.5	10	1862.5.
	71.25	780	525	1376.25	10	1386.25.
	48.75	570	390	1008.7.	10	1018.7.
	30	390	285	705.	10	715.
	16.5	240	195	451.5.	10	461.5.
	7.5	132	120	259.5	10	269.5
	0.	60	66	126.	10	136.
		0	30	30	10	40
			0.	0		

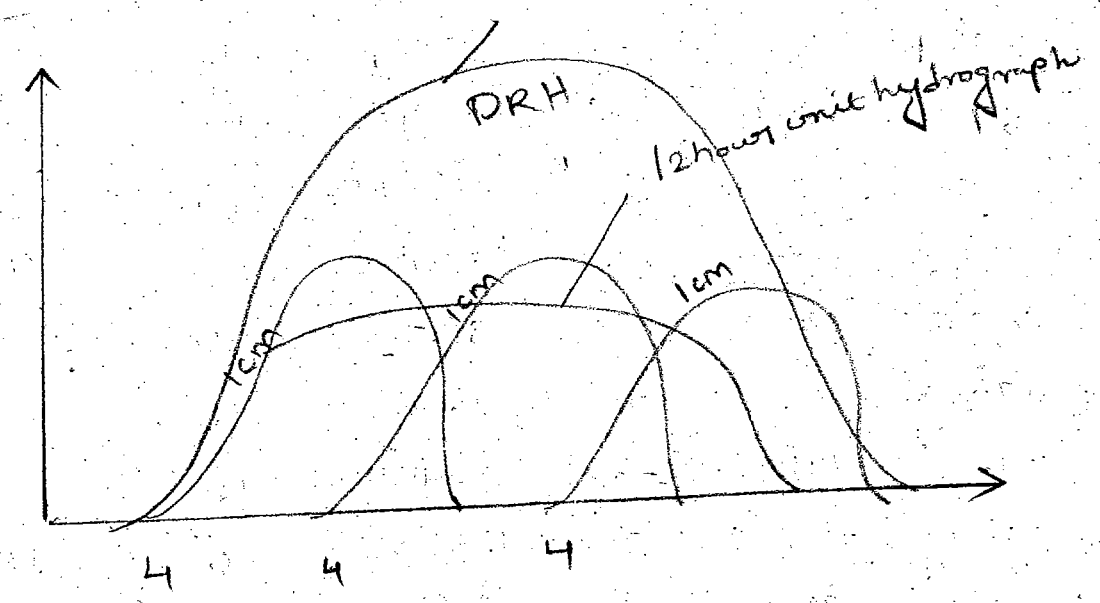
14/02/19.

S-Hydrograph.

S = Summation

It is mainly imp for unithydrograph to many hydrographs @

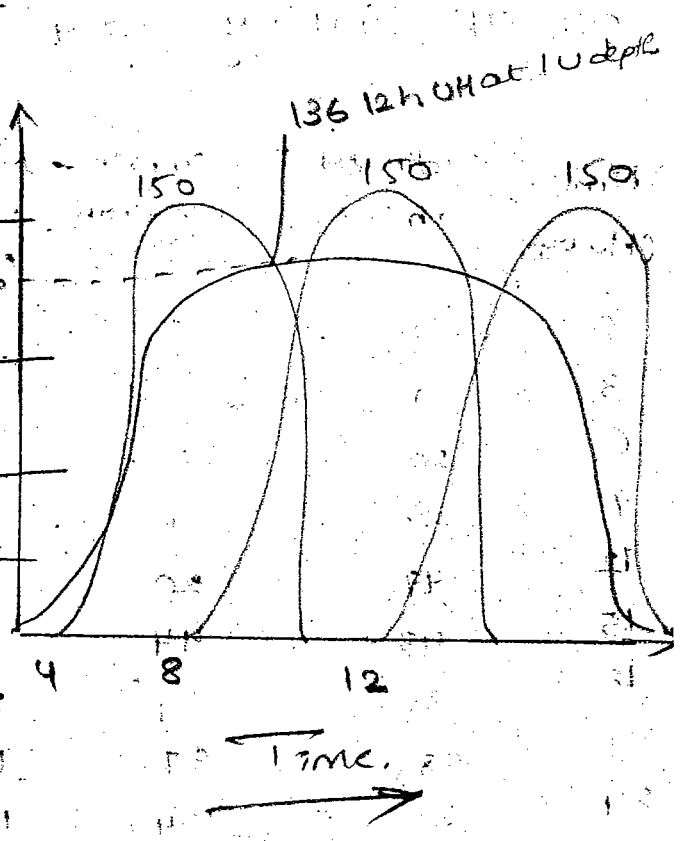




15/02/19.

* Given the ORD of 4-hour UH below. Derive the Ordinates of 12-H for the same catchment.

Hours	Ord. of 4hr UH. (A)	Ord of 4h UH lagged by (4h) (B)
0	0	—
4	20	0
8	80	20
12	130	80
16	150	130
20	130	150
24	90	130
28	52	90
32	27	52
36	15	27
40	5	15
44	0	5
48		0
52		



Hours	Ord of 4h-UH (A)	Ord of UH lagged by 4h (B)	Ord of UH lagged by 4h (C)	Ord 12h UH with 3cm	Ord of 12h with $(\frac{2}{3})$ 1U depth.
0	0	—	—	0	0
4	20	0	—	20	6.67
8	80	20	0	100	33.3
12	130	80	20	230	76.67
16	150	130	80	360	120
20	130	150	130	410	136.6
24	90	130	150	370	123.3
28	52	90	130	272	90.6
32	27	52	90	169	56.3
36	15	27	52	94	31.0
40	5	15	27	47	15.6
44	0	5	15	20	6.6
48		0	5	5	1.6
52			0	0	0

