CIVL 3066 Engineering Hydrology
Spring 2009
Solution : Assignment Number 2

2.5. A sketch of the Buffalo Creek Watershed is shown in Fig. P2.5. Areas *A* and *B* are identical in size, shape, slope, and channel length. UHs (1 hr) are provided for natural and fully developed conditions for both areas.

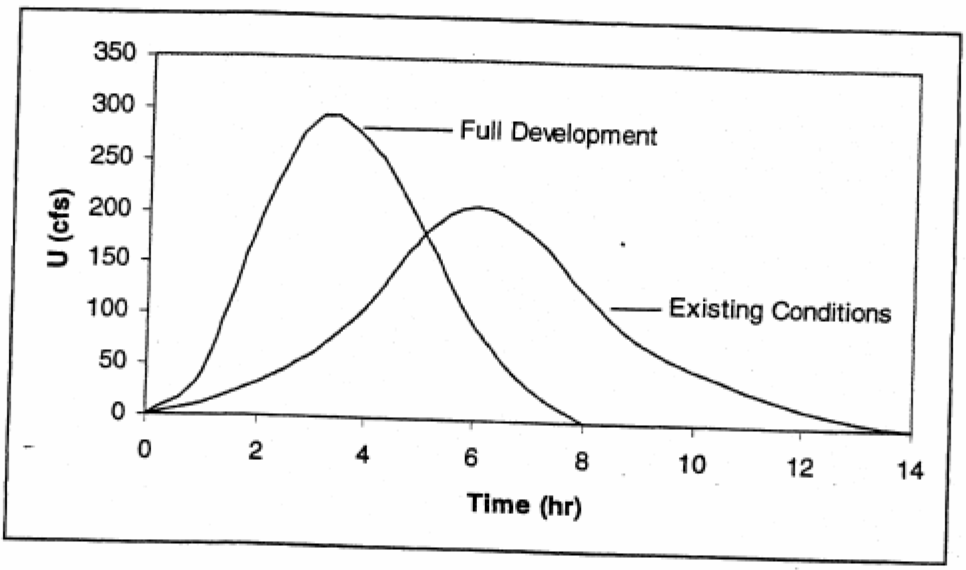
a) Assuming natural conditions for both areas, evaluate the peak outflow at point 1 if 2.5 in./hr of rain falls for 2 hr. Assume a total infiltration loss of 1 in.

b) Assume that area *B* has reached full development and area *A* has remained in natural conditions. Determine the outflow hydrograph at point 1 if a net rainfall of 2 in./hr falls for 1 hr.

c) Sketch the outflow hydrograph for the Buffalo Creek Watershed under complete development (*A* and *B* both urbanized) for the rainfall given in part (b).

Time (hr)	0	1	2	3	4	5	6	7	8
UH_{dev}(cfs)	0	40	196	290	268	185	90	30	0

Time (hr)	0	1	2	3	4	5	6	7	8
UH (nat)	0	12	32	62	108	180	208	182	126
Time (hr)	9	10	11	12	13	14			
UH (nat)	80	53	32	18	6	0			



2.5. (cont)

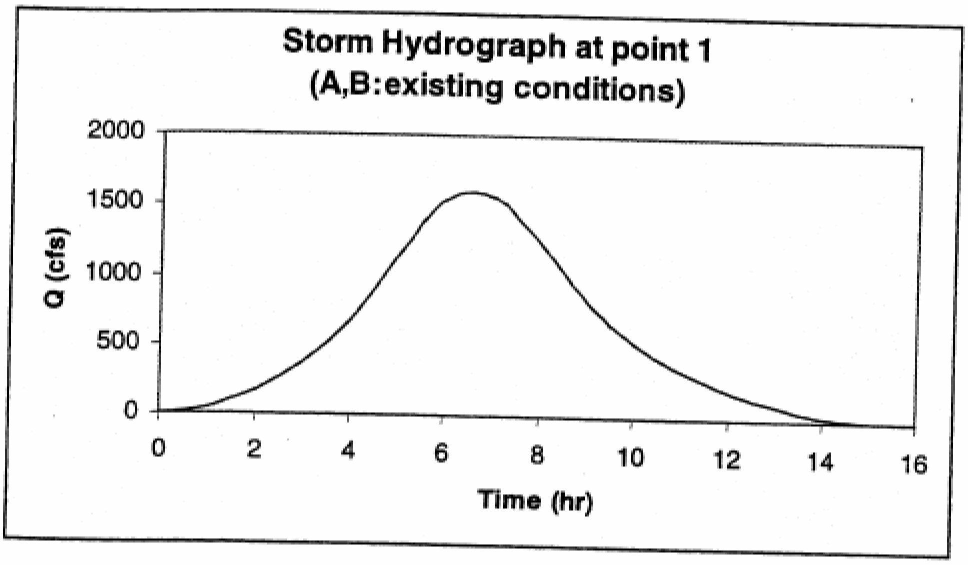
a) Assuming uniform loss, we get a loss rate of 0.5 in/hr.

