CE 3354 Engineering Hydrology
Exercise Set 6

Exercises

1. An agricultural watershed was urbanized over a 20 year interval. A triangular one-hour unit hydrograph was developed for this watershed for an excess rainfall duration of one hour.

   Before urbanization, the average loss rate was 0.30 in/hr.

   Figure 1 is the unit hydrograph that has a peak discharge of 400 cfs/in occurring at 3 hours, and a base time of 9 hours.

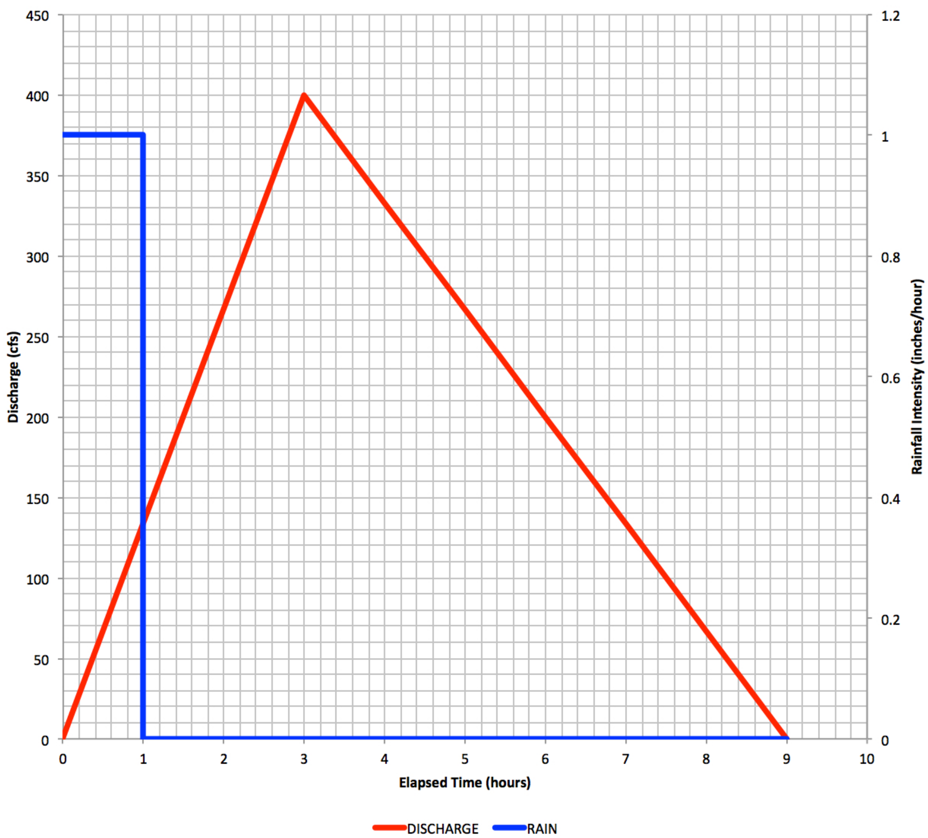


Figure 1: Pre-Urbanization unit hydrograph for excess rainfall of 1 in/hr for 1 hour.

After urbanization the loss rate was reduced to 0.15 in/hr and the peak discharge of the unit hydrograph increased to 600 cfs/in occurring at 1 hour, and the base time reduced to 6 hours. Figure 2 is the unit hydrograph with a peak discharge of 600 cfs occurring at 1 hours, and a time base of 6 hours.