* Ordinates of 6H unit hydrograph are derive S-curve of 9H unit hydrograph

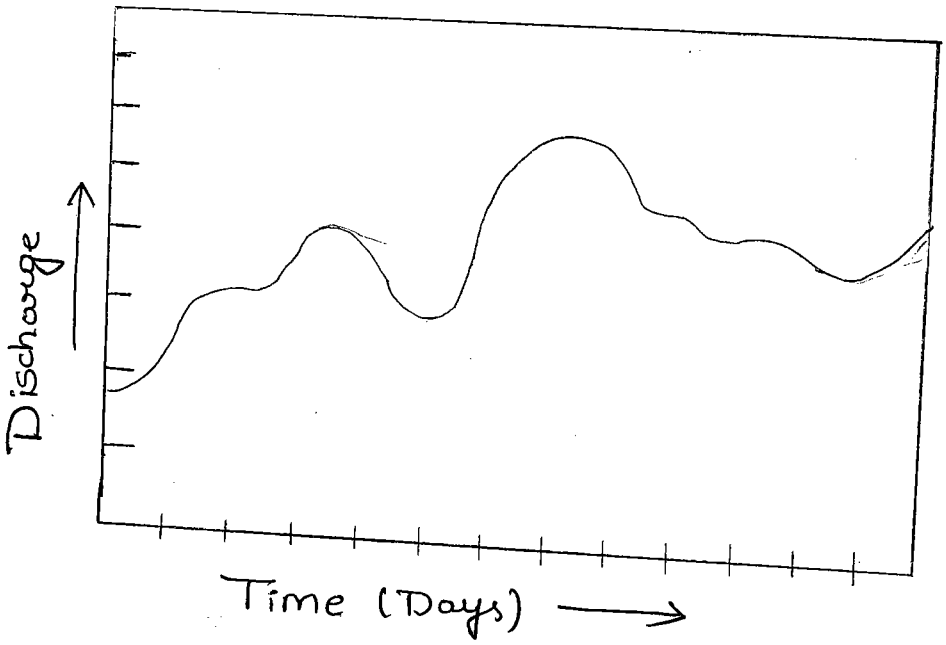
Time (Hours)	Ordinates of 6h UH	Offset ordinate	S-curve Ordinates	offset of s-curve ordinates	Δ of 3rd	9hour UH with S-curve (Δ×2/3)
0	0	–	0	–	0	0
3	9	–	9	0	9	6
6	20	0	20	9	11	7.3
9	35	9	44	20	24	16
12	49	20	69	44	25	16.67
15	43	44	87	69	18	12
18	35	69	104	87	17	11.33
21	28	87	115	104	11	7.33
24	22	104	126	115	11	7.33
27	17	115	132	126	6	4
30	12	126	138	132	6	4
33	9	132	144	138	3	2
36	6	138	144	141	3	2
39	3	141	144	144	0	0
42	0	144	144	144	0	0
45						
48.						

9h UH = $\Delta \times \frac{2}{3}$ of each ordinate.

* Hydrograph Analysis

A hydrograph is a graph showing variations of discharge with time, at a particular point of stream. It shows the time distribution of total runoff at the point of measurement.

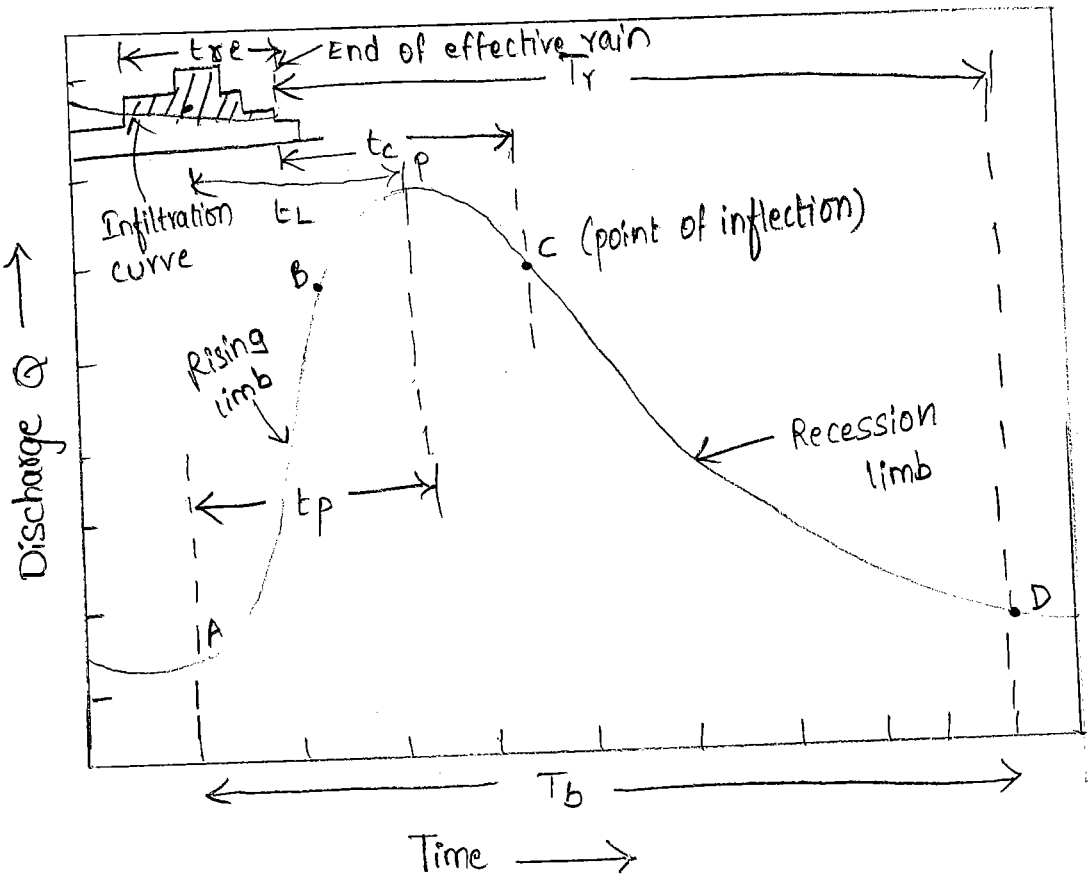
As the runoff includes the contributions from surface runoff, subsurface runoff (or inter flow) and groundwater runoff. (or base flow).



STROM HYDROGRAPH

* Components of Hydrograph

The figure shows a single peaked hydrograph resulting from an isolated storm. The rainfall hyetograph, along with infiltration curve, is shown on the top of the diagram.