Net rainfall intensity = 2.5 – 0.5 = 2 in/hr for 2 hours

The storm hydrograph at point 1 is found by combining the storm hydrographs for areas A and B.

Existing conditions for both areas } => $Q_A = Q_B$

Time (hr)	U_{exist}(cfs)	P1*U	P2*U	Q_A (cfs)	Q_B (cfs)	Q (cfs)
0	0	0		0	0	0
1	12	24	0	24	24	48
2	32	64	24	88	88	176
3	62	124	64	188	188	376
4	108	216	124	340	340	680
5	180	360	216	576	576	1152
6	208	416	360	776	776	1552
7	182	364	416	780	780	1560
8	126	252	364	616	616	1232
9	80	160	252	412	412	824
10	53	106	160	266	266	532
11	32	64	106	170	170	340
12	18	36	64	100	100	200
13	6	12	36	48	48	96
14	0	0	12	12	12	24
15	0	0	0	0	0	0



Qp = 1560 cfs at t = 7hr.

2.5. (cont)

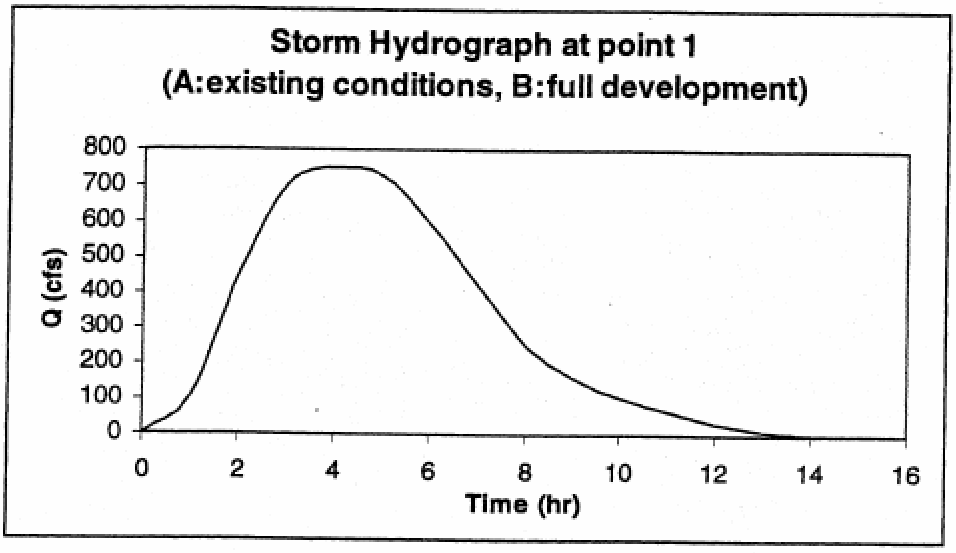
b) In this case we have to determine the storm hydrograph at point one for a 1 – hr duration rainfall.

$Q_A \longrightarrow$ natural (existing) conditions

$Q_B \longrightarrow$ full development

i = 2 in/ hr for 1 – hr.

Time (hr)	U_{exist}(cfs)	U_{devel} (cfs)	Q_A (cfs)	Q_B (cfs)	Q (cfs)
0	0	0	0	0	0
1	12	40	24	80	104
2	32	196	64	392	456
3	62	290	124	580	704
4	108	268	216	536	752
5	180	185	360	370	730
6	208	90	416	180	596
7	182	30	364	60	424
8	126	0	252	0	252
9	80		160		160
10	53		106		106
11	32		64		64
12	18		36		36
13	6		12		12
14	0		0		0



