Montogue

Quiz HY102

Hydrographs and Runoff

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An Excel spreadsheet containing the calculations for problems 1 – 7 can be downloaded from this Google Drive folder.

Problems

Problem 1

Given a triangular 1-hour unit hydrograph with

→ Time base of the UH, T_B = 12 hr;
→ Time of rise, T_R = 4 hr;
→ Peak flow, Q_P = 200 cfs;

Part 1: Develop a storm hydrograph for hourly rainfall (in.) of P = [0.1; 0.5; 1.2].
Part 2: Repeat the above problem for hourly rainfall (in.) of P = [0.2; 1.0; 0.4].

Problem 2

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 specified below.

Time (hr)	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
i (cm/hr)	0	1.0	1.25	2.5	1.0						
f (cm/h)	0	0.75	0.5	0.4	0.3						
U (m^3/s)	0	33	66	90	75	55	35	20	10	4	0

Problem 3

The 1-hr unit hydrogaph in the accompanying table was recorded for a particular watershed. Determine the size of the watershed in acres and then convert the 1-hour UH into a 3-hour UH for the watershed.

Time (h)	0	1	2	3	4	5	6	7	8	9	10
U (cfs)	0	8	25	46	78	61	50	36	20	7	0

Problem 4

Develop the S-curve from the given 30-minute unit hydrograph, and then develop the 15-min UH from the 30-min UH.

Time (h)	**U (cfs)**	**Time (h)**	**U (cfs)**
0	0	2.75	27
0.25	12	3.0	24
0.5	67	3.25	23
0.75	121	3.5	20
1.0	102	3.75	18
1.25	86	4.0	15
1.5	64	4.25	12
1.75	40	4.5	9
2.0	34	4.75	7
2.25	25	5.0	3
2.5	30	5.25	0

Problem 5

Develop the S-curve for the given 3-hour UH, and then develop the 2-hour UH from the 3-hr UH.

Time (h)	U (cfs)
0	0
1	75
2	180
3	275
4	280
5	210
6	130
7	60
8	30
9	15
10	5
11	0

Problem 6

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

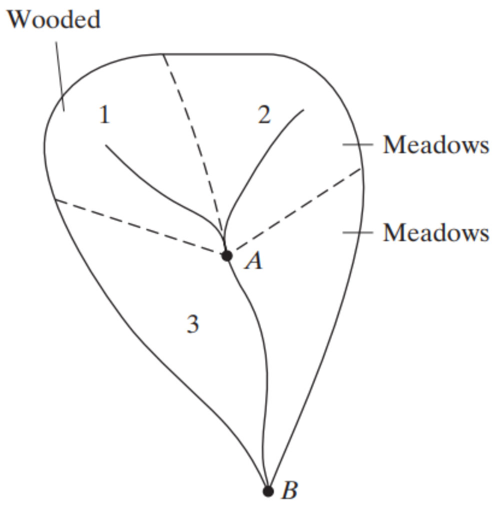
Time (h)	U (cfs)
0	0
1	25
2	125
3	250
4	400
5	500
6	450
7	350
8	300
9	225
10	150
11	100
12	25
13	0

Problem 7

Develop storm hydrographs from UHs of subareas 1 and 2 shown in the following figure for the given rainfall (*i*) and infiltration (*f*).

t (hr)	i (in./hr)	f (in./h)
1	0.5	0.4
2	1.1	0.2
3	3	0.2
4	0.9	0.2

Time (h)	0	1	2	3	4	5	6	7	8	9
UH1 (cfs)	0	200	450	650	450	300	150	0		
UH2 (cfs)	0	100	300	450	350	250	130	100	50	0



Problem 8

Sketch the SCS triangular unit hydrograph 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.

Problem 9

Consider a subbasin in an elongated watershed. The length to divide for the subbasin is L = 14.2 mi and the subbasin area is A = 111 mi^2. Compute an SCS unit hydrograph for the area drained by the subbasin, assuming a watershed slope of 0.5% and a curve number CN = 70.

Problem 10

A watershed has the following land use:

(i) 400 ha of straight row crop;
(ii) 100 ha of good pasture land.

The soil is of hydrologic soil group B. Estimate the runoff volume for the watershed under antecedent moisture category III when 2 days of consecutive rainfall of 100 mm and 90 mm occur. Use standard SCS-CN equations.

Problem 11

Compute the runoff volume due to a rainfall of 15 cm in a day on a 550 ha watershed. The hydrological soil groups are 50% of group C and 50% of group D, randomly distributed in the watershed. The land use is 55% cultivated with good quality bunding and 45% waste land. Assume antecedent moisture condition of Type-III and use standard SCS-CN equations.

Problem 12

Part 1: A 2000-ha watershed consists of 35% group B soil, 40% group C soil, and 25% group D soil. The land use is 50% residential (65% imperviousness), 25% commercial and business areas (85% imperviousness), and 25% good-condition lawns and parks. Compute the runoff in the watershed due to 15 cm rainfall in a day. Use the standard SCS-CN equation and assume AMC-II conditions.
Part 2: If, prior to development, the commercial/business area consisted of good pasture, what would have been the runoff volume under the same rainfall? What is the percentage increase in runoff volume due to urbanization?

Additional Information

Table 1. Curve numbers *CN* for different land uses; all values refer to Antecedent Moisture Conditions (AMC) Type II.