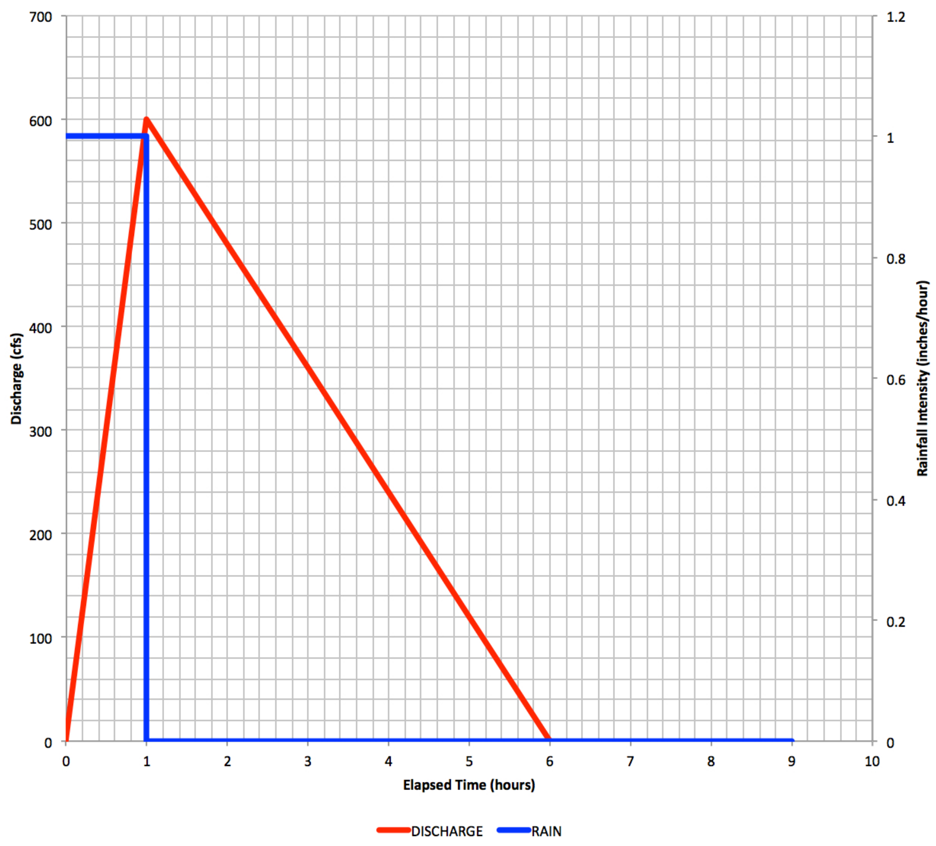


Figure 2: Post-Urbanization unit hydrograph for excess rainfall of 1 in/hr for 1 hour.

For a two hour storm in which 1 inch of rain fell in the first hour and 0.5 inch in the second hour, determine the direct runoff hydrographs before and after urbanization.[1]

[1]This exercise is the same as problem 7.5.7, pg. 238 in Chow, Maidment, Mays

Solution

a) Using Figure 1 as a template, the two increments of rainfall are directly plotted onto the template, then loss is applied to each increment. The resulting unitgraphs from each increment are plotted (in magenta/purple) and then ordinate-by-ordinate addition is used to construct the composite direct runoff hydrograph, as depicted in Figure 3