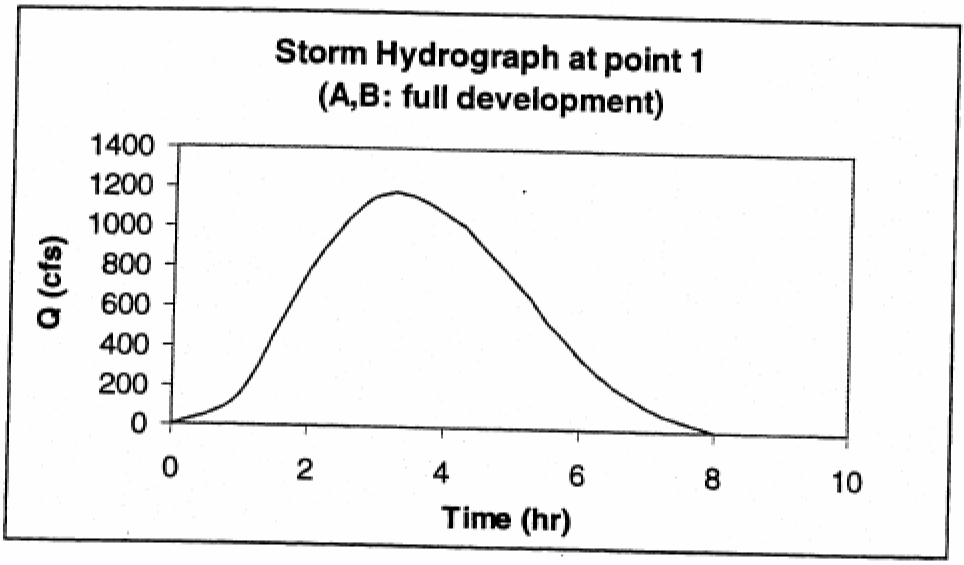
Q_p = 752 cfs at t = 4 hr

2.5. (cont)

c) Full Development for both areas} => $Q_A = Q_B$

i = 2in/ hr for 1 hr

Time (hr)	U_{devel} (cfs)	Q_A (cfs)	Q_B(cfs)	Q (cfs)
0	0	0	0	0
1	40	80	80	160
2	196	392	392	784
3	290	580	580	1160
4	268	536	536	1072
5	185	370	370	740
6	90	180	180	360
7	30	60	60	120
8	0	0	0	0



Q_P = 1160 cfs at t= 3 hr

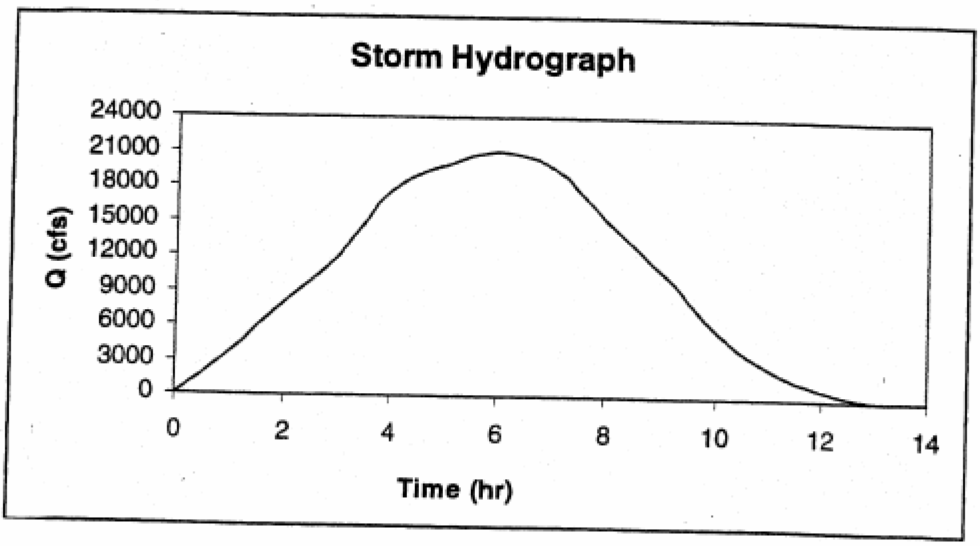
2.6. A watershed basin is approximately 43 square miles and has the following time-area relationship between its subbasins and the outlet.

