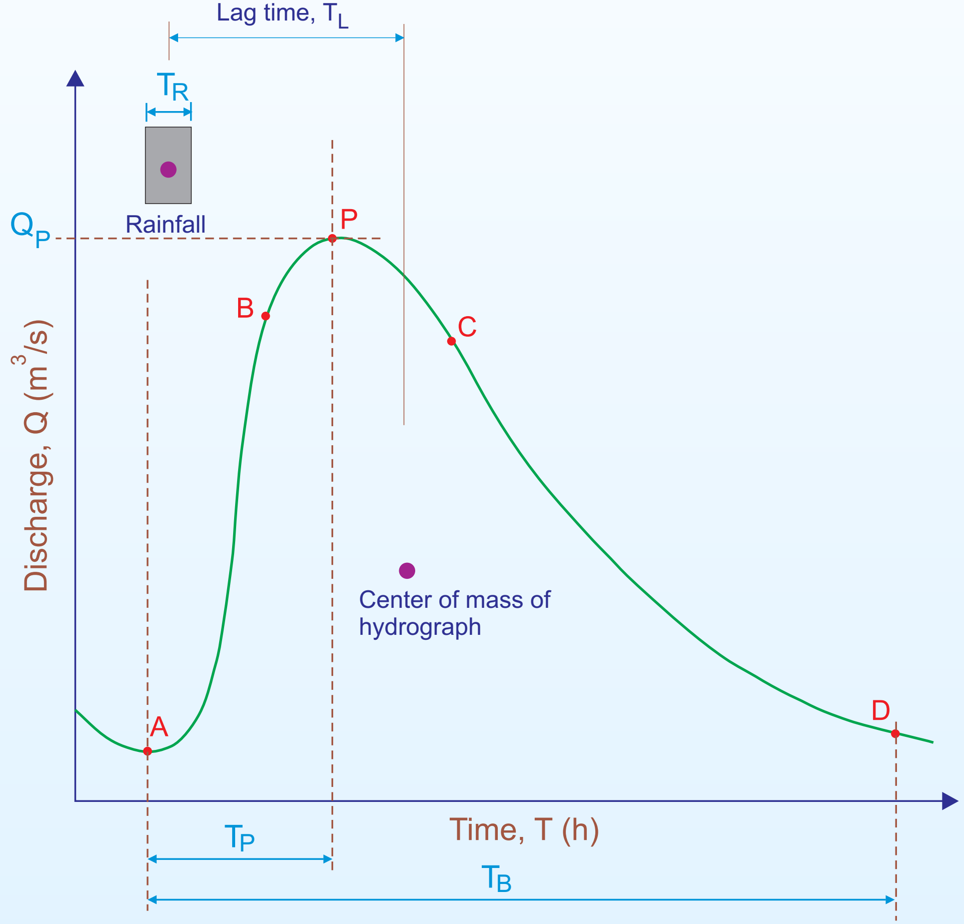
Hydrograph

Introduction

Flood Hydrograph

Flood hydrograph or storm hydrograph is a plot of variation of runoff with time at the catchment outlet, due to a precipitation over the catchment.



Elements of a Flood Hydrograph

Q_P = peak discharge
T_P = time to peak
T_B = time base
T_R = duration of rainfall
A = starting point
B = first inflection point
C = second inflection point
P = peak
D = end of effect of rainfall
AB = rising limb
BC = crest segment
CD = falling limb

Factors Affecting

Physiographic factors

Factors Affecting

Physiographic factors

- Basin Characteristics

Factors Affecting

Physiographic factors

- Basin Characteristics
  - Shape
  - Size
  - Slope
  - Elevation
  - Drainage density

Factors Affecting

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- Basin Characteristics
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  - Elevation
  - Drainage density
- Infiltration charateristics

Factors Affecting

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- Infiltration charateristics
  - Land use and land cover
  - Soil type and geological conditions
  - Lakes and other storage

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  - Land use and land cover
  - Soil type and geological conditions
  - Lakes and other storage
- Channel characteristics

Factors Affecting

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- Channel characteristics
  - Cross section
  - Roughness
  - Storage capacity

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Climatic Factors

Factors Affecting

Physiographic factors

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Climatic Factors

- Storm characteristics

Factors Affecting

Physiographic factors

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- Channel characteristics
  - Cross section
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  - Storage capacity

Climatic Factors

- Storm characteristics
  - Intensity
  - Duration
  - Magnitude
  - Movement of storm

Factors Affecting

Physiographic factors

- Basin Characteristics
  - Shape
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Climatic Factors

- Storm characteristics
  - Intensity
  - Duration
  - Magnitude
  - Movement of storm
- Initial loss

Factors Affecting

Physiographic factors

- Basin Characteristics
  - Shape
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  - Slope
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  - Drainage density
- Infiltration charateristics
  - Land use and land cover
  - Soil type and geological conditions
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Climatic Factors

- Storm characteristics
  - Intensity
  - Duration
  - Magnitude
  - Movement of storm
- Initial loss
- Evapotranspiration

Hydrograph

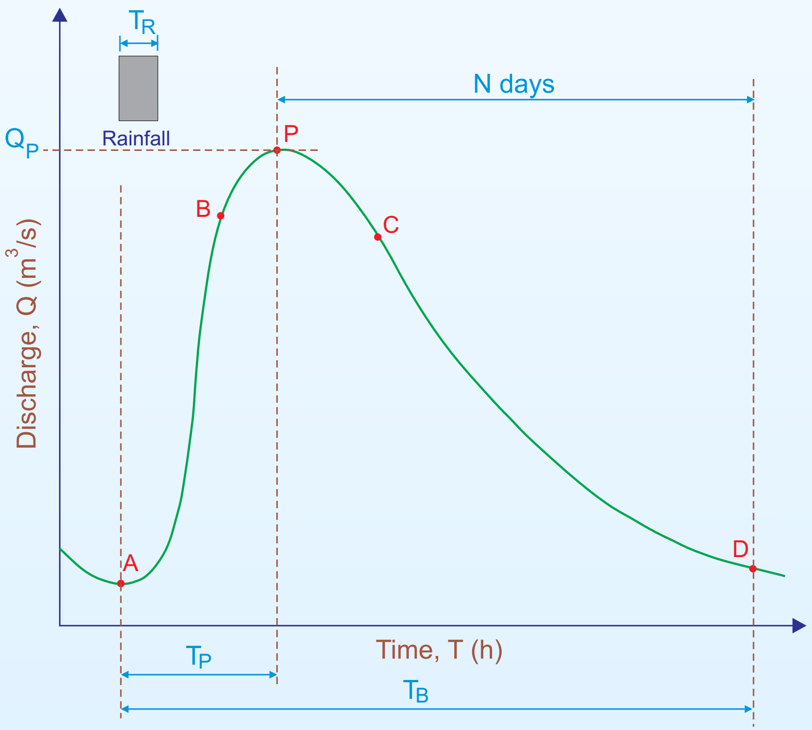
- Introduction
- Factors Affecting
- Base Flow Separation
- Method 1
- Method 2
- Method 3

Base Flow Separation

Total flow at the catchment outlet may include base flow also. Hence the resulting flood hydrograph also includes base flow. In order to get the direct runoff hydrograph (DRH), base flow is to be separated from the flood hydrograph. Usually, three different types of methods are used in pratice for this task.

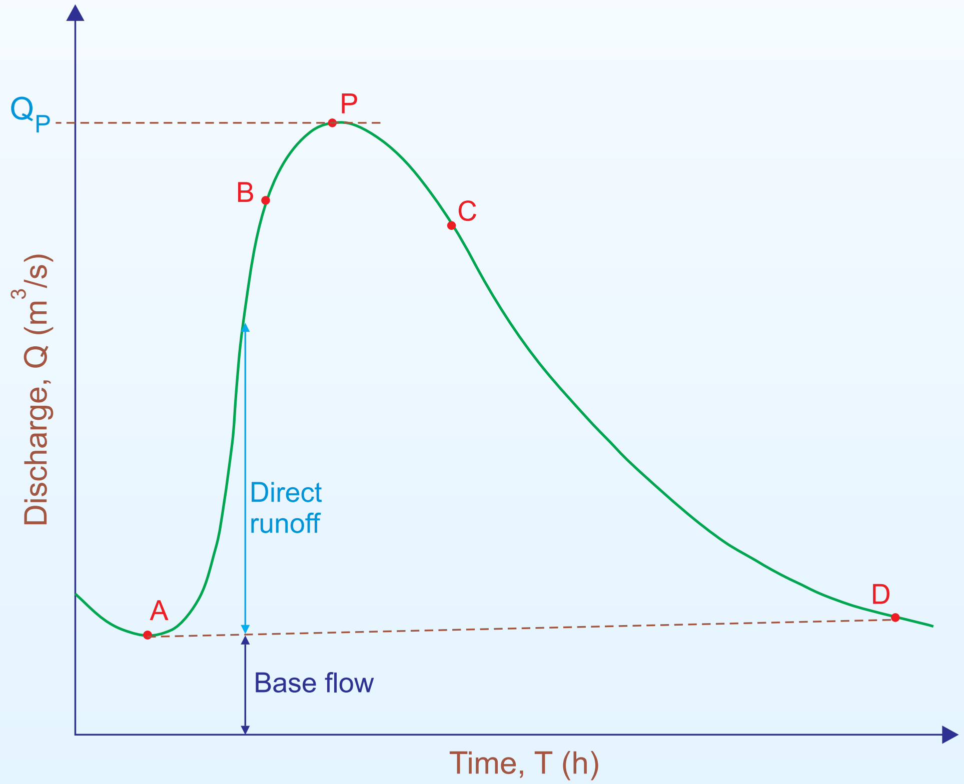
Each of these three methods requires identification of starting point A, peak point P and end point D. Point A can be identified easily, observing the sharp increase in the discharge rate. Point D can be identified approximately as follows:

$T_B = T_P + N$ where $N = 0.83\ A^{0.2}$ days and A = catchment area in km^2.