Land use description		**Hydrologic soil group**			
		A	**B**	**C**	**D**
Cultivated land	Bunded - good	59	69	76	79
	Contoured - poor	70	79	84	88
	Contoured - good	65	75	82	86
	Straight row	76	86	90	93
Forest land	Good cover	45	66	77	83
	Thin stand, poor cover, no mulch	25	55	70	77
Meadow – Good condition		30	58	71	78
Pasture	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Wasteland		71	80	85	88
Urban land uses					
Open spaces, lawns, parks – Good condition		39	61	74	80
Residential (avg. 65% imperviousness)		77	85	90	92
Commercial and business areas (85% imperviousness)		89	92	94	95
Industrial districts (72% imperviousness)		81	88	91	93
Paved parking lots, paved roads with curbs, roofs, driveways		98	98	98	98
Streets and roads	Gravel	76	85	89	91
	Dirt	72	82	87	89

Equations

→ *Equation for conversion of curve numbers CN from AMC-II (Antecedent Moisture Conditions Type II) to AMC-I*

$$\overline{CN}_I = \frac{\overline{CN}_{II}}{2.281 - 0.01281\overline{CN}_{II}}$$

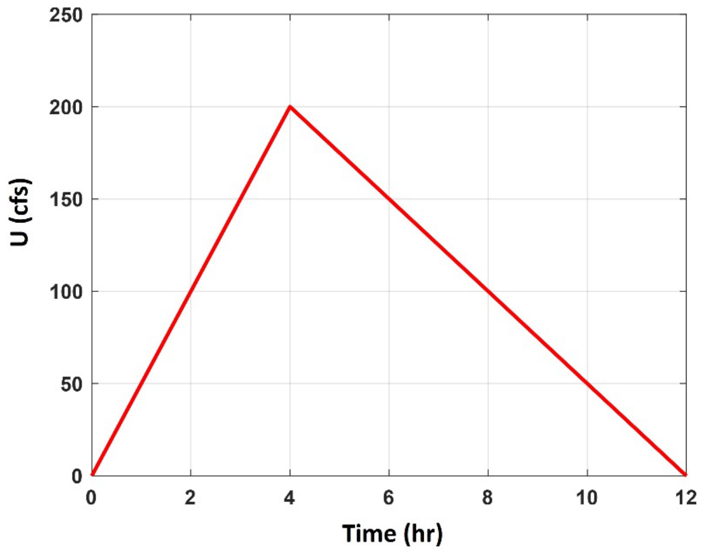
→ *Equation for conversion of curve numbers CN from AMC-II (Antecedent Moisture Conditions Type II) to AMC-III*

$$\overline{CN}_{III} = \frac{\overline{CN}_{II}}{0.427 + 0.00573\overline{CN}_{II}}$$

Solutions

P.1 ■ Solution

Part 1: Given the specifications listed in the problem statement, we have the following triangular UH:

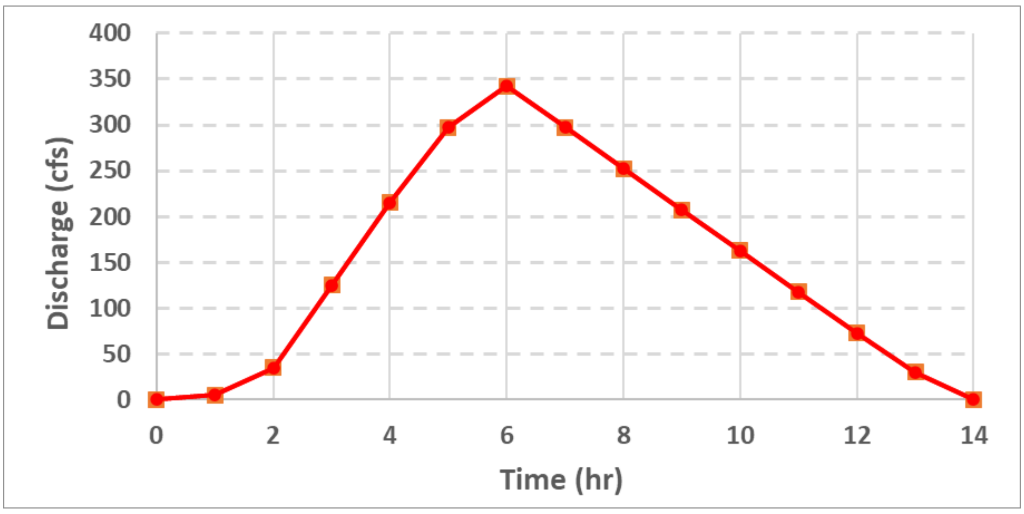


The discharge data are tabulated below.

Time (hr)	U (cfs)
0	0
1	50
2	100
3	150
4	200
5	175
6	150
7	125
8	100
9	75
10	50
11	25
12	0
13	
14	

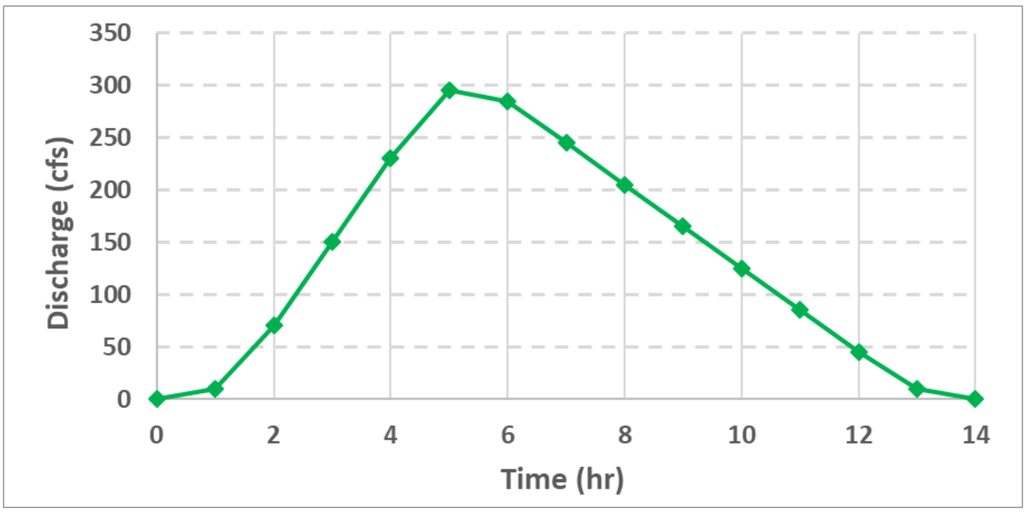
The hydrograph is processed and plotted below.