TIME (hr)	AREA (sq mi)
1	9.5
2	6.7
3	5.2
4	8.0
5	6.6
6	7.0

STORM DATA

Time (hr)	Rainfall Excess (in./hr)
1	0.6
2	0.9
3	1.0
4	1.2
5	0.7
6	0.4
7	0.2

Use the storm measurements to produce an outflow hydrograph in cfs (ac-in/hr) using the time-area method. Use an Excel spreadsheet to perform calculations.



Time	Area	Time to	Area	Intensity	R1*Area	R2*Area	R3*Area	R4*Area	R5*Area	R6*Area	R7*Area	Q
(hr)	(mi^2)	gage (hr)	(ac)	(in/hr)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
0												0
1	9.5	1	6080	0.6	3648							3648
2	6.7	2	4288	0.9	2572.8	5472						8045
3	5.2	3	3328	1	1996.8	3859.2	6080					11936
4	8	4	5120	1.2	3072	2995.2	4288	7296				17651
5	6.6	5	4224	0.7	2534.4	4608	3328	5145.6	4256			19872
6	7	6	4480	0.4	2688	3801.6	5120	3993.6	3001.6	2432		21037
7				0.2	0	4032	4224	6144	2329.6	1715.2	1216	19661
8						0	4480	5068.8	3584	1331.2	857.6	15322
9							0	5376	2956.8	2048	665.6	11046
10								0	3136	1689.6	1024	5850
11									0	1792	844.8	2637
12										0	896	896
13											0	0

2.12. Using the convolution equation, develop a storm hydrograph for the rainfall intensity *i* and infiltration *f* given in the table (at the end of each time step) using the 30-min unit hydrograph *U* given below.

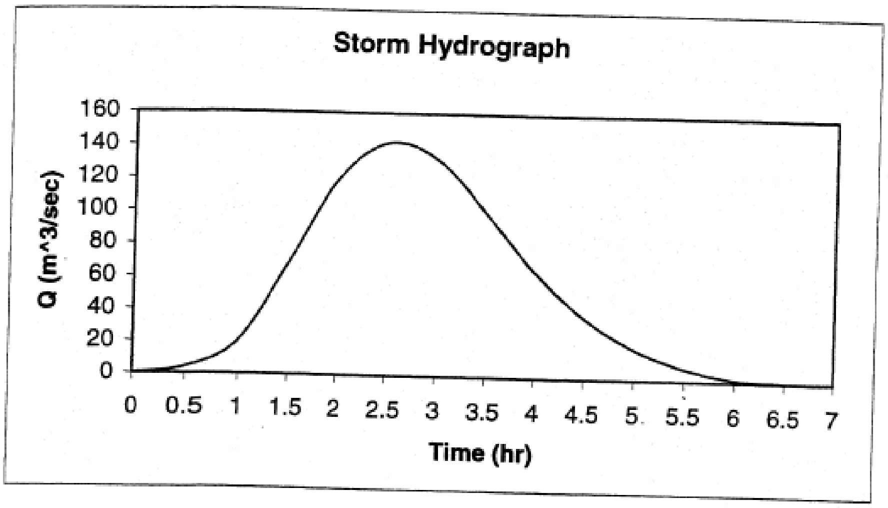
For each interval, the net rainfall intensity is as follows:

Time (hr)	Gross Rainfall Intensity (cm/hr)	Infiltration Rate (cm/hr)	Net Rainfall Intensity (cm/hr)
0-0.5	1	0.75	0.25
0.5-1	1.25	0.5	0.75
1-1.5	2.5	0.4	2.1
1.5-2	1	0.3	0.7

Then P_n = [0.125, 0.375, 1.05, 0.35]

Using an Excel Spreadsheet program, we develop the storm hydrograph.

Time (hr)	U (m^3/s)	P1*Un	P2*Un	P3*Un	P4*Un	Q (m^3/s)
0	0	0				0
0.5	33	4.125	0			4.125
1	66	8.25	12.375	0		20.625
1.5	80	10	24.75	34.65	0	69.4
2	75	9.375	30	69.3	11.55	120.225
2.5	55	6.875	28.125	84	23.1	142.1
3	35	4.375	20.625	78.75	28	131.75
3.5	20	2.5	13.125	57.75	26.25	99.625
4	10	1.25	7.5	36.75	19.25	64.75
4.5	4	0.5	3.75	21	12.25	37.5
5	0	0	1.5	10.5	7	19
5.5			0	4.2	3.5	7.7
6				0	1.4	1.4
6.5					0	0



2.17.