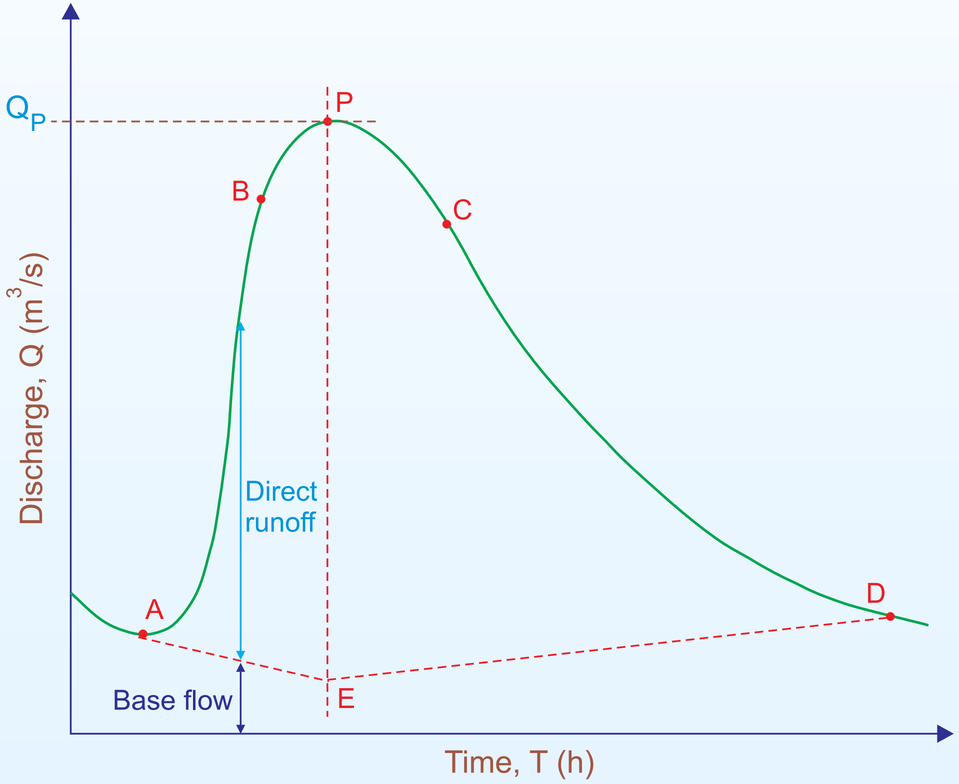
Method 1

1. Identify points A and D.
2. Join points A and D by a straight line to demarcate base flow and surface runoff. Line AD is the base flow curve.



Method 2

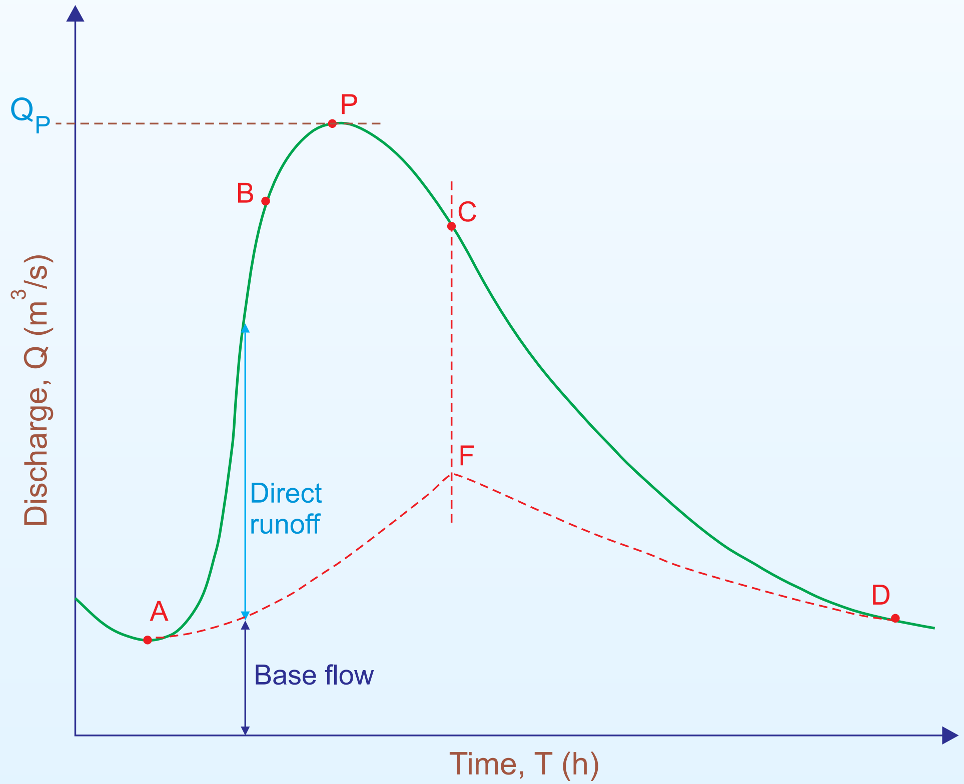
1. Draw vertical line through P.
2. Extend curve before A forward to cut the vertical line at E.
3. Join points D and E by straight line. Curve AED is the base flow curve.



Method 3

1. Draw vertical line through second inflection point C.
2. Extend the graph after D backwards to cut the vertical at F.
3. Join points A and F by smooth curve. Segment AF and FD indicate the base flow curve.

This type of base flow curve is realistic where groundwater contributions are significant.