Time (hr)	U (cfs)	P1 * U	P2 * U	P3 * U	Q (cfs)
0	0	0			0
1	50	5	0		5
2	100	10	25	0	35
3	150	15	50	60	125
4	200	20	75	120	215
5	175	17.5	100	180	297.5
6	150	15	87.5	240	342.5
7	125	12.5	75	210	297.5
8	100	10	62.5	180	252.5
9	75	7.5	50	150	207.5
10	50	5	37.5	120	162.5
11	25	2.5	25	90	117.5
12	0	0	12.5	60	72.5
13			0	30	30
14				0	0



Part 2: Using the same discharges tabulated in part 1, the hydrograph is processed and plotted below.

Time (hr)	U (cfs)	P1 * U	P2 * U	P3 * U	Q (cfs)
0	0	0			0
1	50	10	0		10
2	100	20	50	0	70
3	150	30	100	20	150
4	200	40	150	40	230
5	175	35	200	60	295
6	150	30	175	80	285
7	125	25	150	70	245
8	100	20	125	60	205
9	75	15	100	50	165
10	50	10	75	40	125
11	25	5	50	30	85
12	0	0	25	20	45
13			0	10	10
14				0	0



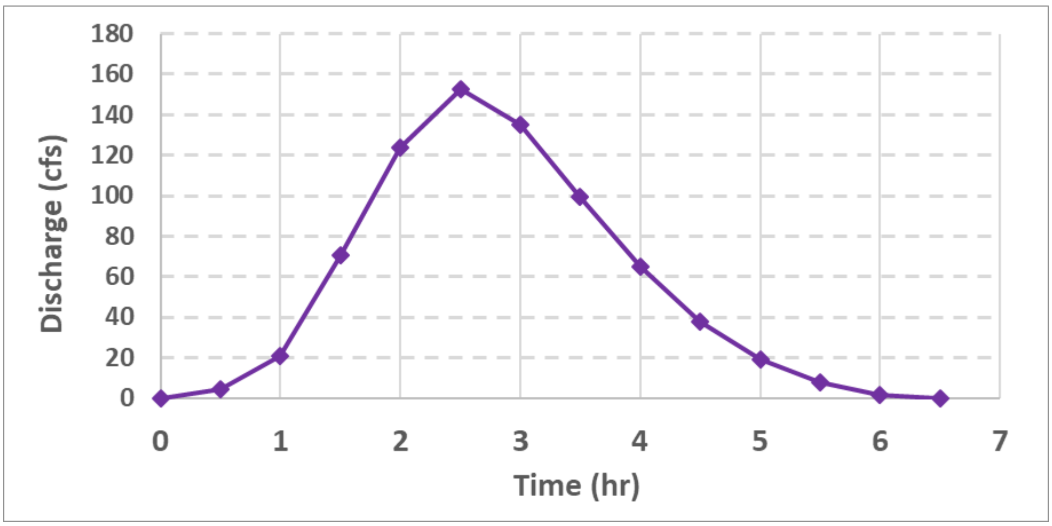
P.2 ■ Solution

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

Time (hr)	Gross rainfall Intensity (cm/h)	Infiltration rate (cm/hr)	Net rainfall Intensity (cm/hr)
0 → 0.5	1	0.75	0.25
0.5 → 1.0	1.25	0.5	0.75
1.0 → 1.5	2.5	0.4	2.1
1.5 → 2.0	1.0	0.3	0.7

The net rainfall is found by multiplying the net rainfall intensity by 30 min (= 0.5 hr), so that $P_n = 0.5 \times \{0.25, 0.75, 2.1, 0.7\} = \{0.125, 0.375, 1.05, 0.35\}$. The storm hydrograph is processed and plotted on the next page.

Time (hr)	U (m^3/s)	P1 * U	P2 * U	P3 * U	P4 * U	Q (m^3/s)
0	0	0				0.00
0.5	33	4.125	0			4.13
1	66	8.25	12.38	0		20.63
1.5	90	11.25	24.75	34.65	0	70.65
2	75	9.375	33.75	69.3	11.55	123.98
2.5	55	6.875	28.13	94.5	23.1	152.60
3	35	4.375	20.63	78.75	31.5	135.25
3.5	20	2.5	13.13	57.75	26.25	99.63
4	10	1.25	7.50	36.75	19.25	64.75
4.5	4	0.5	3.75	21	12.25	37.50
5	0	0	1.50	10.5	7	19.00
5.5			0	4.2	3.5	7.70
6				0	1.4	1.40
6.5					0	0.00