Given the following 2-hr unit hydrograph, calculate the 1-hr unit hydrograph. Then back calculate and find the 2-hr unit hydrograph to prove that the method of calculation is accurate. Graph both unit hydrographs against time on the same plot.

TIME (hr)	0	1	2	3	4	5	6
FLOW (cfs)	0	33	100	200	400	500	433

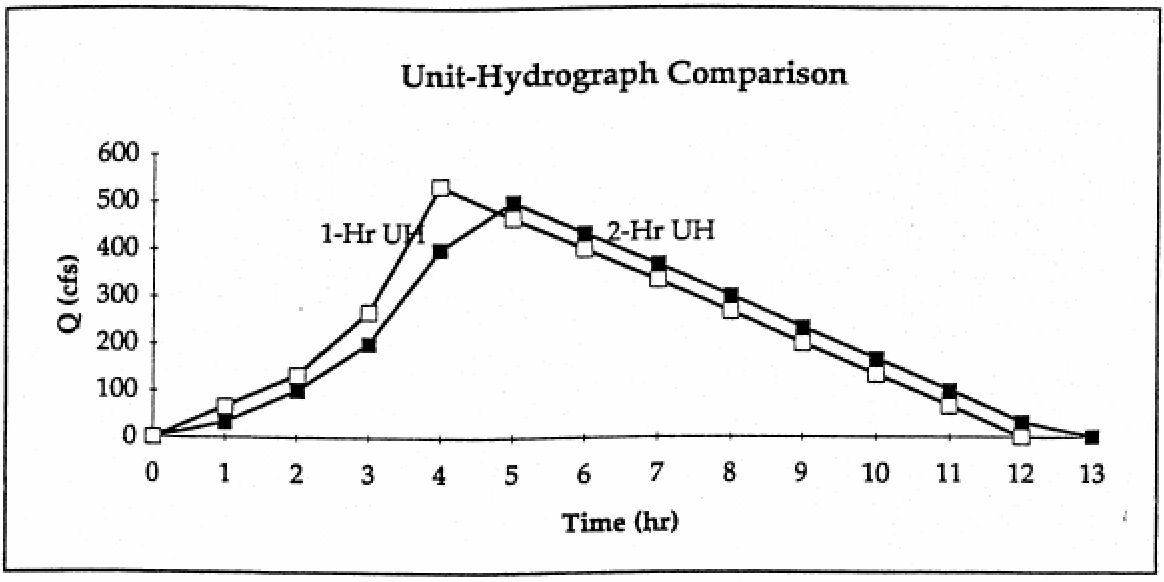
TIME (hr)	7	8	9	10	11	12	13
FLOW (cfs)	367	300	233	167	100	33	0

- The following steps describe the procedure used to achieve the results summarized in the spreadsheet and graph below

- Lag the 2 – hr unit hydrograph by 2 – hr increments to obtain the S –curve
- Then lag the S –curve by the time of duration of the new unit hydrograph – in this case, 1 –hr.
- Multiply the resulting ordinate values by the ratio D/D' where D is the original duration and D' is the desired duration. D/D = 2/1 = 2.

Time (hr)	2-Hr UH (cfs)							S-Curve	Lagged S-Curve	Difference (cfs)	1-Hr UH (cfs)
0	0							0		0	0
1	33							33	0	33	66
2	100	0						100	33	67	134
3	200	33						233	100	133	266
4	400	100	0					500	233	267	534
5	500	200	33					733	500	233	466
6	433	400	100	0				933	733	200	400
7	367	500	200	33				1100	933	167	334
8	300	433	400	100	0			1233	1100	133	266
9	233	367	500	200	33			1333	1233	100	200
10	167	300	433	400	100	0		1400	1333	67	134
11	100	233	367	500	200	33		1433	1400	33	66
12	33	167	300	433	400	100	0	1433	1433	0	0
13	0	100	233	367	500	200	33	1433	1433	0	

2.17. (cont)



Performing the process in reverse, we can verify our solution:

Note; D/D' = ½ for the reverse process.