There are three essential components of a single peaked hydrograph resulting from an isolated storm:

(i) The rising limb (AB)

(ii) The peak or crest element (BPC)

and (iii) The recession limb (CD).

(i) Rising Limb:

The rising limb AB is the ascending portion of the hydrograph corresponding the increase of discharge due to gradual formation of storage in the channels existing in the area and also over the watershed surface. The rising limb also known as the "concentration curve." In the early period of a storm, there are initial losses as well as high infiltration losses and hence the discharge rises slowly. As the time increases, the initial losses stop and the infiltration rate also decreases. Due to this, more and more discharge from the distant parts reach the basin outlet. Point A is the starting point while B is the point of inflection. The shape of the rising limb is controlled by the characteristics of basin and duration, intensity and uniformity of the rain.

(ii) The Peak (or) Crest Segment (BPc)

The peak or crest segment includes the part of the hydrograph from the inflection point (B) on the rising limb to an inflection point (c) on the recession limb. Crest segment is one of the most important component of the hydrograph because

it indicates the peak flow rate.

(iii) The recession limb (CD):

The recession limb extends from the point of inflection (point C) of the crest segment to the point D, the point of commencement of the natural ground water flow. The recession limb indicates the storage contribution from surface storage, interflow and ground water flow.

Time Parameters used in Hydrograph Analysis

1. Effective time duration (t_{re}):

It is the net duration of precipitation during which rainfall rates more than infiltration rates.

2. Lag time or basin lag (t_l):

It is the time interval between the centre of mass of net rainfall and centre of mass of runoff hydrograph. More commonly, it is also taken as the time lapse between the centre of mass of effective rainfall and the peak (P) of the hydrograph.

3. Time to peak (t_p):

It is the time interval between the starting of the rising limb (A) to the peak (P) of the hydrograph.

* Seperation Of Base flow:

There are three methods.

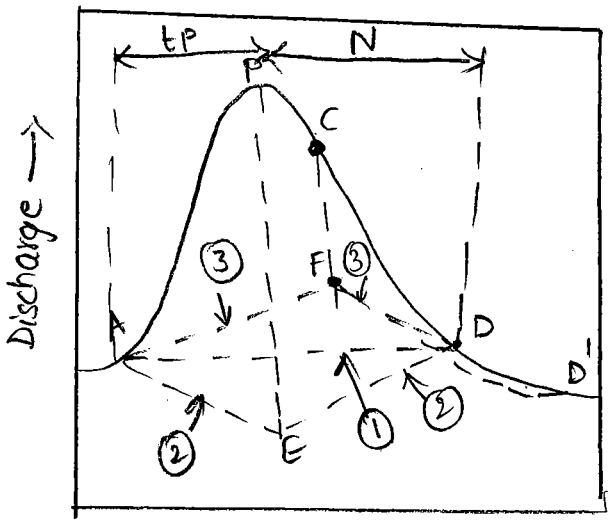
1. Straight line Method
2. Two line Method
3. Curves extension method.

1. Straight line Method:

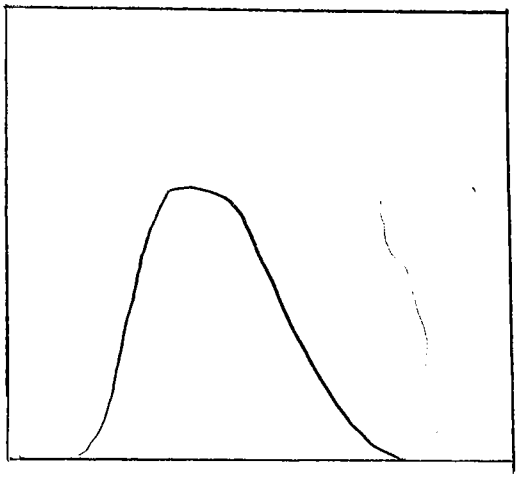
In a strom hydrograph direct runoff & baied flow can be seperated by joining point of rise and point of end by a simple straight line Ac.

* Portion above Ac - Runoff
  Below Ac - Baseflow.

* Simplest Method.



(a) Three methods of Seperation.



(b) Resulting DRH.

2. Two line Method:

Recession curve existing before A is extended to a point under peak of hydrograph (F).

From this point a straight line is drawn to C.

AFC = Baseflow seperation Line.

3. Curves extension Method:

Baseflow on recession is extended backside to point below P.O.I then it is connected to point of rise by a smooth curve (A G D)

This method is preferred when stream and ground water are hydrocally collected and flow from G.W storage quickly appears as ronoff at outlet.

* UNIT HYDROGRAPH (UH)

A unit hydrograph is a hydrograph representing 1cm (or 1inch) of runoff from a rainfall of some unit duration and specific areal distribution. Unit duration refers to the duration of a run-off producing rainfall-excess, that results in a unit hydrograph. For example, if a unit hydrograph results from a 3 hours unit rainfall duration, it is known as a 3-hours unit hydrograph, meaning thereby a hydrograph produced by surface run-off from a storm lasting for 3 hours and yielding rainfall excess of 1cm.

Assumptions Of Unit Hydrograph Theory

The assumptions of unit hydrograph theory must be properly understood before applying it to actual problems, as these assumptions impose certain limitations which must be carefully noted. The various assumptions are given below.