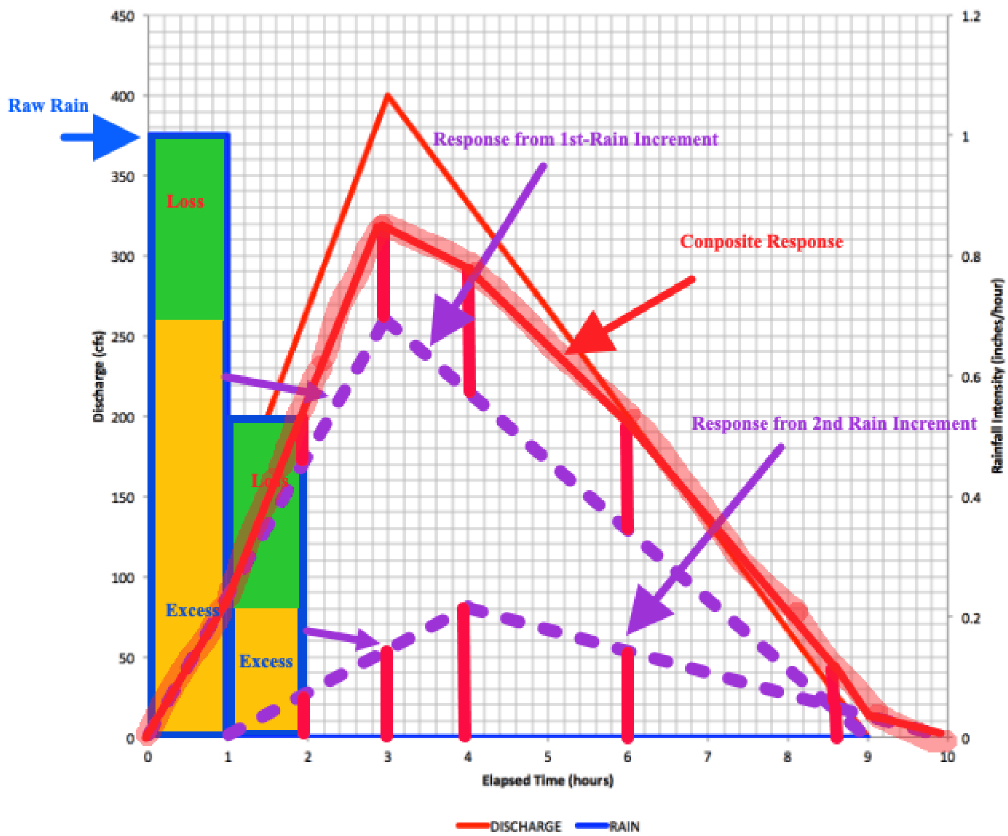


Figure 3: Pre-Urbanization unit hydrograph for excess rainfall of 1 in/hr for 1 hour.

b) Using Figure 2 as a template, the two increments of rainfall are directly plotted onto the template, then loss is applied to each increment. The resulting unitgraphs from each increment are plotted (in magenta/purple) and thenordinate-by-ordinate addition is used to construct the composite direct runoff hydrograph, as depicted in Figure 4

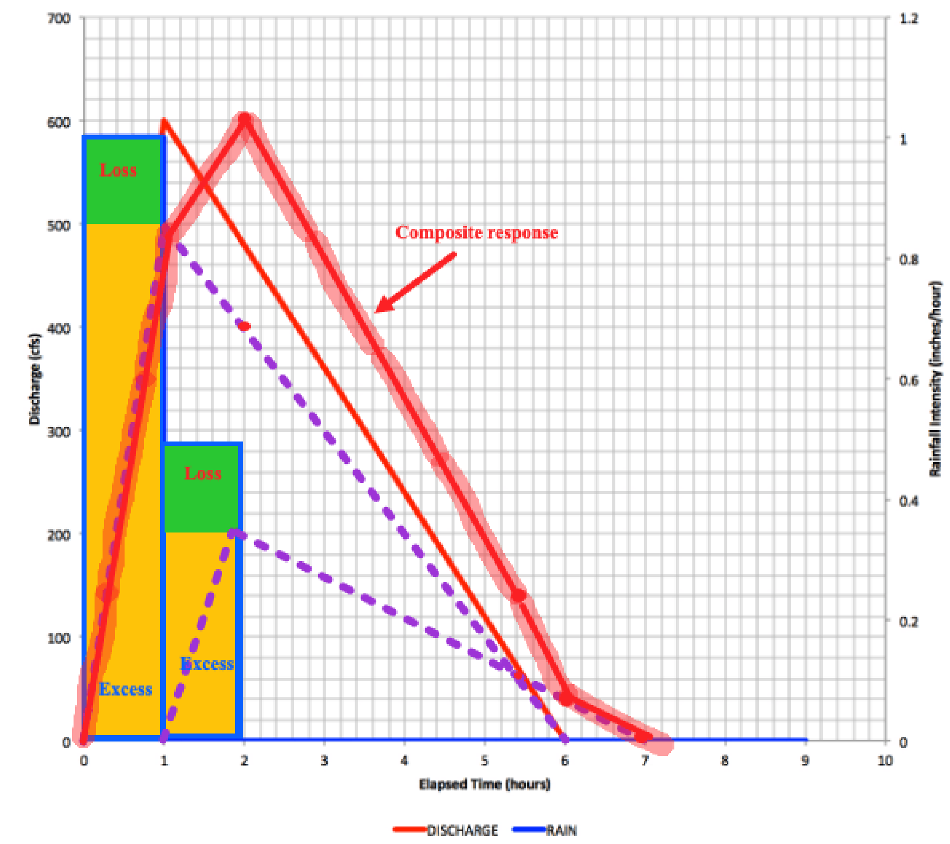


Figure 4: Post-Urbanization unit hydrograph for excess rainfall of 1 in/hr for 1 hour.

c) Alternatively (and more usefully) the responses can be incorporated into a spreadsheet as depicted in Figure 5.