Time (hr)	1-Hr UH (cfs)								S-Curve	Lagged S-Curve	Difference (cfs)	2-Hr UH (cfs)
0	0								0		0	0
1	66	0							66		66	33
2	134	66	0						200	0	200	100
3	266	134	66	0					466	66	400	200
4	534	266	134	66	0				1000	200	800	400
5	466	534	266	134	66	0			1466	466	1000	500
6	400	466	534	266	134	66	0		1866	1000	866	433
7	334	400	466	534	266	134	66	.	2200	1466	734	367
8	266	334	400	466	534	266	134	..	2466	1866	600	300
9	200	266	334	400	466	534	266	...	2666	2200	466	233
10	134	200	266	334	400	466	534	....	2800	2466	334	167
11	66	134	200	266	334	400	466	.....	2866	2666	200	100
12	0	66	134	200	266	334	400	......	2866	2800	66	33
13	0		66	134	200	266	334	....	2866	2866	0	0

This 2 – hr unit hydrograph is the same as given.

2.19. Develop storm hydrographs from UHs of subarea 1 and 2 for the given rainfall and infiltration.

Time (hr)	0	1	2	3	4	5	6	7	8	9
UH_1 (cfs)	0	200	400	600	450	300	150	0		
UH_2 (cfs)	0	100	300	450	350	250	150	100	50	0

Time Interval (hr)	Gross Rainfall (in/hr)	Infiltration Capacity (in/hr)	Rainfall Excess (in/hr)
0-1	0.5	0.4	0.1
1-2	1.1	0.2	0.9
2-3	3	0.2	2.8
3-4	0.9	0.2	0.7

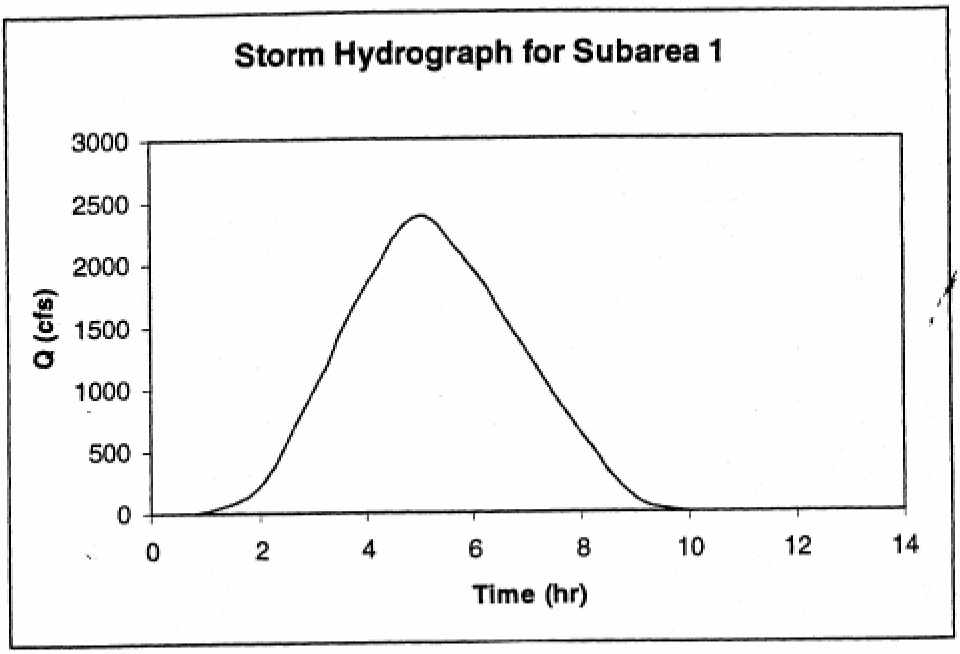
So P_N = [0.1, 0.9, 2.8, 0.7]

Using the convolution equation, we calculate the storm hydrograph for subareas 1 and 2.