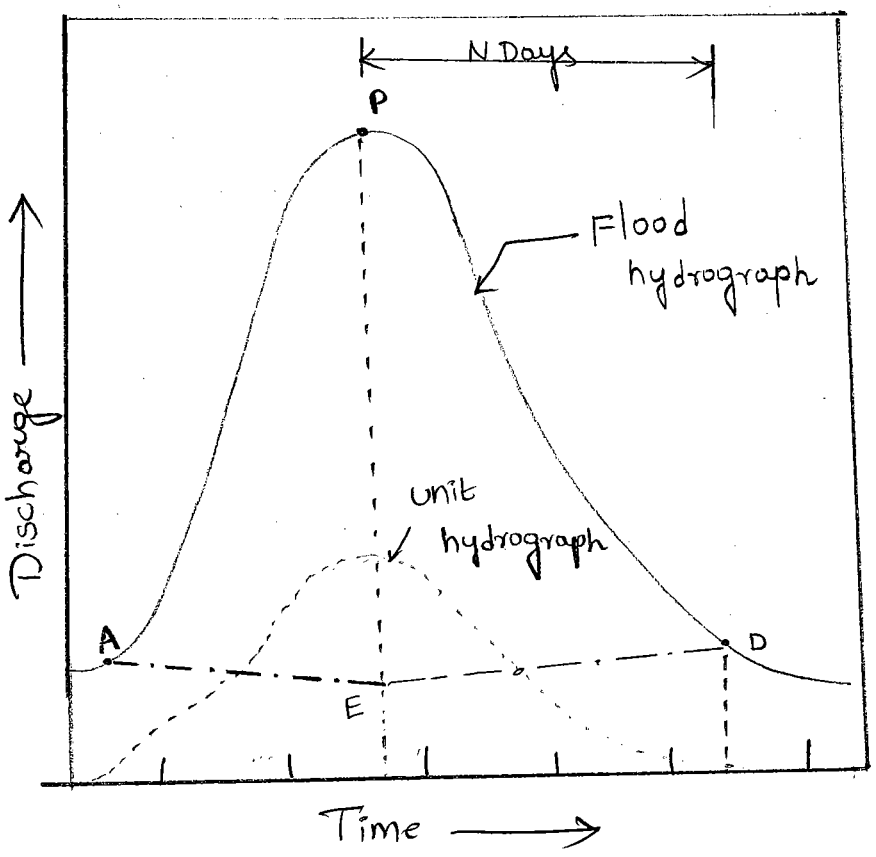
1. The effective rainfall is uniformly distributed within its duration of specified period of time.
2. The effective rainfall is uniformly distributed throughout the whole area of drainage basin
3. The base (or) time duration of the hydrograph

of direct run-off due to an effective rainfall of unit duration is constant.

CONSTRUCTION OF UNIT HYDROGRAPH.

The following are the steps for constructing a unit hydrograph of some unit duration from a storm hydrograph of the same unit duration.

1. From the past records, select some unit period of intense rainfall duration corresponding to an isolated storm uniformly distributed over the area.



CONSTRUCTION OF UNIT HYDROGRAPH.

2. From the past records of the river discharge for that storm, plot the storm hydrograph for some days before and after the period of rainfall of that unit duration.

3. By the method indicated in § 4.20, seperate the ground water flow (base flow) from the direct run off.

4. Subtracting the ordinates of base flow from the total ordinates, find the ordinates of direct run-off.

5. Calculate direct run-off n (in centimeters) by the expression:

$$\text{Direct run-off, } n = 0.36 \frac{(\Sigma O) \times t}{A} \text{ cm.}$$

Where

ΣO = sum of the discharge ordinates (direct run-off) in cumecs.

t = Time interval between successive ordinates in hours.

A = Area of drainage basin in Sq. km

6. Calculate the ordinates of unit hydrograph by the relation:

$$\text{Ordinate of unit hydrograph} = \frac{\text{Ordinate of direct run-off}}{\text{Direct run-off in cm}}$$

1. The following are the ordinates of a runoff hydrograph from 3hours Storm. Runoff readings are measured at 3hr intervals.

Time (Hours)	0	3	6	9	12	15	18	21	24
Ord. of TRH (m^3/s)	10	25	40	60	75	35	20	15	10

Assume baseflow to be 10 cumecs uniform. Find out ordinates of direct runoff hydrograph and Runoff depth in cm if Area of catchment is $20 km^2$.

Sol: Given data:

Base flow = $10 m^3/sec.$

Area of catchment = $20 km^2$

Time t = 3hours

$$\text{Runoff} = \frac{\left[(\Sigma \text{ Ord. of TRH}) - (10 \times \text{baseflow}\right] \times 0.36 \times 3}{A.}$$

$$\text{Runoff} = \frac{216}{20} = 10.8 cm.$$

2. The following runoff values are available for outlet for 4hr, rainfall over a catchment. Derive 4hour unit hydrograph for a catchment. Assuming baseflow is uniform at $20 m^3/sec.$, Area of catchment is $200 km^2$.

2 sol:

Time (hours)	Ordinates of flood hydrograph	Baseflow	ordinates of DRH	Depth of Runoff	Ordinates of Unit hydrograph (DRHord / Runoff)
0	20	20	0	11.124	$\frac{0}{11.124} = 0$
4	35	20	15	11.124	1.348
8	60	20	40	11.124	3.595
12	220	20	200	11.124	17.979
16	430	20	410	11.124	36.853
20	450	20	430	11.124	38.655
24	250	20	230	11.124	20.676
28	180	20	160	11.124	14.383
32	80	20	60	11.124	5.393
36	20	20	0	11.124.	0

$$\text{Direct runoff} = \frac{0.36(1545)4}{200}$$

$$= 11.124\text{cm.}$$

Ordinates of unit hydrograph $\left(\frac{\text{DRH ord}}{\text{runoff}}\right)$

1. $\frac{0}{11.124} = 0$
2. $\frac{15}{11.124} = 1.348$
3. $\frac{40}{11.124} = 3.595$
4. $\frac{200}{11.124} = 17.979.$
5. $\frac{410}{11.124} = 36.853$
6. $\frac{430}{11.124} = 38.655$
7. $\frac{230}{11.124} = 20.676$
8. $\frac{160}{11.124} = 14.383$
9. $\frac{60}{11.124} = 5.393$
10. $\frac{0}{11.124} = 0.$

Check: Depth of runoff for U.H = 1cm

$$\Rightarrow \frac{(0.36 \times 1 \times 138.88)4}{200} = 1\text{cm.}$$

3. Derive a 2-hour unit hydrograph from following total runoff hydrograph resulting from rainfall of effective duration 2hours. Drainage basin area is 104 km².