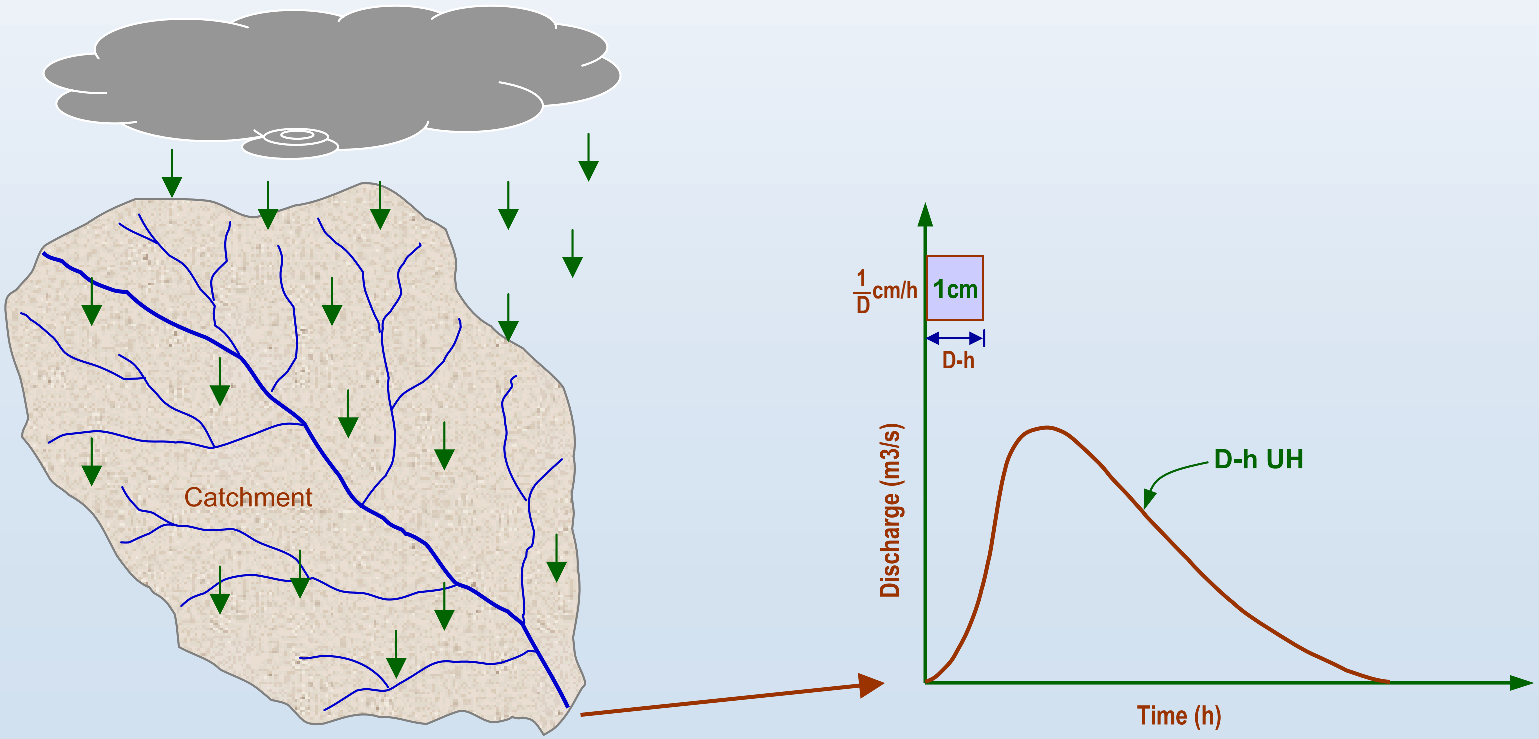
Unit Hydrograph

Kalyan Kumar Bhar

Definition

Sherman (1932) has introduced the concept of unit hydrograph.

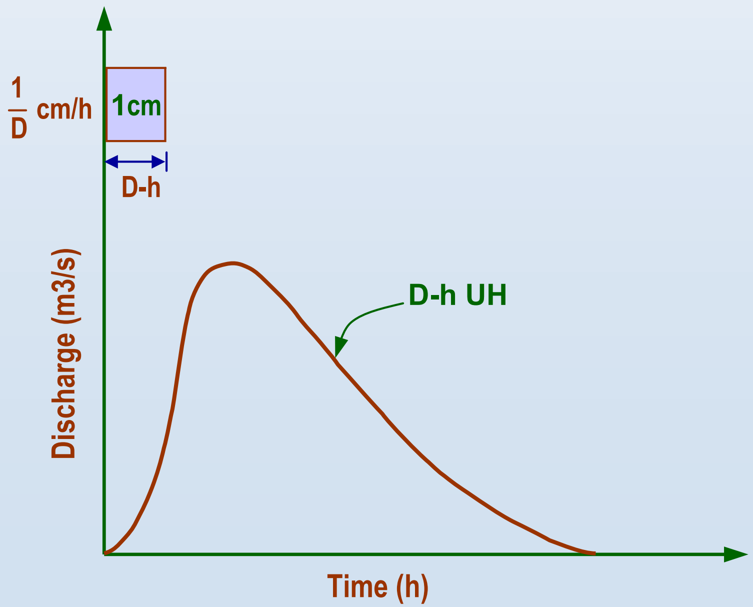
Unit hydrograph is a direct runoff hydrograph resulting from unit (1cm) rainfall excess, occurring uniformly over the entire catchment at a constant rate for a period of D-h.



Characteristics

A D-h Unit Hydrograph has the following characteristics:

- Unit hydrograph is a direct runoff hydrograph. It has no base flow contribution.
- Unit hydrograph is a lumped response of the catchment to a unit rainfall excess of D-h duration.
- Area under the UH curve = 1cm x A km^2
- Intensity of the excess rainfall = 1/D cm/h
- The UH has a steeper rising limb and a flatter falling limb.



Assumptions

Two basic assumptions are involved in the UH theory.

Time Invariance

DRH for a given ER in a catchment is always the same, irrespective of the time of occurrence of the precipitation. It means, shape of the UH will be the same at the beginning, in the middle or at the end of the monsoon.

Linear Response

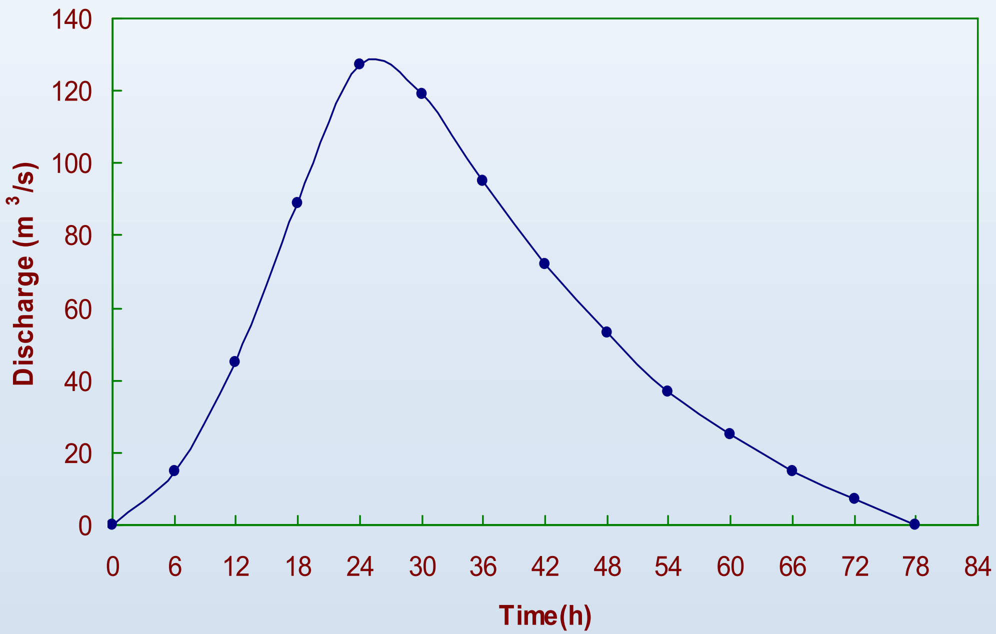
Direct runoff is linearly proportional to the excess rainfall. It implies, if 1cm excess rainfall produces 2.5m^3/s runoff, the 3cm excess rainfall will produce 3 x 2.5 = 7.5m^3/s runoff.

This assumption also enables the principle of superposition to be used. If two or more excess rainfall occur successively, their effects (i.e., resulting DRH) can be estimated independently. These DRH can then be added together maintaining proper time lag, to get the combined DRH.

Example 1

Ordinates of a 6-h UH for a catchment are given below. Calculate the ordinates of a DRH due a rainfall excess of 4.5cm occurring in 6-h on this catchment.

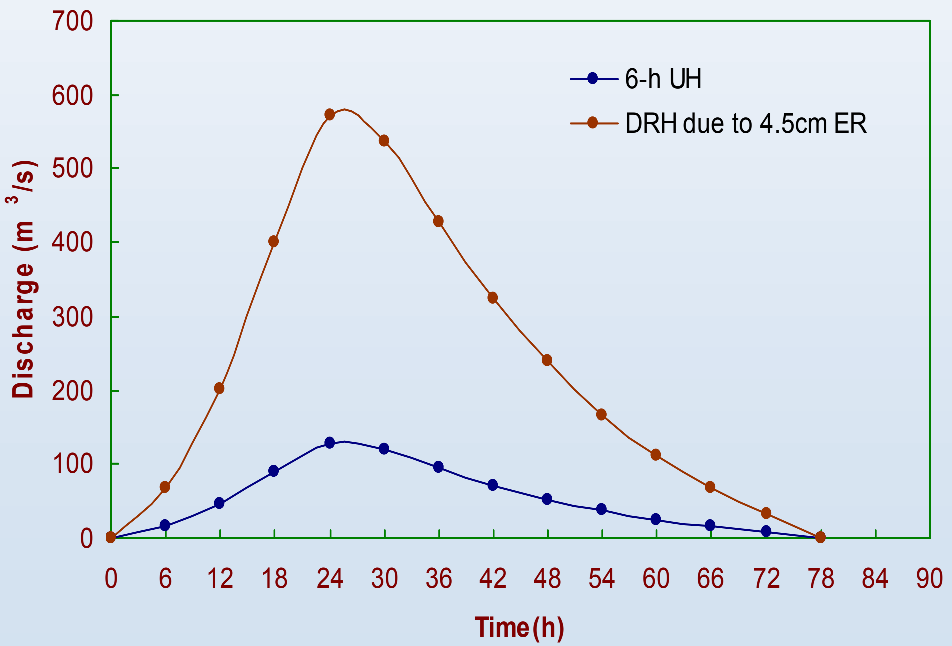
Time (h)	6-h UH Ordinates (m^3/s)
0	0
6	15
12	45
18	89
24	127
30	119
36	95
42	72
48	53
54	37
60	25
66	15
72	7
78	0



Solution

Multiply all the ordinates of the 6-h UH by 4.5, to get the ordinates of the resulting DRH due to 4.5cm ER.