P.3 ■ Solution

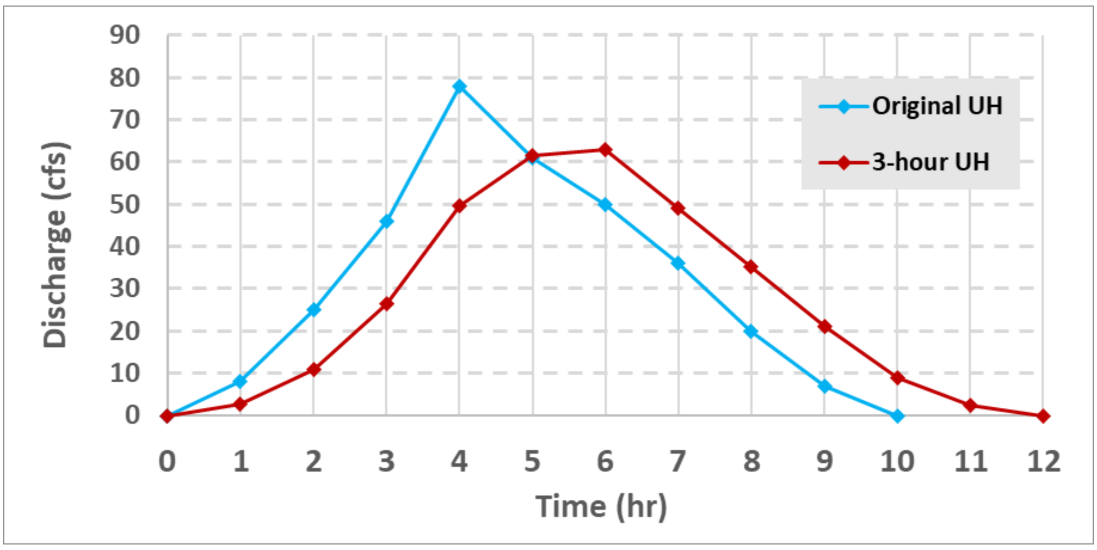
We first use the given data to create the hydrograph. The hydrograph is shown at the end of the solution. Then, to find the area of the watershed, we first multiply the time intervals by the discharges and add up the products, as tabulated below.

Time (h)	U (cfs)	Vol (cfs-hr)
0	0	0
1	8	8
2	25	25
3	46	46
4	78	78
5	61	61
6	50	50
7	36	36
8	20	20
9	7	7
10	0	0
	Sum:	**331**

The hydrologic volume adds up to 331 cfs-hr or 331 ac-in. By definition, a unit hydrograph represents the direct runoff associated with 1 in. of rainfall excess over the watershed, hence the size of the watershed in focus is 331 acres.

To create a 3-hour unit hydrograph, we add together three incremental 1-hour unit hydrographs, lagging each by 1 hour, and divide the total by three, hence 3-hr UH = (U1 + U2 + U3)/3. The data are processed to the side and plotted on the next page.

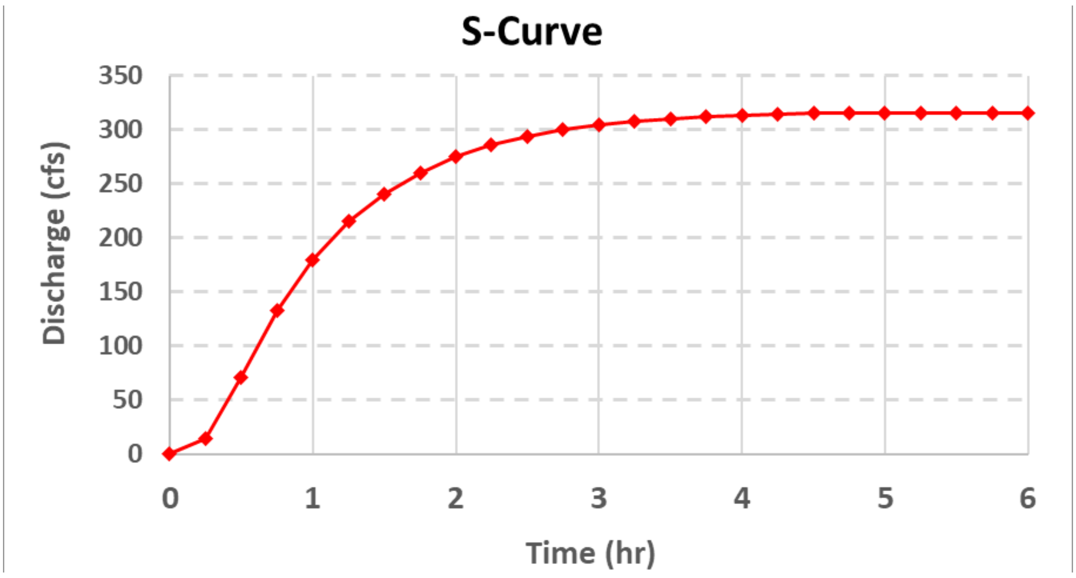
Time (h)	Q (cfs)	U1	U2	U3	3-h UH
0	0	0			0.0
1	8	8	0		2.7
2	25	25	8	0	11.0
3	46	46	25	8	26.3
4	78	78	46	25	49.7
5	61	61	78	46	61.7
6	50	50	61	78	63.0
7	36	36	50	61	49.0
8	20	20	36	50	35.3
9	7	7	20	36	21.0
10	0	0	7	20	9.0
11			0	7	2.3
12				0	0.0



P.4 ■ Solution

To obtain the S-curve, we lag the given hydrograph by 30 min until we reach zero, and then we convolute the results.