Date	Time (hour)	Runoff (m^3/s)	Baseflow (m^3/s)	Ordinates of DRH	Ordinates of 2hour hydrograph
July 10	6	14.2	14.2	0	0
	8	158.5	14.7	143.8	12.52
	10	260	15.2	244.8	21.32
	12	286	15.7	270.3	23.54
	14	221	16.2	204.8	17.83
	16	186.5	16.7	169.8	14.79
	18	157	17.2	139.8	12.17
	20	133	17.3	115.7	10.07
	22	113	17.7	95.3	8.30
	24	93.4	18.7	74.7	6.50
July 11	2	76.4	19.2	57.2	4.98
	4	65.0	19.7	45.3	3.945
	6	55.2	20.2	35.0	3.048
	8	46.7	20.7	26.0	2.264
	10	39.6	21.2	18.4	1.602
	12	34	21.7	12.3	1.071
	14	28.3	22.2	6.1	0.531
	16.	22.7.	22.7	0	0

Direct runff depth $= \frac{0.36(\Sigma O) \times t}{A}$

$= \frac{0.36(1659.3)2}{104}$

$= 11.48 cm.$

Σ ordinates of unit hydrograph $= 144.481$

Check:

$\frac{(\Sigma O) \times 0.36 \times 2}{104} = \frac{144.481 \times 0.36 \times 2}{104.}$

$= 1cm.$

Application of UH for the construction of flood hydrograph resulting from the rainfall of unit duration.

1. Ordinates of Direct runoff hydrograph is calculated

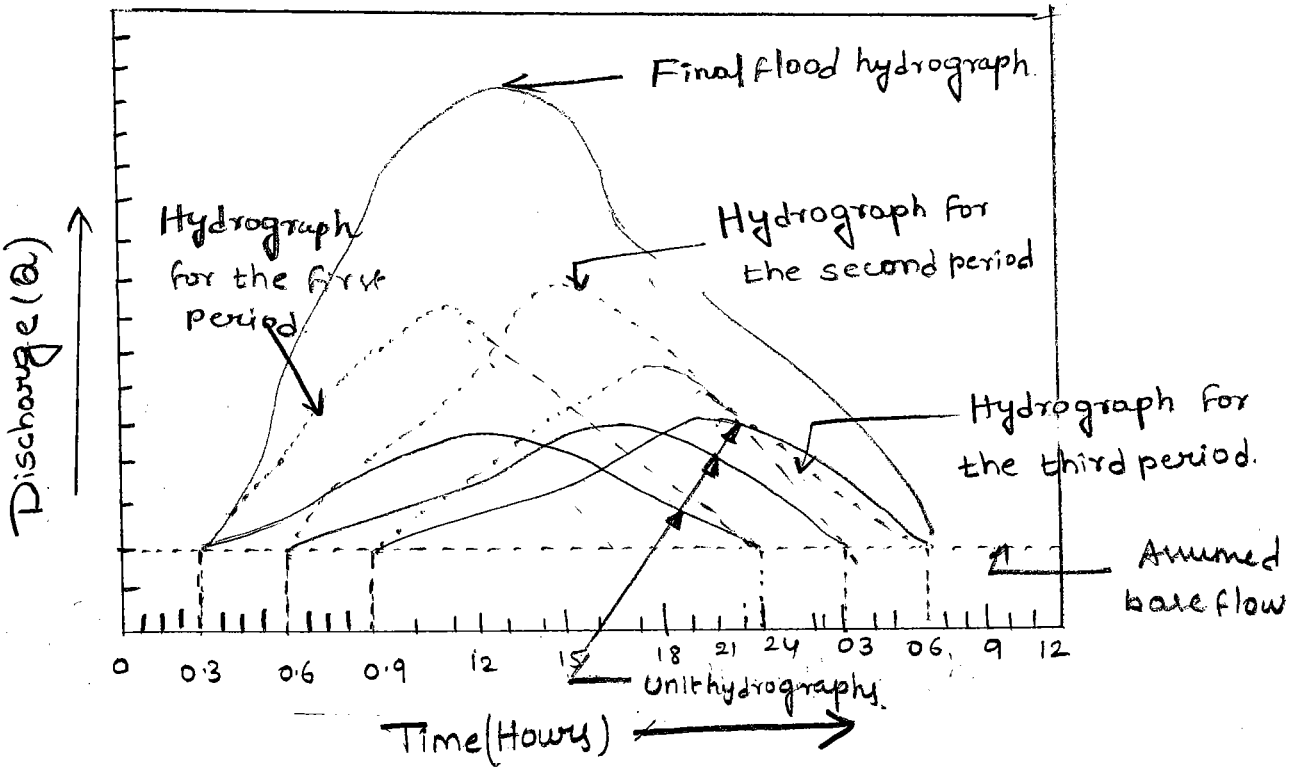
   DRH = (runoff)cm x Ordinates of UH.

2. Ordinates of flood hydrograph = ord of DRH + Base flow.

4. Following is data of 2 hour unit hydrograph. If rainfall exceeds 8cm for an intence rainfall of 2hour on same catchment. Determine the ordinate of flood hydrograph. Base flow of ordinates are given.

Date (1)	Time (hours) (2)	Ordinates of unit hydrograph. (3)	Ordinates of D.R (4) = (3) x n	Base flow (5)	Total ordinates of FH (6) = (4) + (5)
22 July	6	0.00	0	4.0	4
	9	0.12	0.96	3.5	4.46
	12	0.35	2.80	3.0	5.80
	15	0.88	7.04	2.5	9.54
	18	1.50	12.00	2.0	14.00
	21	2.80	22.40	1.5	23.90
	24	2.00	16.00	1.8	17.80
	3	1.85	14.80	2.1	16.90
	6	1.53	12.24	2.4	14.64
	9	1.26	10.08	2.7	12.78
	12	0.84	6.72	3.0	9.72
	15	0.50	4.00	3.3	7.30
	18	0.35	2.80	3.6	6.40
	21	0.12	0.96	3.8	4.76
	24	0.00	0	4.0	4.0

Application of Unit hydrograph to Construction of a flood hydrograph resulting from Two (or) More periods of Rainfall



Flood Hydrograph Resulting from a Storm of Longer duration

A unit hydrograph of some specific unit duration can also be utilised for construction of flood hydrograph resulting from the rainfall lasting for a long duration. The essential condition, however is that the storm pattern should be the same as that for the unit hydrograph. As an example, let us say that a 3-hour unit hydrograph is available and it is required to compute the flood hydrograph resulting from a rainfall lasting for 9 hours with variable intensities of rainfall- the intensity rates having n_1 cm/3-hours for the first period of 3 hours, n_2 cm/3-hours for 2nd 3 hours,

and n_3 cm/3-hour for the last 3 hours. The storm is divided into 3 parts, and the flood hydrograph of the storm starts 3 hours later than that for the first part. Similarly, the hydrograph for the third part of the storm starts 6 hours later than that for the first, or 3 hours later than that for the second part.