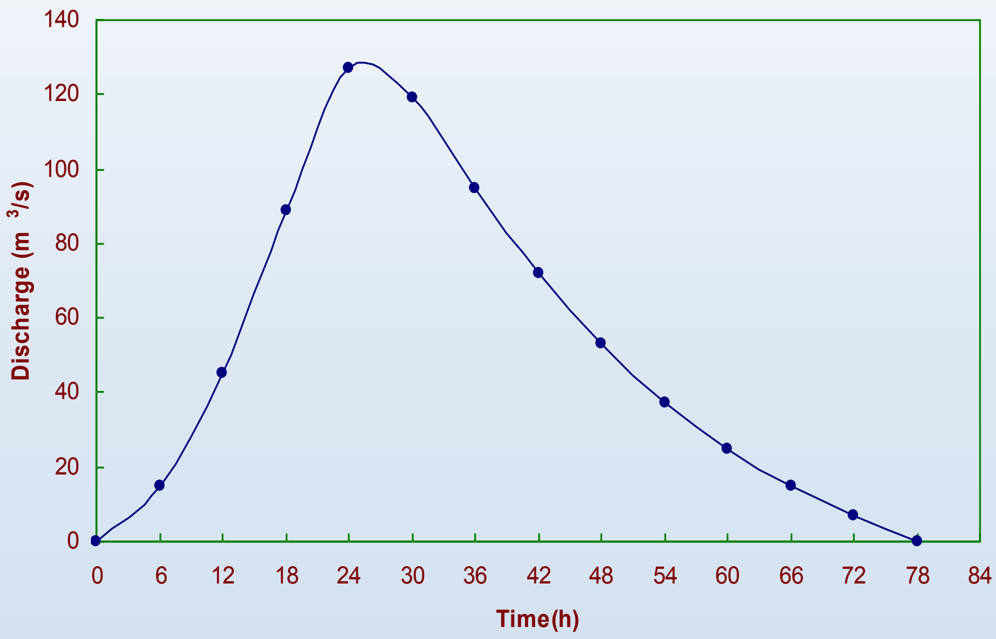
Time (h)	6-h UH Ordinates (m^3/s)	DRH due to 4.5cm ER (m^3/s)
0	0	0
6	15	67.5
12	45	202.5
18	89	400.5
24	127	571.5
30	119	535.5
36	95	427.5
42	72	324
48	53	238.5
54	37	166.5
60	25	112.5
66	15	67.5
72	7	31.5
78	0	0



Example 2

Ordinates of a 6-h UH for a catchment are given below. Calculate the ordinates of a DRH due a rainfall excess of 2cm occurring during first 6-h and a rainfall excess of 3.5cm occurring in the next 6-h over this catchment.

Time (h)	6-h UH Ordinates (m^3/s)
0	0
6	15
12	45
18	89
24	127
30	119
36	95
42	72
48	53
54	37
60	25
66	15
72	7
78	0

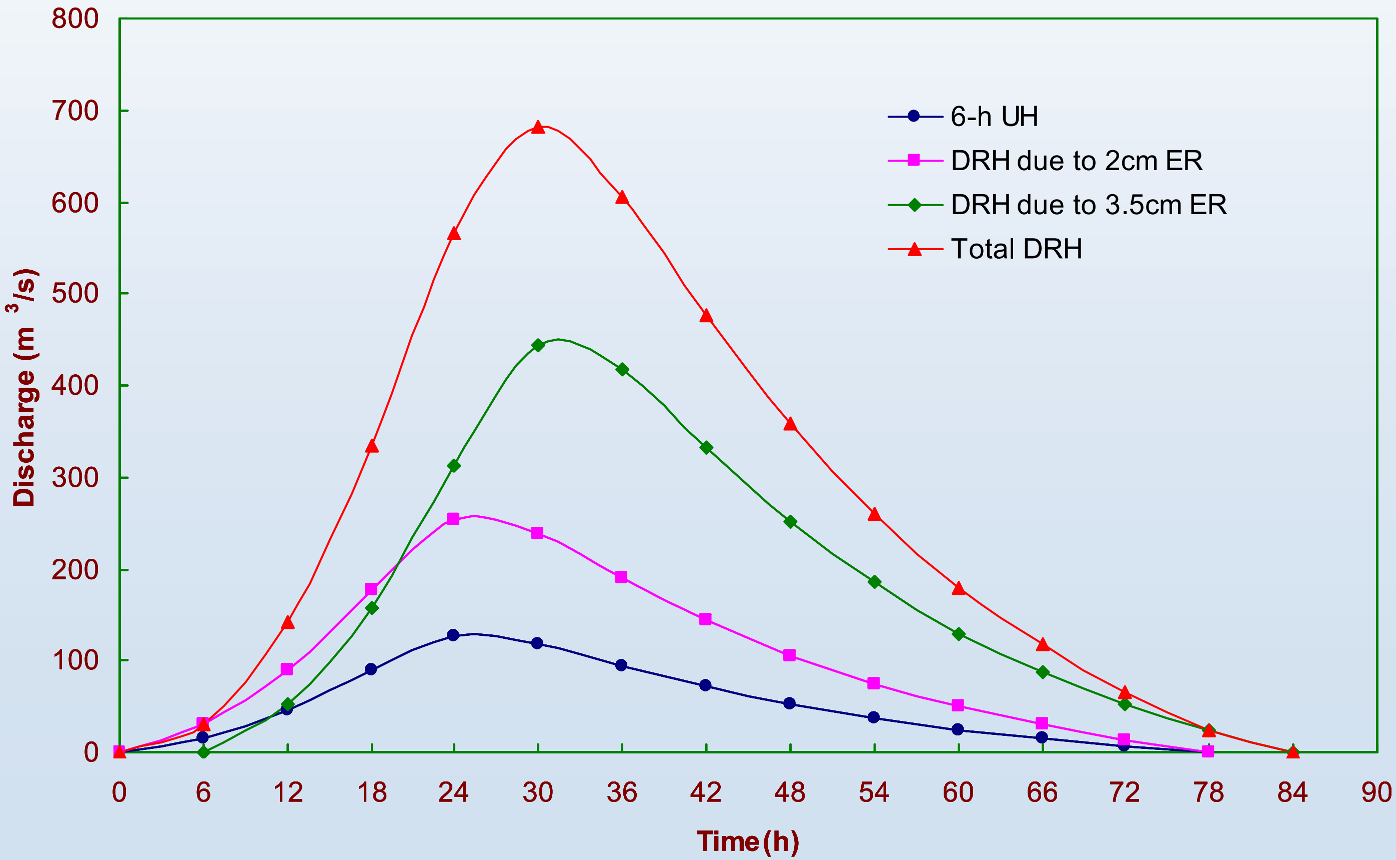


Solution

Time (h)	6-h UH Ordinates (m^3/s)	DRH due to 2 cm ER (m^3/s)	DRH due to 3.5 cm ER (m^3/s) lag = 6h	Total DRH (m^3/s)
(1)	(2)	(3) = (2) x 2	(4) = (2) x 3.5	(3) + (4)
0	0	0		0.0
6	15	30	0.0	30.0
12	45	90	52.5	142.5
18	89	178	157.5	335.5
24	127	254	311.5	565.5
30	119	238	444.5	682.5
36	95	190	416.5	606.5
42	72	144	332.5	476.5
48	53	106	252.0	358.0
54	37	74	185.5	259.5
60	25	50	129.5	179.5
66	15	30	87.5	117.5
72	7	14	52.5	66.5
78	0	0	24.5	24.5
84	0		0.0	0.0

Solution

- Draw 6-h UH
- Multiply all ordinates of 6-h UH by 2. Draw the DRH due to 2cm ER.
- Multiply all ordinates of 6-h UH by 3.5. Draw the DRH due to 3.5cm ER starting from 6-h (i.e., lag = 6h), because 3.5cm ER starts at 6-h.
- Add ordinates of the two DRH to get the combined DRH.