	A	B	C	D	F	G	H	J	K	L	M	N	O	P	Q	R	S	T	U
1	BEFORE URBANIZATION					DESIGN STORM													
2	TIME	RAW RAIN	EXCESS RAIN	UNITGRAPH	TIME	RAW RAIN	EXCESS RAIN	[P]											[P]*[U]
3	0	1	1	0	0	1	0.7	0.7	0	0	0	0	0	0	0	0	0	0	0
4	1	0	0	133.3	1	0.5	0.2	0.2	0.7	0	0	0	0	0	0	0	0	0	93.33
5	2	0	0	266.7	2	0	0	0	0.2	0.7	0	0	0	0	0	0	0	0	213.3
6	3	0	0	400	3	0	0	0	0	0.2	0.7	0	0	0	0	0	0	0	333.3
7	4	0	0	333.3	4	0	0	0	0	0	0.2	0.7	0	0	0	0	0	0	313.3
eenshot			0	266.7	5	0	0	0	0	0	0	0.2	0.7	0	0	0	0	0	253.3
9	6	0	0	200	6	0	0	0	0	0	0	0	0.2	0.7	0	0	0	0	193.3
10	7	0	0	133.3	7	0	0	0	0	0	0	0	0	0.2	0.7	0	0	0	133.3
11	8	0	0	66.67	8	0	0	0	0	0	0	0	0	0	0.2	0.7	0	0	73.33
12	9	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0.2	0.7	0	13.33
13	10	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0.2	0.7	0
14	AFTER URBANIZATION					DESIGN STORM													
15	TIME	RAW RAIN	EXCESS RAIN	UNITGRAPH	TIME	RAW RAIN	EXCESS RAIN	[P]											[P]*[U]
16	0	1	1	0	0	1	0.85	85	0	0	0	0	0	0	0	0	0	0	0
17	1	0	0	600	1	0.5	0.35	0.35	0.85	0	0	0	0	0	0	0	0	0	510
18	2	0	0	480	2	0	0	0	0.35	0.85	0	0	0	0	0	0	0	0	618
19	3	0	0	360	3	0	0	0	0	0.35	0.85	0	0	0	0	0	0	0	474
20	4	0	0	240	4	0	0	0	0	0	0.35	0.85	0	0	0	0	0	0	330
21	5	0	0	120	5	0	0	0	0	0	0	0.35	0.85	0	0	0	0	0	186
22	6	0	0	0	6	0	0	0	0	0	0	0	0.35	0.85	0	0	0	0	42
23	7	0	0	0	7	0	0	0	0	0	0	0	0	0.35	0.85	0	0	0	0
24	8	0	0	0	8	0	0	0	0	0	0	0	0	0	0.35	0.85	0	0	0
25	9	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0.35	0.85	0	0
26	10	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0.35	0.85	0
27																			

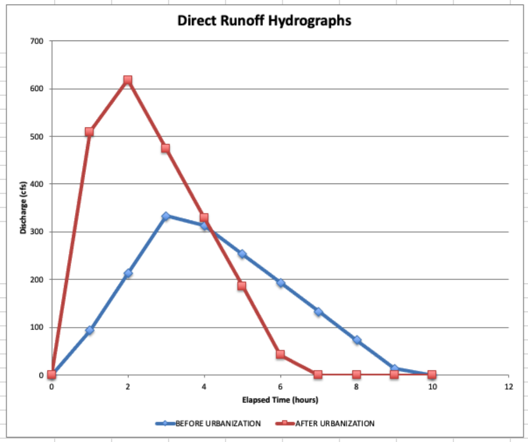


Figure 5: Spreadsheet solution

The working spreadsheet is located at `http://54.243.252.9/ce-3354-webroot/2-Exercises/ES-6/ES6-SourceCode/ES6-Solution.xlsx`. Figure 5 is captures from Tab Sheet "P1."

2. A storm on April 16, 1977, on the Shoal Creek watershed at Northwest Park in Austin, Texas, resulted in the rainfall-runoff values in Figure 6.