Time (h)	U (cfs)	30-min lagged UH												S-Curve
0	0													0
0.25	15													15
0.5	70.9	0												70.9
0.75	118.6	15												133.6
1	109.4	70.9	0											180.3
1.25	81.6	118.6	15											215.2
1.5	60.9	109.4	70.9	0										241.2
1.75	45.4	81.6	118.6	15										260.6
2	33.9	60.9	109.4	70.9	0									275.1
2.25	25.3	45.4	81.6	118.6	15									285.9
2.5	18.9	33.9	60.9	109.4	70.9	0								294
2.75	14.1	25.3	45.4	81.6	118.6	15								300
3	10.5	18.9	33.9	60.9	109.4	70.9	0							304.5
3.25	7.8	14.1	25.3	45.4	81.6	118.6	15							307.8
3.5	5.8	10.5	18.9	33.9	60.9	109.4	70.9	0						310.3
3.75	4.4	7.8	14.1	25.3	45.4	81.6	118.6	15						312.2
4	3.3	5.8	10.5	18.9	33.9	60.9	109.4	70.9	0					313.6
4.25	2.4	4.4	7.8	14.1	25.3	45.4	81.6	118.6	15					314.6
4.5	1.8	3.3	5.8	10.5	18.9	33.9	60.9	109.4	70.9	0				315.4
4.75	1.6	2.4	4.4	7.8	14.1	25.3	45.4	81.6	118.6	15				316.2
5	0.8	1.8	3.3	5.8	10.5	18.9	33.9	60.9	109.4	70.9	0			316.2
5.25	0	1.6	2.4	4.4	7.8	14.1	25.3	45.4	81.6	118.6	15			316.2
5.5		0.8	1.8	3.3	5.8	10.5	18.9	33.9	60.9	109.4	70.9	0		316.2
5.75		0	1.6	2.4	4.4	7.8	14.1	25.3	45.4	81.6	118.6	15		316.2
6			0.8	1.8	3.3	5.8	10.5	18.9	33.9	60.9	109.4	70.9	0	316.2



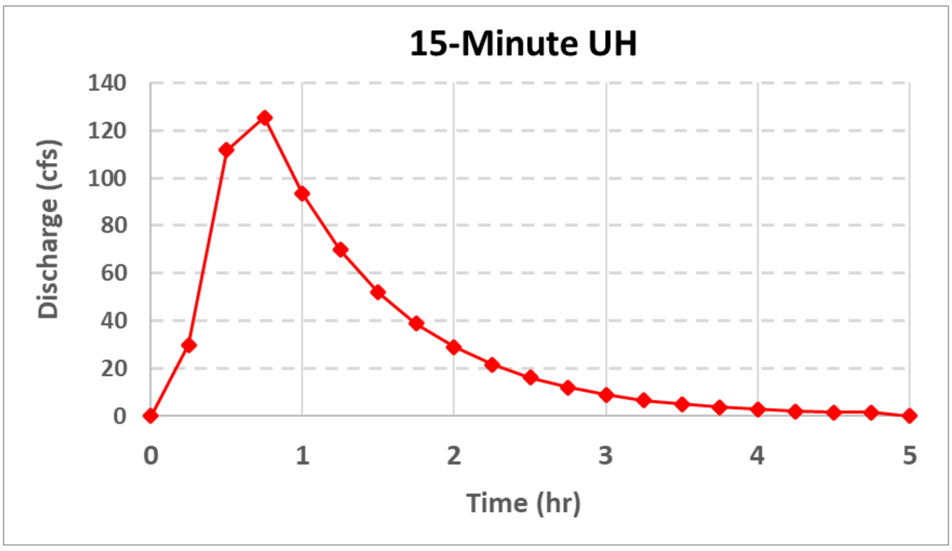
To derive the 15-min UH, we proceed as follows:

→ Lag the S-curve by 15 min and take the difference between the original S-curve and the lagged S-curve.

→ Multiply the resulting ordinate values by the ratio $D/D' = 2$, where $D = 30$ min is the duration of the original hydrograph and $D' = 15$ min is the duration of the desired hydrograph.

The desired hydrograph is processed and plotted on the next page.

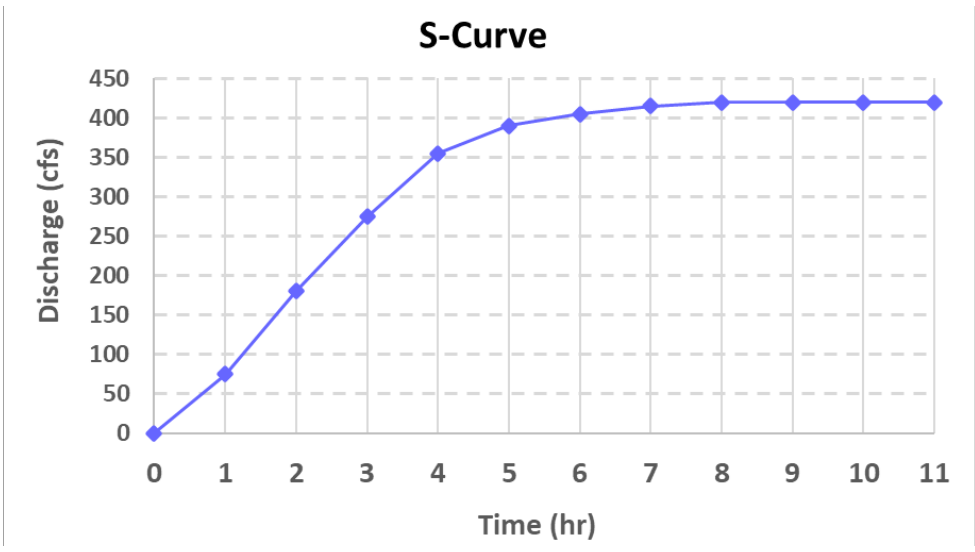
Time (h)	S-Curve	S-Curve lagged 15 min	Difference	15-min UH
0	0		0	0
0.25	15	0	15	30
0.5	70.9	15	55.9	111.8
0.75	133.6	70.9	62.7	125.4
1	180.3	133.6	46.7	93.4
1.25	215.2	180.3	34.9	69.8
1.5	241.2	215.2	26	52
1.75	260.6	241.2	19.4	38.8
2	275.1	260.6	14.5	29
2.25	285.9	275.1	10.8	21.6
2.5	294	285.9	8.1	16.2
2.75	300	294	6	12
3	304.5	300	4.5	9
3.25	307.8	304.5	3.3	6.6
3.5	310.3	307.8	2.5	5
3.75	312.2	310.3	1.9	3.8
4	313.6	312.2	1.4	2.8
4.25	314.6	313.6	1	2
4.5	315.4	314.6	0.8	1.6
4.75	316.2	315.4	0.8	1.6
5	316.2	316.2	0	0