5. Find the ordinates of a storm hydrograph resulting from a 3 hour storm with rainfall of 2, 6.75 & 3.75 cm. during subsequent 3 hours intervals. The ordinates of unit 3-hour hydrograph are given in the following data.

Hours	3	6	9	12	15	18	21	24	03	6	9	12	15	18	21	24
Ordinates of UH (Cumecs)	0	110	365	500	390	310	250	235	175	130	95	65	40	22	10	0

Assume an initial loss of 5mm, infiltration index of 2.5mm/hr and baseflow of 10 cumecs.

Sol: (i) Rainfall excess during the first three hours

$= 20 - (2.5 \times 3) - 5 = 7.5\text{mm} = 0.75\text{cm}$

(ii) Rainfall excess during the second three hours

$= 67.5 - (3 \times 2.5) = 60\text{mm} = 6\text{cm}.$

(iii) Rainfall excess during the last three hours.

$= 37.5 - (3 \times 2.5) = 30\text{mm} = 3\text{cm}.$

7

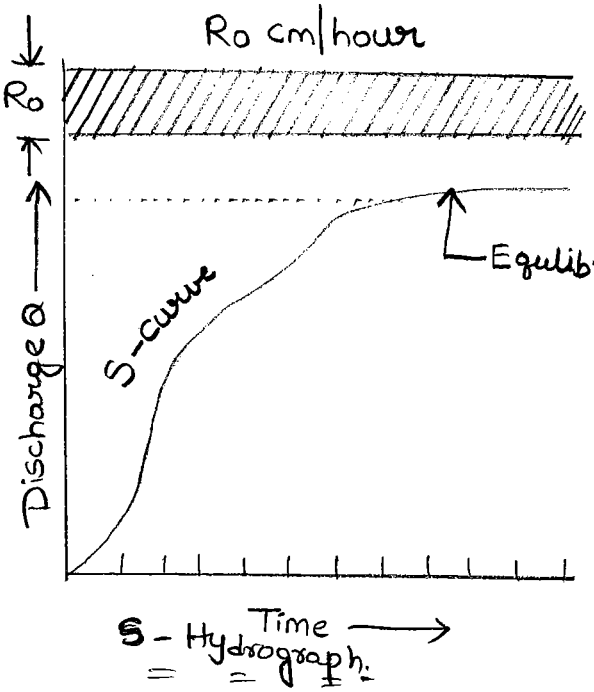
Time in hours	Ordinates of 3-hour unit hydrograph (cumecs)	Rainfall excess cm/2 hours	Surface run-off from rainfall excess during successive unit periods				Baseflow (cumecs)	Total discharge (cumecs)
			0.75	6.0	3.0	Sub Total		
3	0	0.75	0			0	10	10.0
6	110	6.00	82.5	0		82.5	10	92.5
9	365	3.00	274.0	660	0	934.0	10	944.0
12	500		375.0	2190	330	2895	10	2905.0
15	390		295.5	3000	1045	4337.5	10	4347.5
18	310		232.5	2340	1500	4072.5	10	4082.5
21	250		187.5	1860	1170	3217.5	10	3227.5
24	235		176.0	1500	930	2606.0	10	2616.0
3	175		131.5	1410	750	2291.5	10	2301.5
6	130		97.5	1050	705	1852.5	10	1862.5
9	95		71.3	780	525	1376.3	10	1386.0
12	65		48.6	570	390	1008.6	10	1018.6
15	40		30.0	390	285	705.0	10	715.0
18	22		16.5	240	195	451.5	10	461.5
21	10		7.5	132	120	259.5	10	269.5
24	0		0	60	66	126.0	10	136.0
30				0	30	30.0	10	40.0
36					0	0	10	100.0.

S - Hydrograph (Summation Hydrograph).

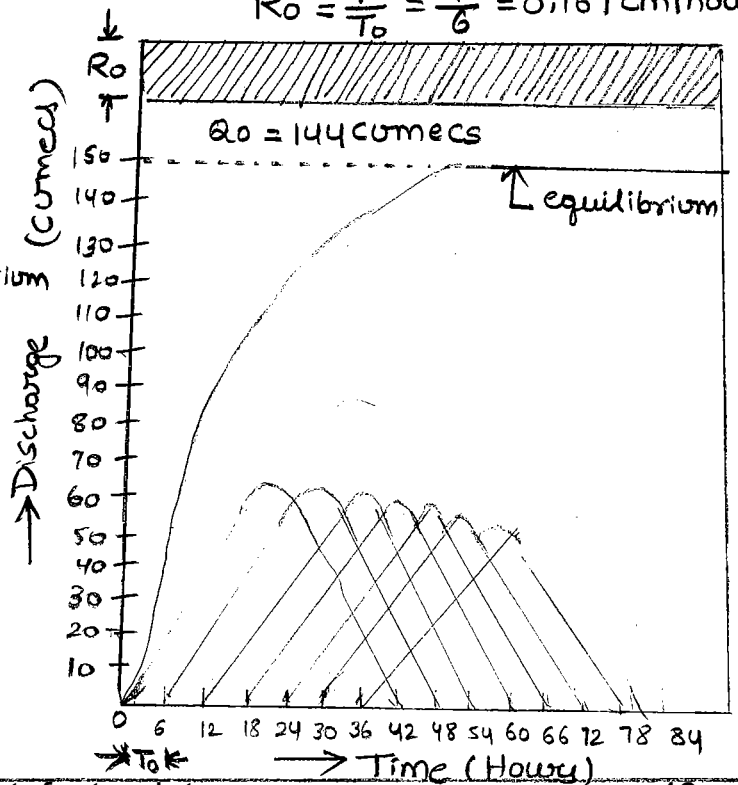
S - hydrograph (or) S - curve is a hydrograph that is produced by a continous effective rainfall at a constant rate for indefinite period. It is a continuos rising curve, in the form of letter S, till equilibrium is reached. At the time of equilibrium it will represent a constant rate of continous effective rainfall, say R_0 cm per hour.

$$Q_0 = \frac{(A \times 1000 \times 1000) R_0}{100 \times 3600} = 2.778 A R_0 \text{ (cumecs)}$$

The S - hydrograph (or) S - curve is constructed by adding together a number of unit hydrographs of unit time duration (T_0) spaced at a unit time duration T_0. (i.e duration of effective rainfall.