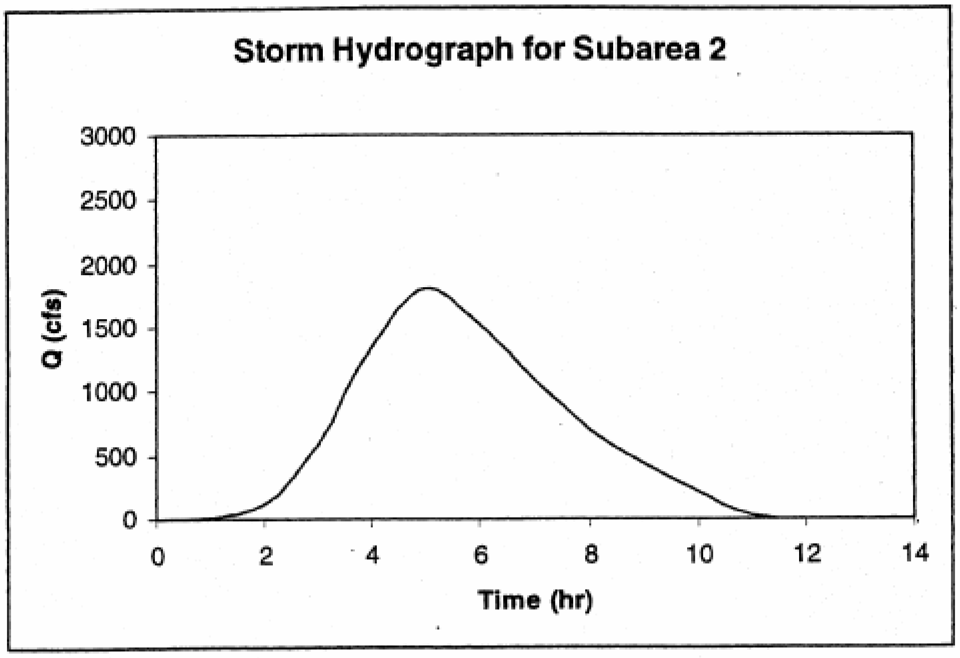
Time (hr)	UH1	P1*UH1 (cfs)	P2*UH1 (cfs)	P3*UH1 (cfs)	P4*UH1 (cfs)	Q1 (cfs)
0	0	0				0
1	200	20	0			20
2	400	40	180	0		220
3	600	60	360	560	0	980
4	450	45	540	1120	140	1845
5	300	30	405	1680	280	2395
6	150	15	270	1260	420	1965
7	0	0	135	840	315	1290
8			0	420	210	630
9				0	105	105
10					0	0

Time (hr)	UH2	P1*UH2 (cfs)	P2*UH2 (cfs)	P3*UH2 (cfs)	P4*UH2 (cfs)	Q2 (cfs)
0	0	0				0
1	100	10	0			10
2	300	30	90	0		120
3	450	45	270	280	0	595
4	350	35	405	840	70	1350
5	250	25	315	1260	210	1810
6	150	15	225	980	315	1535
7	100	10	135	700	245	1090
8	50	5	90	420	175	690
9	0	0	45	280	105	430
10			0	140	70	210
11				0	35	35
12					0	0

2.19. (cont.)



Storm Hydrograph for Subarea 1
Q (cfs)
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
14
Time (hr)



Storm Hydrograph for Subarea 2
Q (cfs)
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
14
Time (hr)

2.23. Sketch the SCS triangular and curvilinear UHs and the mass curve for a 100 mi^2 watershed which is 60% good condition meadow and 40% good cover forest land. The watershed consists of 70% soil group C and 30% soil group A. The average slope is 100 ft/mi, the rainfall duration is 3 hr, and the length to divide is 18 mi.

	Soil group		CN
Good condition meadow	C	0.6*0.7= 0.42	71
	A	0.6*0.3= 0.18	30
Good cover forest land	C	0.4*0.7= 0.28	70
	A	0.4*0.3= 0.12	25

The weighted CN is : $0.42 \cdot 71 + 0.18 \cdot 30 + 0.28 \cdot 70 + 0.12 \cdot 25 = 57.82 \approx 58$