P.5 ■ Solution

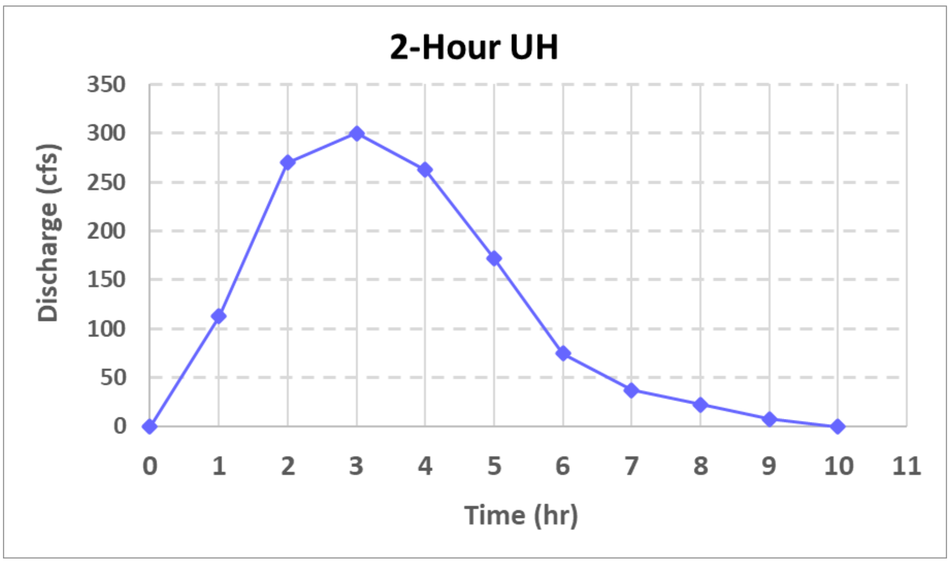
The procedure to obtain the S-curve is no different from the one adopted in Problem 4. The curve is processed and plotted in continuation.

Time (h)	U (cfs)	3-hour lagged UH			S-Curve
0	0				0
1	75				75
2	180				180
3	275	0			275
4	280	75			355
5	210	180			390
6	130	275	0		405
7	60	280	75		415
8	30	210	180		420
9	15	130	275	0	420
10	5	60	280	75	420
11	0	30	210	180	420



To extract the 2-hour hydrograph from the S-curve, we proceed as we did in Problem 4; note that $D = 3$ and $D' = 2$, so the ordinates in the penultimate column must be multiplied by $D/D' = 3/2 = 1.5$.

Time (h)	S-Curve	S-Curve lagged 2 hours	Difference	2-hour UH
0	0		0	0
1	75		75	112.5
2	180	0	180	270
3	275	75	200	300
4	355	180	175	262.5
5	390	275	115	172.5
6	405	355	50	75
7	415	390	25	37.5
8	420	405	15	22.5
9	420	415	5	7.5
10	420	420	0	0



P.6 ■ Solution

The procedure to obtain the 1-hour hydrograph goes as follows:

→ Lag the 2-hour hydrograph by 2 hour increments to obtain the S-curve;
→ Lag the S-curve by the time of duration of the desired unit hydrograph (in this case, 1 hour);
→ Multiply the resulting ordinate values by the ratio D/D', where D is the original duration and D' is the desired duration; in the case at hand, $D = 2$ and $D' = 1$, hence $D'/D = 2/1 = 2$.

The calculations are summarized below.

Time (h)	U (cfs)	2-hr lagged UH						S-curve	Lagged S-curve	Difference (cfs)	1-hr UH
0	0							0		0	0
1	25							25	0	25	50
2	125	0						125	25	100	200
3	250	25						275	125	150	300
4	400	125	0					525	275	250	500
5	500	250	25					775	525	250	500
6	450	400	125	0				975	775	200	400
7	350	500	250	25				1125	975	150	300
8	300	450	400	125	0			1275	1125	150	300
9	225	350	500	250	25			1350	1275	75	150
10	150	300	450	400	125	0		1425	1350	75	150
11	100	225	350	500	250	25		1450	1425	25	50
12	25	150	300	450	400	125	0	1450	1450	0	0
13	0	100	225	350	500	250	25	1450	1450	0	0

To obtain the 2-hour UH from the 1-hour UH, we proceed as follows.