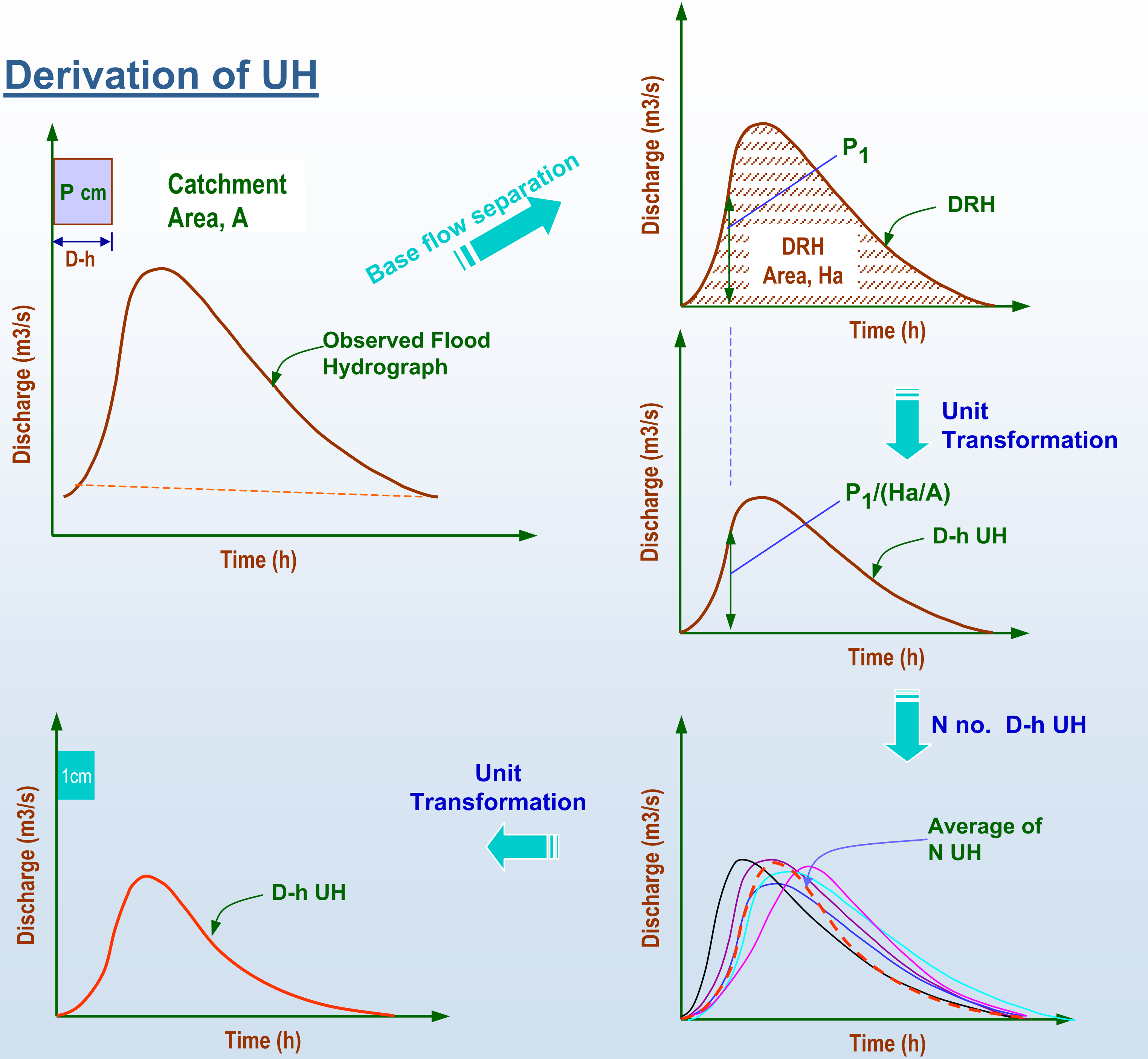


Derivation of UH

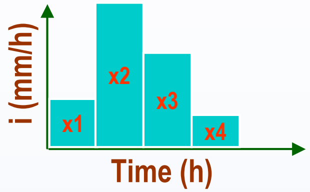
A D-h UH for a catchment is to developed from observed rainfall and corresponding flood hydrograph at the catchment outlet.

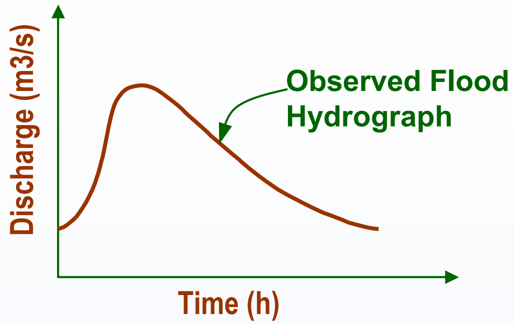
- Select D
- Select a number of isolated storms of duration 10% ± of D.
- Select corresponding flood hydrographs at the catchment outlet.
- For each of these flood hydrographs, separate base flow and get DRHs.
- For each of these DRH,
  - calculate area under the DRH
  - divide the area by the catchment area to get ER
  - divide the ordinates by ER to make it unit hydrograph
- Draw all UH thus derived on a graph paper.
- Calculate average T_B, T_P and Q_P. Draw the average DRH graph.
- Calculate the area under this average graph.
- Divide the area by the catchment area to get ER.
- Divide the ordinates of the average graph by ER to get D-h UH.

Derivation of UH



UH from Compound Storm





Time (h)	UH ordinate (m^3/s)	DRH Due to ER rainfall				Total DRH (m^3/s)		Observed DRH (m^3/s)
		x1 cm	x2 cm	x3 cm	x4 cm			
0	0	0	--	--	--	0	=	0
D	y1	x1y1	0	--	--	x1y1	=	Q1
2D	y2	x1y2	x2y1	0	--	x1y2+x2y1	=	Q2
3D	y3	x1y3	x2y2	x3y1	0	x1y3+x2y2+x3y1	=	Q3
4D	y4	x1y4	x2y3	x3y2	x4y1	x1y4+x2y3+x3y2+x4y1	=	Q4
5D	y5	x1y5	x2y4	x3y3	x4y2	x1y5+x2y4+x3y3+x4y2	=	Q5
6D	y6	x1y6	x2y5	x3y4	x4y3	x1y6+x2y5+x3y4+x4y3	=	Q6
7D	0	0	x2y6	x3y5	x4y4	x2y6+x3y5+x4y4	=	Q7
8D			0	x3y6	x4y5	x3y6+x4y5	=	Q8
9D				0	x4y6	x4y6	=	Q9
10D					0	0	=	0

Unit Hydrograph

- Definition
- Characteristics
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- Example 1
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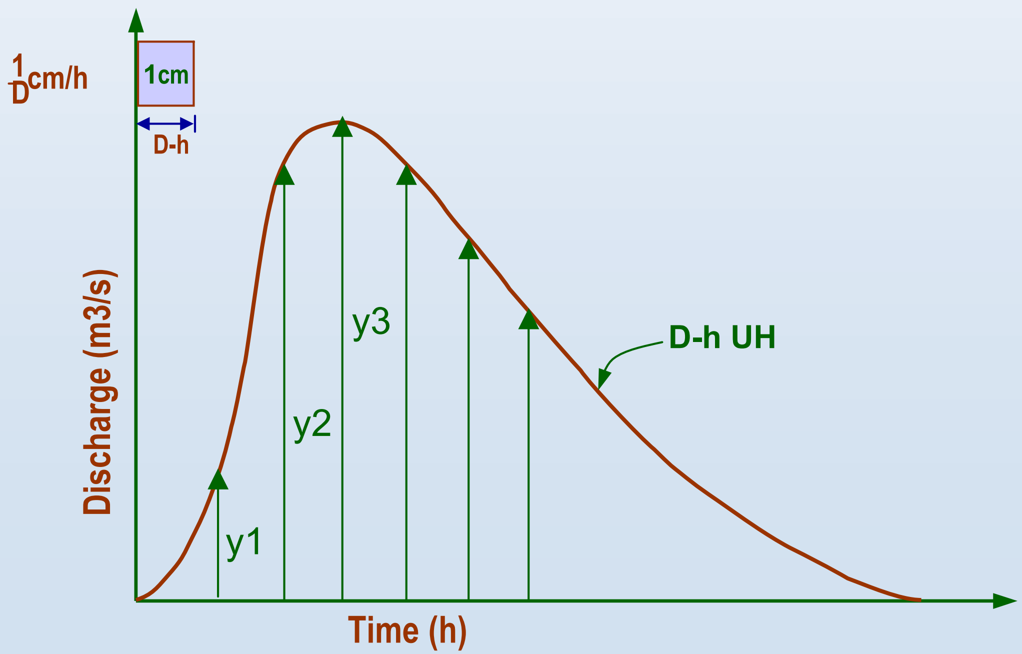
- UH from Compound Storm

UH from Compound Storm

x1y1 = Q1	→	y1 = Q1/x1
x1y2+x2y1 = Q2	→	y2 = (Q2 – x2y1)/x1
x1y3 + x2y2 + x3y1 = Q3	→	y3 = (Q3 – x2y2 – x3y1)/x1
……..		
x1y6 + x2y5 + x3y4 + x4y3 = Q6	→	y6 = (Q6 – x2y5 – x3y4 – x2y5)/x1



UH of Different Durations

For determining flood hydrograph using UH, the type of UH to be used depends on the time interval of the hyetograph. If the hyetograph is having 2-h time interval, then a 2-h UH is to be used. If the time interval is 4-h, then a 4-h UH is to be used. Any other UH cannot be used.