$l = 18\ mi = 18\ mi \cdot 5280\ ft/mi = 95,040\ ft$

The slope is 100 ft/mi => $y = (100\ ft/mi)\ (1mi/5280\ ft)\ (100\%) = 1.9\ \%$

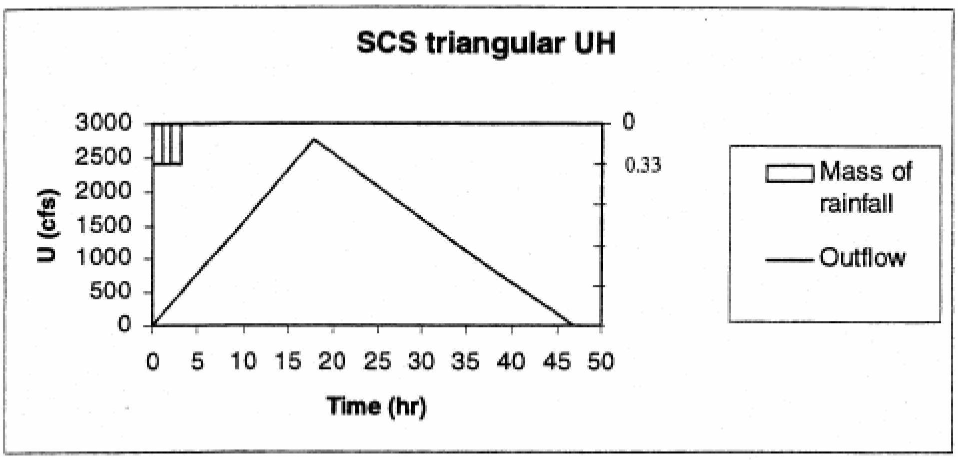
$S = (1000/CN) - 10 = (1000/58) - 10 = 7.24$ in

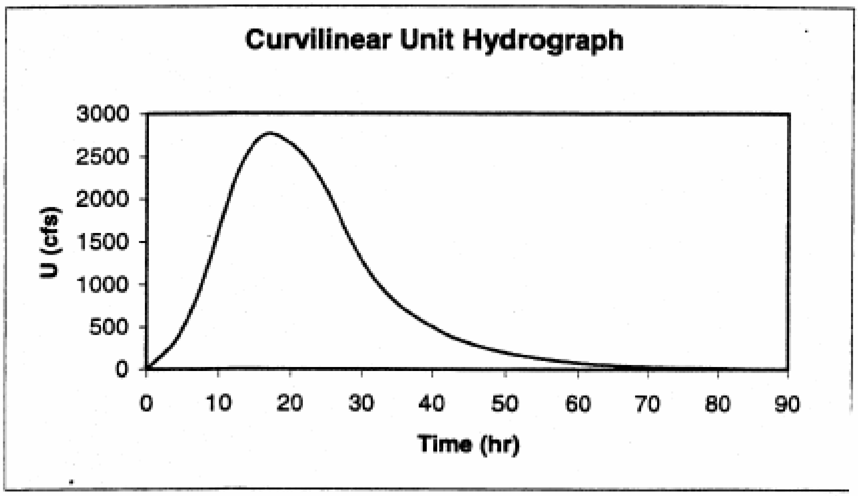
$t_p = (l^{0.8} \cdot (s + 1)^{0.7}/1900y^{1/2}) = (95,040^{\ 0.8}\ (7.24 + 1)^{\ 0.7}/1900 \bullet \sqrt{1.9}) = 16.05$ hr

$T_R = D/2 + t_p = 1.5 + 16.05 = 17.55$ hr

$Q_P = (484 \cdot A/T_R) = (484 \cdot 100/17{,}55) = 2757.83$

$B = 1.67\ T_R = 1.67 \cdot 17.55 = 29.31$ hr





Curvilinear Unit Hydrograph
3000
2500
2000
1500
1000
500
0
U (cfs)
0
10
20
30
40
50
60
70
80
90
Time (hr)

2.24. For a 45 mi^2 watershed with $C_t = 2.2$, L = 15 mi, $L_c = 7$ mi, and $C_p = 0.5$, find t_p, Q_p, T_b, and D. Plot the resulting Snyder UH.

$t_p = C_t (L \cdot L_c)^{0.3} = 2.2 \cdot (15 \cdot 7)^{0.3} = 8.9$ hr

$Q_p = (640 \cdot 0.5 \cdot 45/8.9) = 1618$ cfs

$T_D = 4 \cdot t_p = 4 \cdot 8.9 = 35.6$ hr

$D = t_p/55 = 1.6$ hr

$W_{75} = 440 (Q_p/A)^{-1.08} = 440 \cdot (1618/45)^{-1.08} = 9.2$ (3.1 before Q_p, 6.1 after Q_p)

$W_{50} = 770 (Q_p/A)^{-1.08} = 770 (1618/45)^{-1.08} = 16.1$ (5.4 before Q_p, 10.7 after Q_p)

The time of Q_p is = 8.9 + (1.6/2) = 9.7 hr

At t = 9.7 – 3.1 = 6.6 hr and t = 15.8 hr, Q = 1213.5 cfs

At t = 9.7 – 5.4 = 4.3 hr and t = 9.7 + 10.7 = 20.4 hr, Q = 809 cfs