$R_0 = \frac{1}{T_0} = \frac{1}{6} = 0.167$ cm/hour



1. Ordinates of 6hour unit hydrograph are given. Derive S-curve of 9hour UH.

Time (Hours)	ord of 6h UH.	Offset ordinates	S-curve Ordinates	Offset of S-curve ordinates	difference of ord (Δ)	9h UH. of S-curve ($\Delta \times 2/3$)
0	0	–	0	–	0	0
3	9	–	9	0	9	6
6	20	0	20	9	91	7.3
9	35	9	44	20	24	16
12	49	20	69	44	25	16.67
15	43	44	87	69	18	12
18	35	69	104	87	17	11.33
21	28	87	115	104	11	7.33
24	22	104	126	115	11	7.33
27	17	115	132	126	6	4
30	12	126	138	132	6	4
33	9	132	141	138	3	2
36	6	138	144	141	3	2
39	3	141	144	144	0	0
42	0	144	144	144	0	0

9H UH = $\frac{2}{3}$ of each ordinate $\times \Delta$.

Unit hydrograph of different duration

There are two methods. can be plotted for

1. Longer duration
2. Shorter duration.

* **Longer duration:**

→ If the desired UH is integral multiple of given duration = superposition method.

→ If not integral method = S-curve.

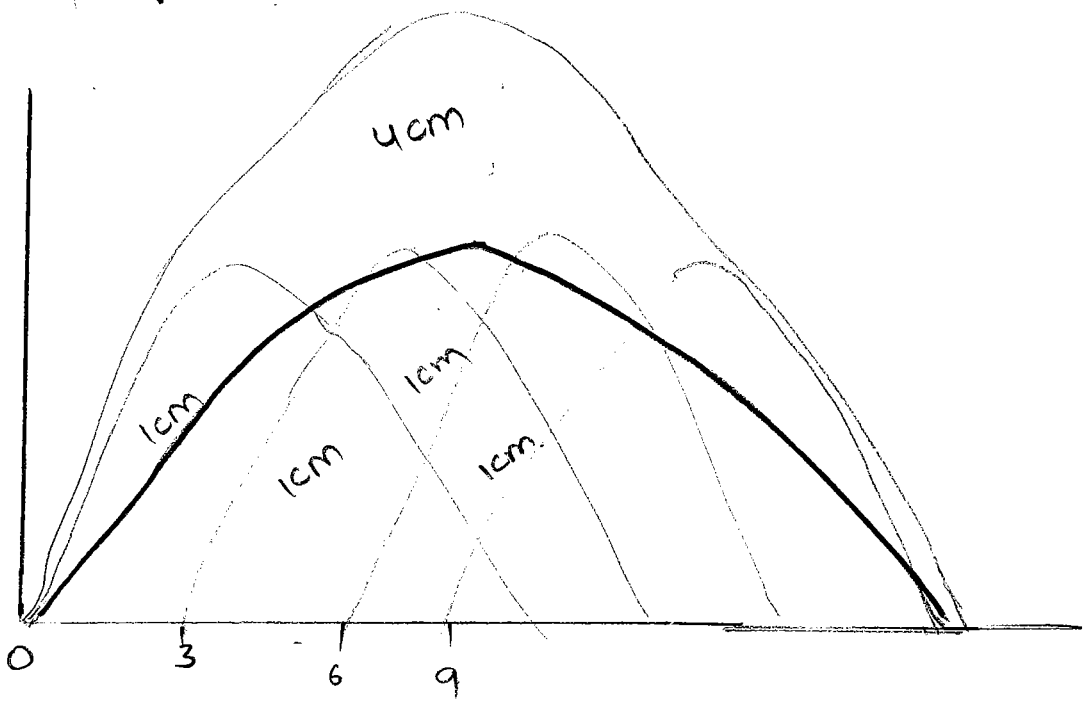
* **Shorter duration:** S-curve method.

Superposition method:

Given duration of UH = t_0 hour.

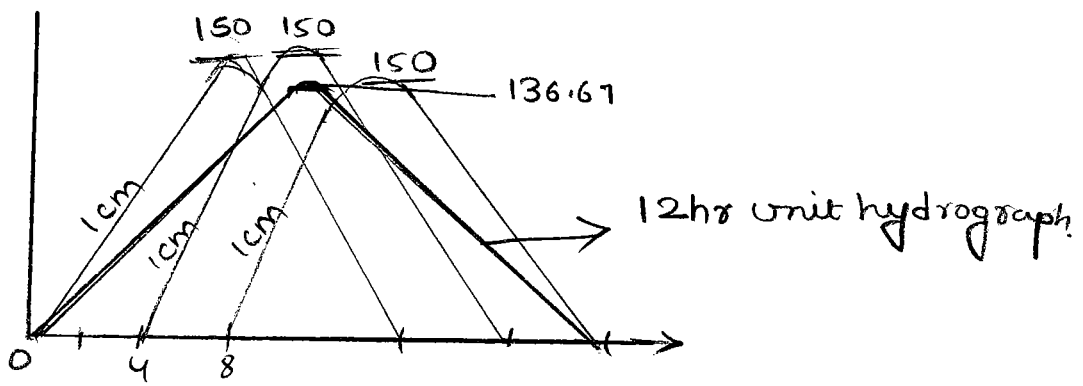
Required UH duration = T_0 hour.