As the development of the UH from observed data is an involved task, usually only one UH is made available for a catchment. Any other UH is to be derived from this UH. That is, if a 2-h UH is available and a 3-h UH or 4-h UH is needed, then these are to be derived from the 2-h UH.

Two different types of tasks are involved while developing a T-h UH from a D-h UH

- T is an integer multiple of D (i.e., T = 1D, 2D, 3D etc.)
- T is a fractional multiple of D (i.e., T = 0.5D, 1.25D, 1.5D etc.)

Method of Superposition can be used for the integer case, whereas

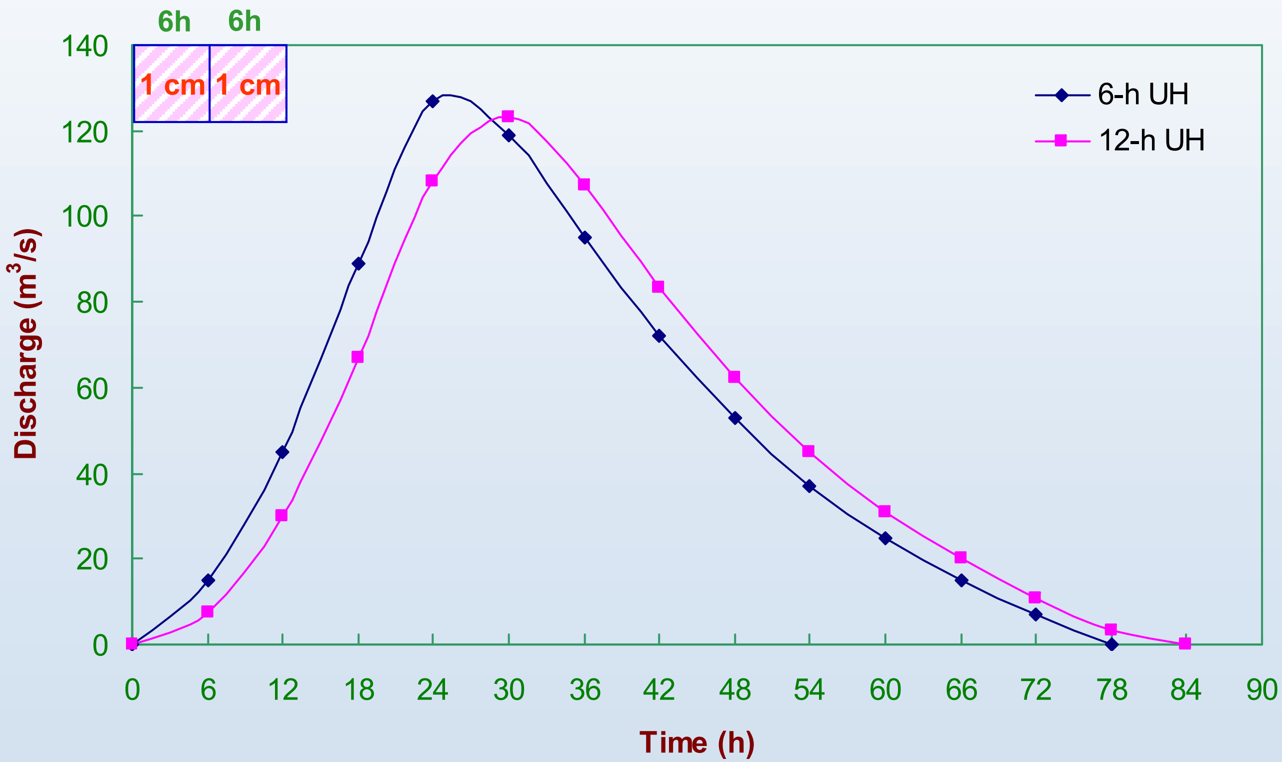
S-curve Technique can be used for both the cases.

Method of Superposition

A 6-h UH for a catchment is given below. Derive a 12-h UH.

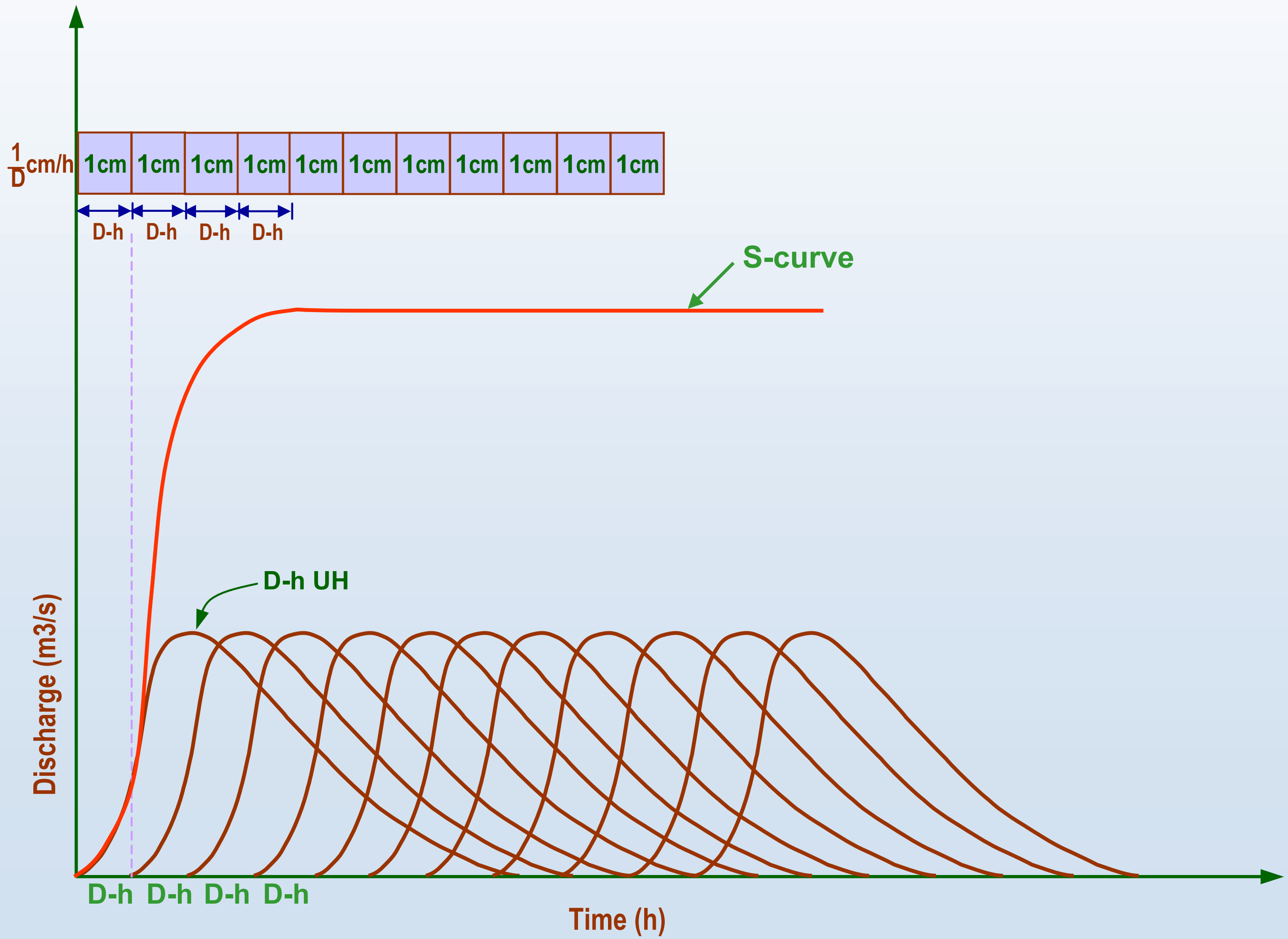
Time (h)	6-h UH Ordinates (m3/s)	6-h UH Lagged by 6-h (m3/s)	12-h DRH due to 1+1 cm ER (m3/s)	12-h UH (m3/s)
col 1	col 2	col 3	col 4	col 4/(1+1)
0	0		0	0.0
6	15	0	15	7.5
12	45	15	60	30.0
18	89	45	134	67.0
24	127	89	216	108.0
30	119	127	246	123.0
36	95	119	214	107.0
42	72	95	167	83.5
48	53	72	125	62.5
54	37	53	90	45.0
60	25	37	62	31.0
66	15	25	40	20.0
72	7	15	22	11.0
78	0	7	7	3.5
84		0	0	0.0

Method of Superposition



S-curve

If a rainfall of intensity 1/D cm/h occurs continuously over a catchment the resulting DRH at the catchment outlet is known as S-curve or S-hydrograph.