   Use the linear regression method to determine the half-hour unit hydrograph for the watershed. The watershed drainage area is 7.03 mi^2. Assume that a uniform loss rate (constant loss model) is valid.[2]

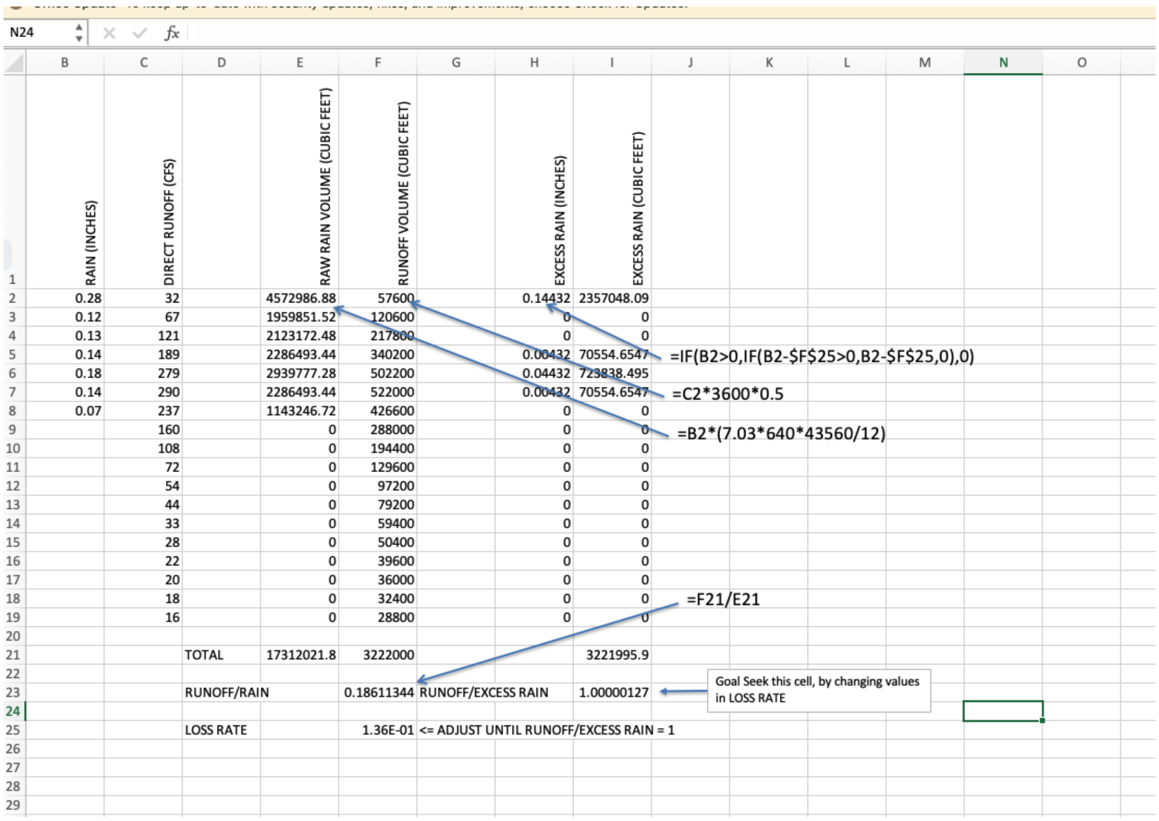
TIME (HRS)	RAIN (IN)	DIRECT RUNOFF (CFS)
0.5	0.28	32.0
1.0	0.12	67.0
1.5	0.13	121.0
2.0	0.14	189.0
2.5	0.18	279.0
3.0	0.14	290.0
3.5	0.07	237.0
4.0		160.0
4.5		108.0
5.0		72.0
5.5		54.0
6.0		44.0
6.5		33.0
7.0		28.0
7.5		22.0
8.0		20.0
8.5		18.0
9.0		16.0

Figure 6: Observed storm rainfall incremental depths and observed direct runoff hydrograph

[2] This exercise is a hybrid of problems 7.6.2 and 7.6.5, pg 239 in Chow, Maidment, and Mays.