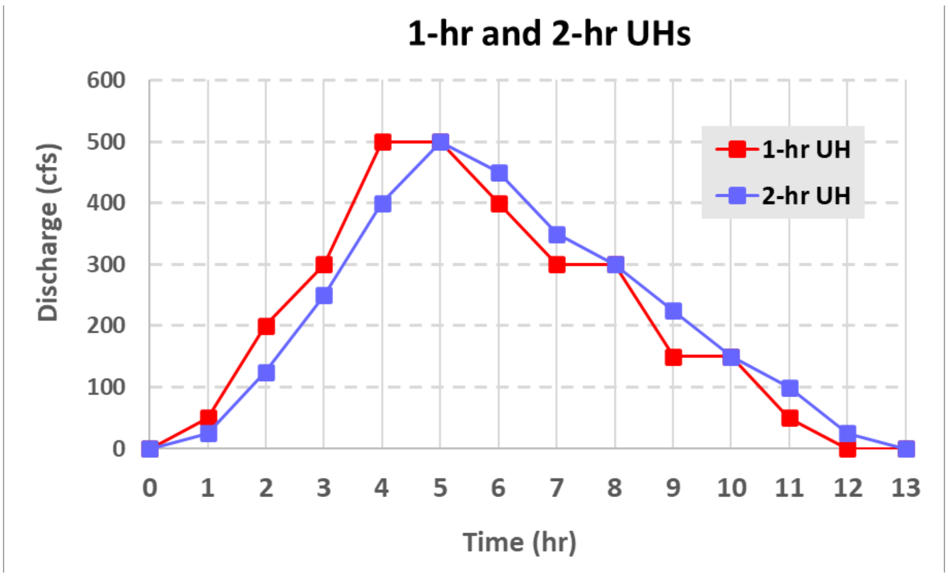
→ Lag the 1-hour hydrograph by 1 hour increments to obtain the *S*-curve;
→ Lag the *S*-curve by the time duration of the new unit hydrograph (in this case, 2 hours);
→ Multiply the resulting ordinate values by the ratio D/D', where D is the original duration and D' is the desired duration; in the case at hand, $D = 1$ and $D' = 2$, hence $D/D' = 1/2 = 0.5$.

The calculations are summarized below.

Time (h)	1-hr UH	1-hr lagged UH													S-curve
0	0														0
1	50	0													50
2	200	50	0												250
3	300	200	50	0											550
4	500	300	200	50	0										1050
5	500	500	300	200	50	0									1550
6	400	500	500	300	200	50	0								1950
7	300	400	500	500	300	200	50	0							2250
8	300	300	400	500	500	300	200	50	0						2550
9	150	300	300	400	500	500	300	200	50	0					2700
10	150	150	300	300	400	500	500	300	200	50	0				2850
11	50	150	150	300	300	400	500	500	300	200	50	0			2900
12	0	50	150	150	300	300	400	500	500	300	200	50	0		2900
13	0	0	50	150	150	300	300	400	500	500	300	200	50	0	2900

S-curve	Lagged S-curve	Difference (cfs)	2-hr UH
0		0	0
50		50	25
250	0	250	125
550	50	500	250
1050	250	800	400
1550	550	1000	500
1950	1050	900	450
2250	1550	700	350
2550	1950	600	300
2700	2250	450	225
2850	2550	300	150
2900	2700	200	100
2900	2850	50	25
2900	2900	0	0

The hydrographs are plotted below.



P.7 ■ Solution

We first compute the net rainfall intensity for the given data.

Time (h)	i (in./hr)	f (in./h)	Net rainfall intensity (in./h)
1	0.5	0.4	0.1
2	1.1	0.2	0.9
3	3	0.2	2.8
4	0.9	0.2	0.7

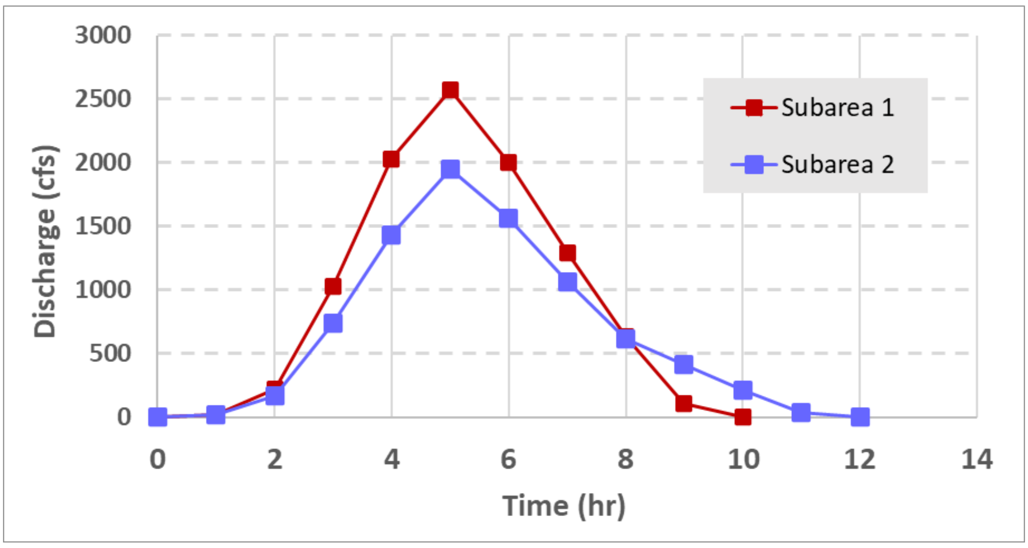
Equipped with the rainfall intensities, we can establish the storm hydrographs. First, for subarea 1:

Time (hr)	UH1 (cfs)	P1 * UH1	P2 * UH1	P3 * UH1	P4 * UH1	Q1 (cfs)
0	0	0				0
1	200	20	0			20
2	450	45	180	0		225
3	650	65	405	560	0	1030
4	450	45	585	1260	140	2030
5	300	30	405	1820	315	2570
6	150	15	270	1260	455	2000
7	0	0	135	840	315	1290
8			0	420	210	630
9				0	105	105
10					0	0

Second, for subarea 2:

Time (hr)	UH2 (cfs)	P1 * UH2	P2 * UH2	P3 * UH2	P4 * UH2	Q2 (cfs)
0	0	0				0
1	150	15	0			15
2	300	30	135	0		165
3	500	50	270	420	0	740
4	350	35	450	840	105	1430
5	250	25	315	1400	210	1950
6	125	12.5	225	980	350	1567.5
7	100	10	112.5	700	245	1067.5
8	50	5	90	350	175	620
9	0	0	45	280	87.5	412.5
10			0	140	70	210
11				0	35	35
12					0	0

The storm hydrographs are plotted below.