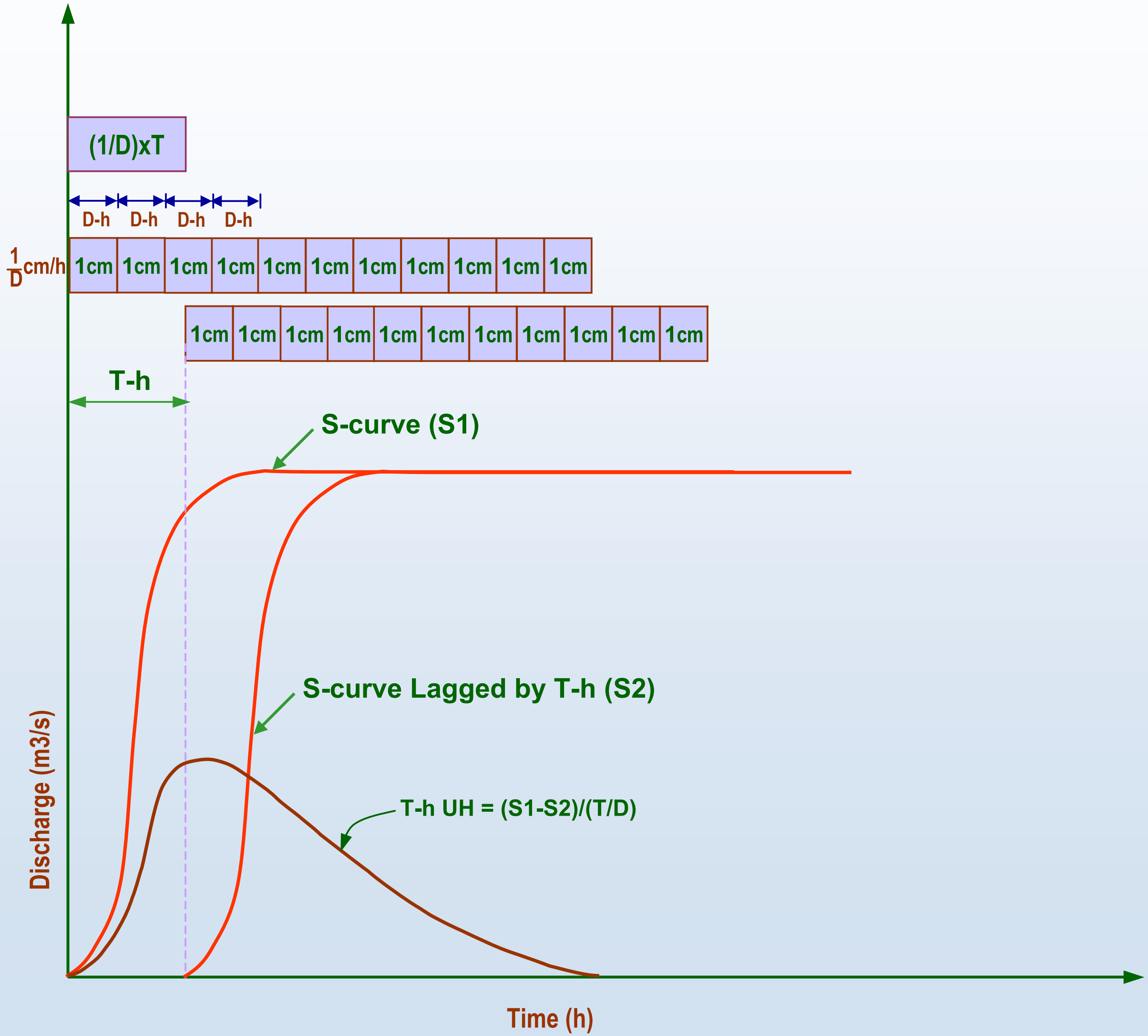


S-curve

If a rainfall of intensity 1/D cm/h occurs continuously over a catchment the resulting DRH at the catchment outlet is known as S-curve or S-hydrograph.

Time (h)	D-h UH (m^3/s)	D-h UH Lagged by D-h	D-h UH Lagged by 2D-h	D-h UH Lagged by 3D-h	D-h UH Lagged by 4D-h	D-h UH Lagged by 4D-h		S-curve ordinates (m^3/s)
0	0						continue	0
D	y1	0						y1
2D	y2	y1	0					y1+y2
3D	y3	y2	y1	0				y1+y2+y3
4D	y4	y3	y2	y1	0			y1+y2+y3+y4
5D	y5	y4	y3	y2	y1	0		y1+y2+y3+y4+y5
6D	0	y5	y4	y3	y2	y1		y1+y2+y3+y4+y5
7D		0	y5	y4	y3	y2		y1+y2+y3+y4+y5
8D			0	y5	y4	y3		y1+y2+y3+y4+y5
				0	y5	y4		y1+y2+y3+y4+y5

S-curve


(1/D)xT
D-h
D-h
D-h
D-h
1/D cm/h
1cm 1cm 1cm 1cm 1cm 1cm 1cm 1cm 1cm 1cm 1cm
1cm 1cm 1cm 1cm 1cm 1cm 1cm 1cm 1cm 1cm 1cm
T-h
S-curve (S1)
S-curve Lagged by T-h (S2)
T-h UH = (S1-S2)/(T/D)
Discharge (m3/s)
Time (h)

S-curve

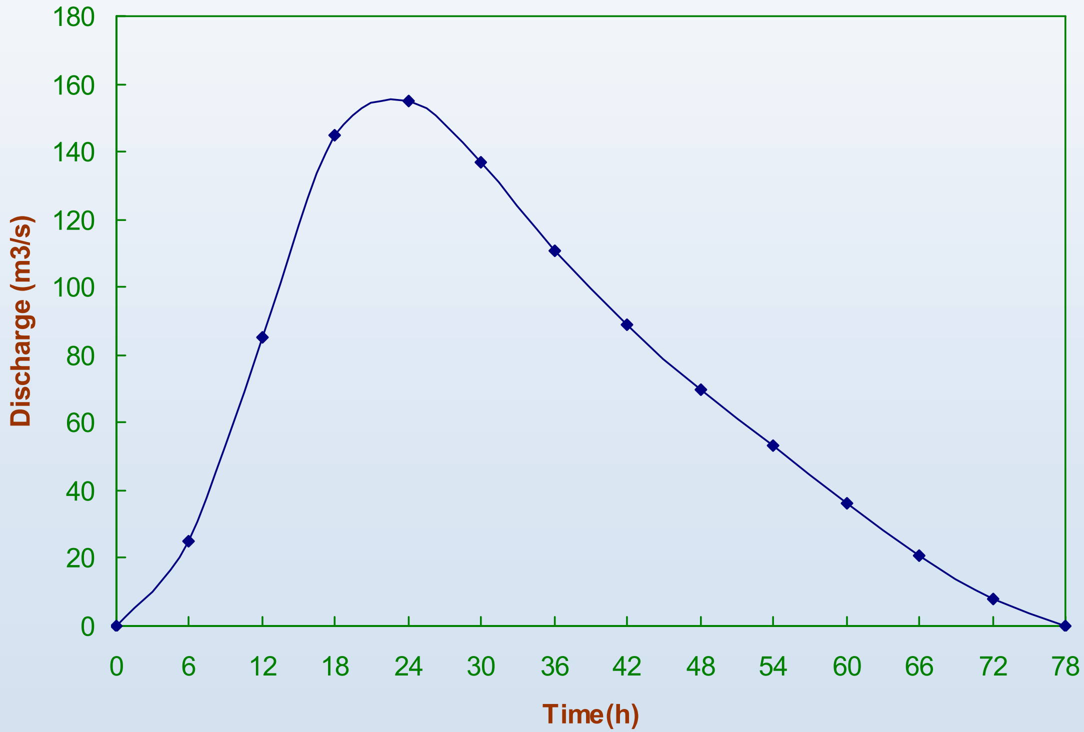
A 6-h UH for a catchment is given below. Derive a 12-h UH using S-curve.

Time (h)	6-h UH Ordinates (m^3/s)	S-Curve Ordinates S1 (m^3/s)	S-curve lagged by 12-h S2 (m^3/s)	S1 - S2 (m^3/s)	12-h UH Ordinates (S1-S2)/2 (m^3/s)
col 1	col 2	col 3	col 4	col 5	col 6
0	0	0		0	0.0
6	15	15		15	7.5
12	45	60	0	60	30.0
18	89	149	15	134	67.0
24	127	276	60	216	108.0
30	119	395	149	246	123.0
36	95	490	276	214	107.0
42	72	562	395	167	83.5
48	53	615	490	125	62.5
54	37	652	562	90	45.0
60	25	677	615	62	31.0
66	15	692	652	40	20.0
72	7	699	677	22	11.0
78	0	699	692	7	3.5
84		699	699	0	0.0

S-curve

A 6-h UH for a catchment is given below. Derive a 3-h UH using S-curve.