Solution

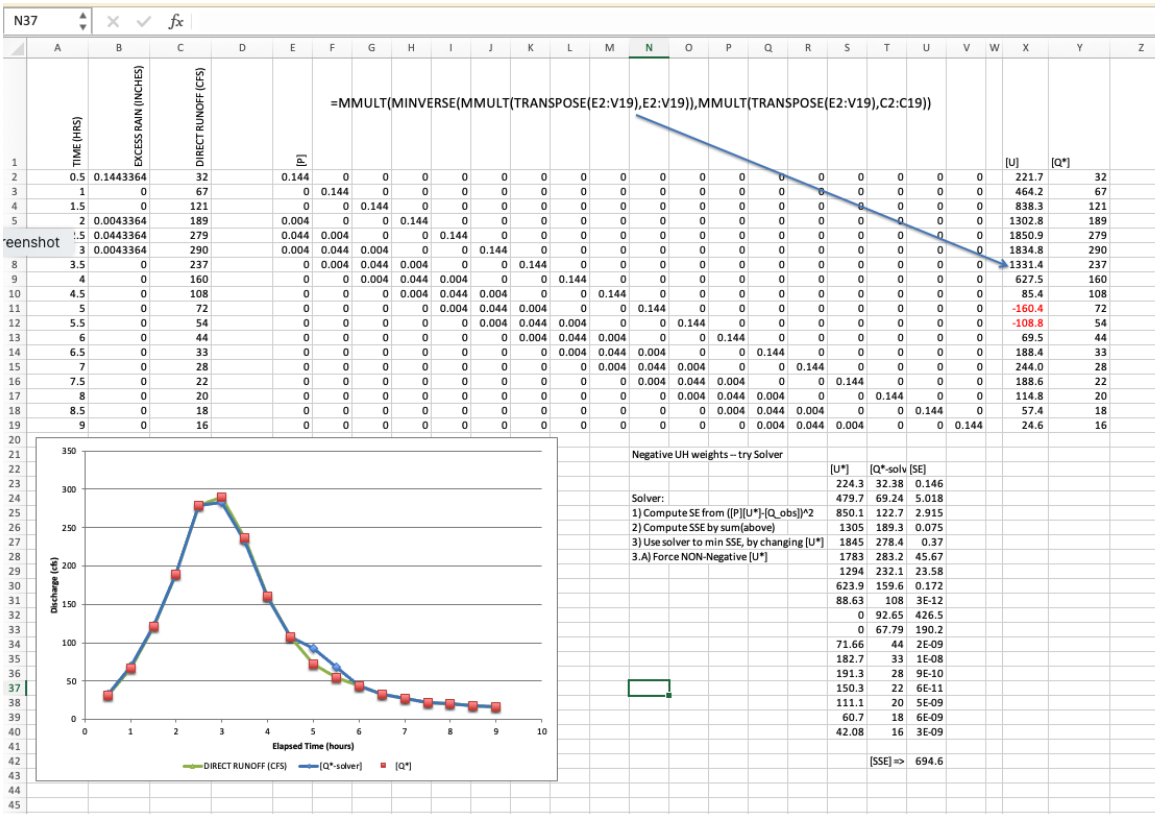
a) Using data from Figure 6 and the supplied watershed area, the rainfall is converted into watershed input volume in same units as watershed runoff volume. A constant loss is applied to the rainfall increments until the ratio of output to input is unity. as a template, the two increments of rainfall are directly plotted onto the template, then loss is applied to each increment. Predict-and-correct or Goal Seek is sufficient as depicted in Figure 7



	B	C	D	E	F	G	H	I
1	RAIN (INCHES)	DIRECT RUNOFF (CFS)		RAW RAIN VOLUME (CUBIC FEET)	RUNOFF VOLUME (CUBIC FEET)		EXCESS RAIN (INCHES)	EXCESS RAIN (CUBIC FEET)
2	0.28	32		4572986.88	57600		0.14432	2357048.09
3	0.12	67		1959851.52	120600		0	0
4	0.13	121		2123172.48	217800		0	0
5	0.14	189		2286493.44	340200		0.00432	70554.6547
6	0.18	279		2939777.28	502200		0.04432	723838.495
7	0.14	290		2286493.44	522000		0.00432	70554.6547
8	0.07	237		1143246.72	426600		0	0
9		160		0	288000		0	0
10		108		0	194400		0	0
11		72		0	129600		0	0
12		54		0	97200		0	0
13		44		0	79200		0	0
14		33		0	59400		0	0
15		28		0	50400		0	0
16		22		0	39600		0	0
17		20		0	36000		0	0
18		18		0	32400		0	0
19		16		0	28800		0	0
20								
21			TOTAL	17312021.8	3222000			3221995.9
22								
23			RUNOFF/RAIN		0.18611344	RUNOFF/EXCESS RAIN		1.00000127
24								
25			LOSS RATE		1.36E-01	<= ADJUST UNTIL RUNOFF/EXCESS RAIN = 1		