'T_0' is an integral multiple of 't_0'



2. Given the ordinates of a 4hour unit hydrograph Derive the ordinates of 12hour unit hydrograph for the same catchment.

Hours	ord of 4h UH (A)	Ord of UH lagged by 4h (B)	Ord of UH lagged by 4h (C)	ord of 12h UH with 3cm	Ord of 12h with 1U depth. (1/3) 12h.
0	0	–	–	0	0
4	20	0	–	20	6.67
8	80	20	0	100	33.3
12	130	80	20	230	76.67
16	150	130	80	360	120
20	130	150	130	410	136.6
24	90	130	150	370	123.3
28	52	90	130	272	90.6
32	27	52	90	169	56.3
36	15	27	52	94	31.0
40	5	15	27	47	15.6
44	0	5	15	20	6.6
48		0	5	5	1.6
52			0	0	0.



* Uses of Unit Hydrographs:

This unit hydrograph establish a relationship between effective rainfall and direct runoff for a catchment. This relationship is very useful in study of the hydrology of catchment, as

(i) In the development of flood hydrograph for extreme rainfall magnitude.

(ii) In extension of flood-flow records based on rainfall records.

(iii) In development of flood forecasting and warming system based on rainfall.

* Limitations of Unit Hydrograph

1. 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.

2. Unit hydrograph method can not be used for a catchment area greater than 5000km^2 and less than 2km^2

3. Precipitation must be from rainfall only. Snowmelt runoff can not be satisfactory represented by U.H.

4. The catchment should not have large storage (Ex: tank pond etc) which affects the linear relationship between storage and discharge.

In the use of unit hydrograph 20%. variation in time base and 10%. variation in peak are expected in reproduction of result.

* Synthetic unit hydrograph – Snyder'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.

Snyder developed a set of empirical equation for construction of syntheic unit hydrograph, which is known as Snyder's synthetic unit hydrograph.

Synder selected three important parameter for construction of SUH.

1. Base time width (T)

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

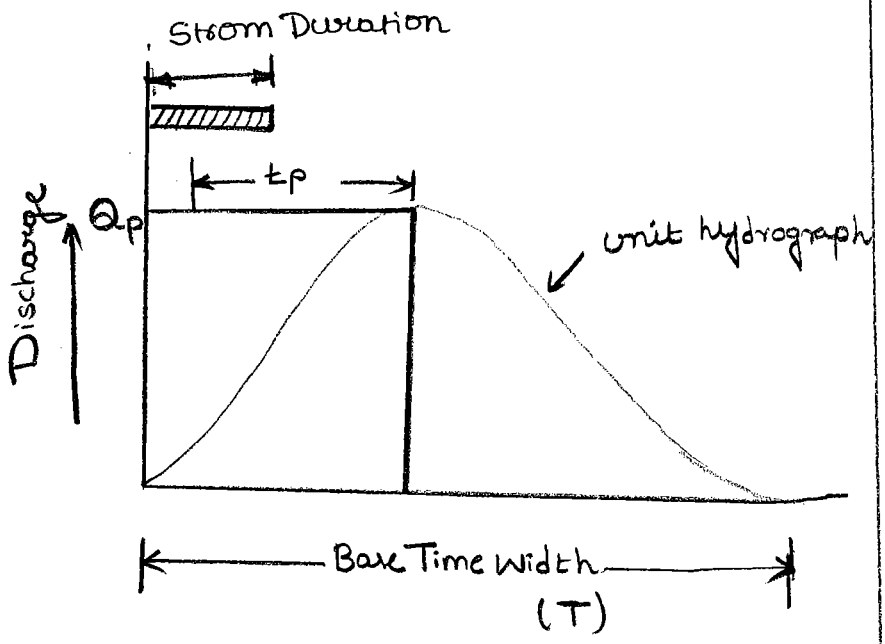
(ii) Peak discharge (Q_p)

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

(iii) Lag time (t_p):

Lag time represents the mean time of travel of water from all parts of catchment to the outlet during a given storm.

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



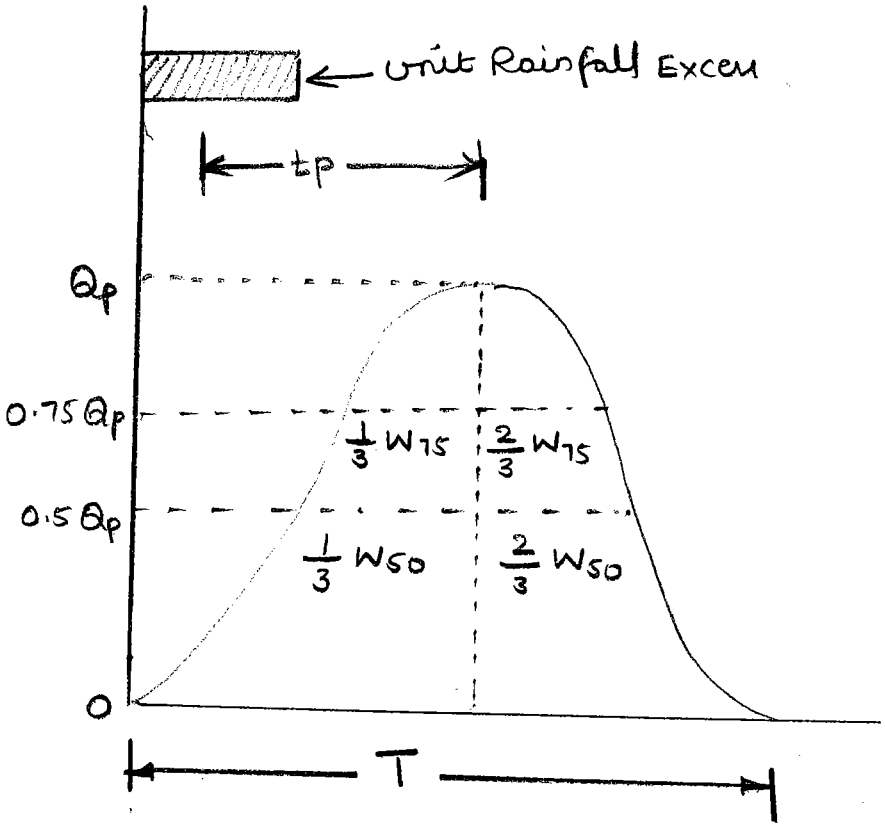
Here

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

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


Unit Rainfall Excess
tp
Qp
0.75Qp
0.5Qp
0
1/3 W75
2/3 W75
1/3 W50
2/3 W50
T