Time (h)	6-h UH (m3/s)
0	0
6	25
12	85
18	145
24	155
30	137
36	111
42	89
48	70
54	53
60	36
66	21
72	8
78	0



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- UH of Different Durations
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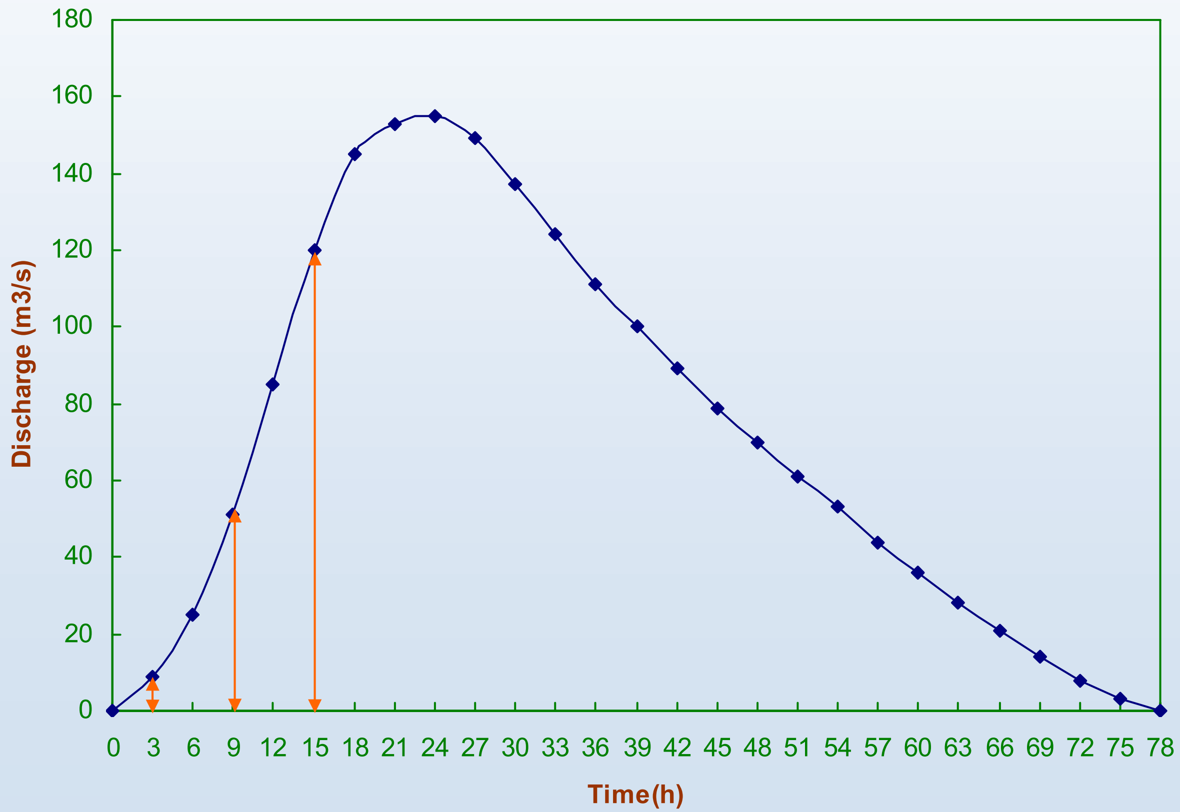
- S-curve

S-curve

Get ordinates at 3-h interval from the graph (or interpolate).



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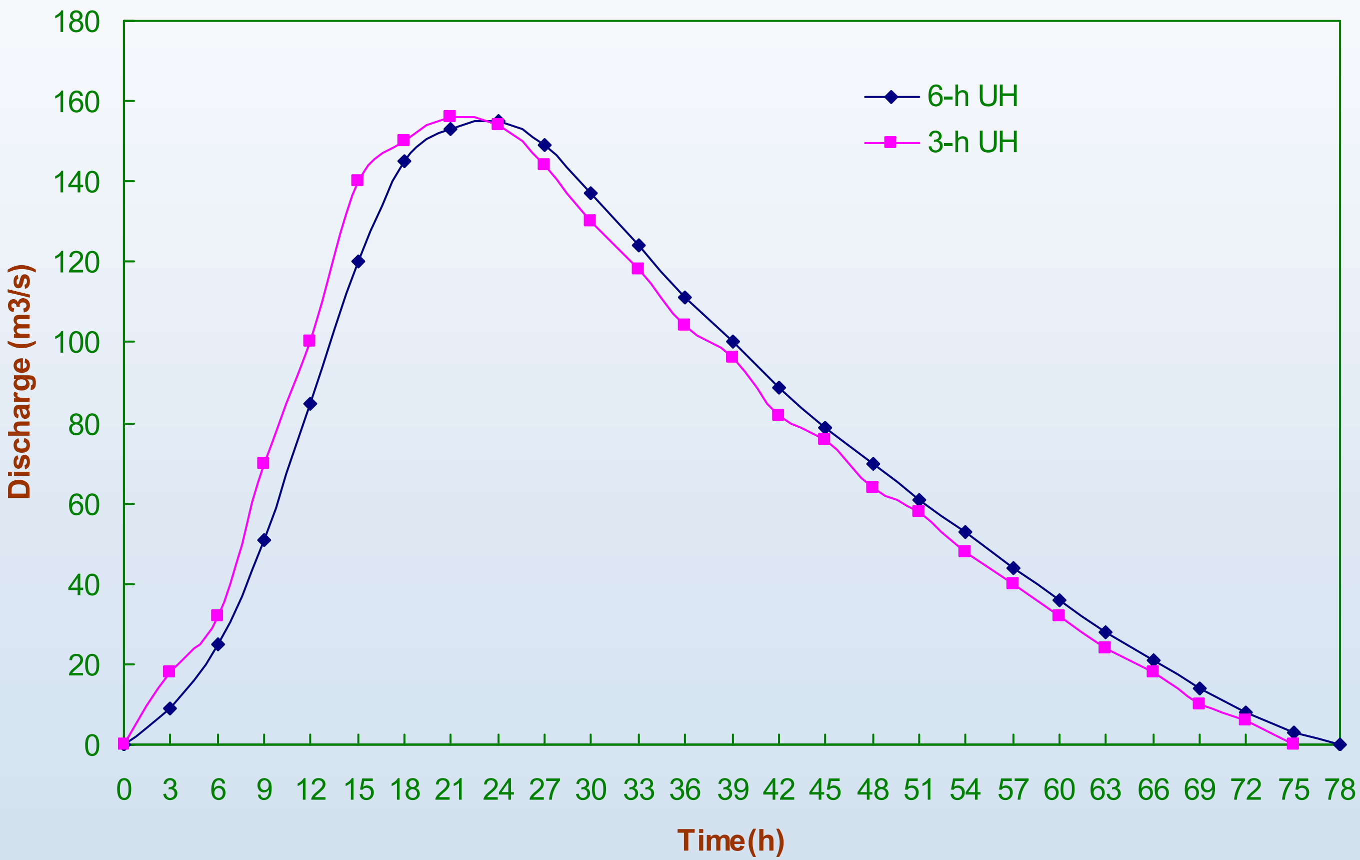
S-curve

Time (h)	6-h UH (m3/s)	6-h S-Curve (m3/s) S1	6-h S-curve 3-h lagged S2	S1-S2	S1-S2	3-h UH m3/s col 5 x 2
col 1	col 2	col 3	col 4	col 5	col 5	col 6
0	0	0		0	0	0
3	9	9	0	9	9	18
6	25	25	9	16	16	32
9	51	60	25	35	35	70
12	85	110	60	50	50	100
15	120	180	110	70	70	140
18	145	255	180	75	75	150
21	153	333	255	78	78	156
24	155	410	333	77	77	154
27	149	482	410	72	72	144
30	137	547	482	65	65	130
33	124	606	547	59	59	118
36	111	658	606	52	52	104
39	100	706	658	48	48	96
42	89	747	706	41	41	82
45	79	785	747	38	38	76
48	70	817	785	32	32	64
51	61	846	817	29	29	58
54	53	870	846	24	24	48
57	44	890	870	20	20	40
60	36	906	890	16	16	32
63	28	918	906	12	12	24
66	21	927	918	9	9	18
69	14	932	927	5	5	10
72	8	935	932	3	3	6
75	3	935	935	0	0	0
78	0	935	935	0	0	0

S-curve


Discharge (m3/s)
0
20
40
60
80
100
120
140
160
180
Time(h)
0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51 54 57 60 63 66 69 72 75 78
6-h UH
3-h UH