Figure 7: Volume Balance for Shoal Creek data to infer constant loss rate

b) Use the Matrix-Vector representation and ordinary-least-squares to construct a unit hydrograph for the watershed as depicted in Figure 8.[3]



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	TIME (HRS)	EXCESS RAIN (INCHES)	DIRECT RUNOFF (CFS)		[P]																			[U]	[Q*]
2	0.5	0.1443364	32		0.144	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		221.7	32
3	1	0	67		0	0.144	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		464.2	67
4	1.5	0	121		0	0	0.144	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		838.3	121
5	2	0.0043364	189		0.004	0	0	0.144	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1302.8	189
	.5	0.0443364	279		0.044	0.004	0	0	0.144	0	0	0	0	0	0	0	0	0	0	0	0	0		1850.9	279
	3	0.0043364	290		0.004	0.044	0.004	0	0	0.144	0	0	0	0	0	0	0	0	0	0	0	0		1834.8	290
8	3.5	0	237		0	0.004	0.044	0.004	0	0	0.144	0	0	0	0	0	0	0	0	0	0	0		1331.4	237
9	4	0	160		0	0	0.004	0.044	0.004	0	0	0.144	0	0	0	0	0	0	0	0	0	0		627.5	160
10	4.5	0	108		0	0	0	0.004	0.044	0.004	0	0	0.144	0	0	0	0	0	0	0	0	0		85.4	108
11	5	0	72		0	0	0	0	0.004	0.044	0.004	0	0	0.144	0	0	0	0	0	0	0	0		-160.4	72
12	5.5	0	54		0	0	0	0	0	0.004	0.044	0.004	0	0	0.144	0	0	0	0	0	0	0		-108.8	54
13	6	0	44		0	0	0	0	0	0	0.004	0.044	0.004	0	0	0.144	0	0	0	0	0	0		69.5	44
14	6.5	0	33		0	0	0	0	0	0	0	0.004	0.044	0.004	0	0	0.144	0	0	0	0	0		188.4	33
15	7	0	28		0	0	0	0	0	0	0	0	0.004	0.044	0.004	0	0	0.144	0	0	0	0		244.0	28
16	7.5	0	22		0	0	0	0	0	0	0	0	0	0.004	0.044	0.004	0	0	0.144	0	0	0		188.6	22
17	8	0	20		0	0	0	0	0	0	0	0	0	0	0.004	0.044	0.004	0	0	0.144	0	0		114.8	20
18	8.5	0	18		0	0	0	0	0	0	0	0	0	0	0	0.004	0.044	0.004	0	0	0.144	0		57.4	18
19	9	0	16		0	0	0	0	0	0	0	0	0	0	0	0	0.004	0.044	0.004	0	0	0.144		24.6	16

		[U*]	[Q*-solv	[SE]
21	Negative UH weights -- try Solver			
22		[U*]	[Q*-solv	[SE]
23		224.3	32.38	0.146
24	Solver:	479.7	69.24	5.018
25	1) Compute SE from ([P][U*]-[Q_obs])^2	850.1	122.7	2.915
26	2) Compute SSE by sum(above)	1305	189.3	0.075
27	3) Use solver to min SSE, by changing [U*]	1845	278.4	0.37
28	3.A) Force NON-Negative [U*]	1783	283.2	45.67
29		1294	232.1	23.58
30		623.9	159.6	0.172
31		88.63	108	3E-12
32		0	92.65	426.5
33		0	67.79	190.2
34		71.66	44	2E-09
35		182.7	33	1E-08
36		191.3	28	9E-10
37		150.3	22	6E-11
38		111.1	20	5E-09
39		60.7	18	6E-09
40		42.08	16	3E-09
42			[SSE] =>	694.6

Figure 8: Spreadsheet solution

The working spreadsheet is located at `http://54.243.252.9/ce-3354-webroot/2-Exercises/ES-6/ES6-SourceCode/ES6-Solution.xlsx`. Figure 5 is captured from Tab Sheet "P2-UH-CL-LOSS-FIT"

[3]This watershed will yield two negative ordinates; a SOLVER result is also shown. Recall negative ordinates are not physically relevant, and require addressing. They may simply be artifacts, or (more likely) sample aliasing.