P.8 ■ Solution

The watershed area distribution is shown below; the curve numbers can be gleaned from Table 1.

Area	Soil group	Percentage cover	CN
Good meadow	A	0.6 × 0.3 = 0.18 = 18%	30
	C	0.6 × 0.7 = 0.42 = 42%	71
Good cover forest land	A	0.4 × 0.3 = 0.12 = 12%	25
	C	0.4 × 0.7 = 0.28 = 28%	70

The weighed CN is

$$\overline{CN} = 0.18 \times 30 + 0.42 \times 71 + 0.12 \times 25 + 0.28 \times 70$$

$$\therefore \overline{CN} = 57.8 \approx 58$$

The area of the watershed is A = 100 mi^2, the length to divide is L = 18 mi × 5280 ft/mi = 95,040 ft, the rainfall duration is D = 3 hr, the average watershed slope is average watershed slope is

$$y = 100 \frac{\text{ft}}{\text{mi}} \times \frac{1}{5280} \frac{\text{mi}}{\text{ft}} \times 100\% = 1.89\%$$

and the retention parameter is

$$S = \frac{1000}{\overline{CN}} - 10 = \frac{1000}{58} - 10 = 7.24 \text{ in.}$$

To compute the lag time, we write

$$t_p = \frac{L^{0.8}(S+1)^{0.7}}{1900\sqrt{y}} = \frac{95,040^{0.8} \times (7.24+1)^{0.7}}{1900 \times \sqrt{1.89}} = 16.1 \text{ hr}$$

The time of rise is

$$T_R = \frac{D}{2} + t_p = \frac{3.0}{2} + 16.1 = 17.6 \text{ hr}$$

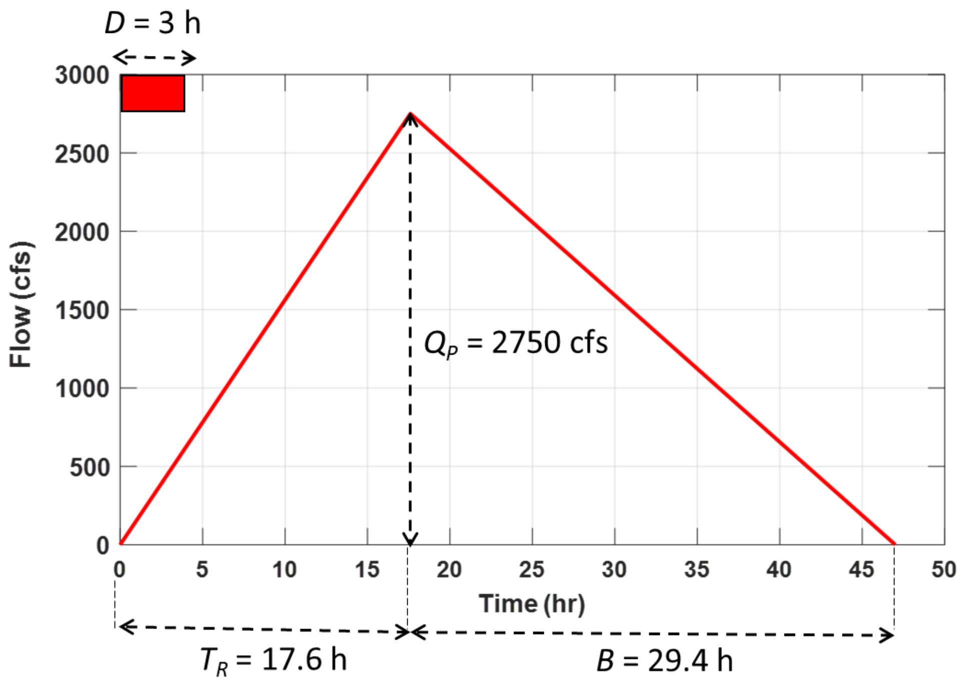
The peak flow is

$$Q_P = \frac{484A}{T_R} = \frac{484 \times 100}{17.6} = 2750 \text{ cfs}$$

The time of fall is

$$B = 1.67T_R = 1.67 \times 17.6 = 29.4 \text{ hr}$$

The triangular hydrograph is shown below.



P.9 ■ Solution

We have $S = 1000/CN - 10 = 1000/70 - 10 = 4.29$ in, $y = 0.5\%$, and $L = 14.2$ mi = 74,980 ft. We proceed to compute the lag time t_P,

$$t_p = \frac{L^{0.8}(S+1)^{0.7}}{1900\sqrt{y}} = \frac{74{,}980^{0.8} \times (4.29+1)^{0.7}}{1900 \times \sqrt{0.5}} = 19.0 \text{ hr}$$

The storm duration may be taken as

$$D = \frac{t_p}{5.5} = \frac{19.0}{5.5} = 3.45 \text{ h}$$

The time of rise is

$$T_R = \frac{D}{2} + t_P = \frac{3.45}{2} + 19.0 = 20.7 \text{ h}$$

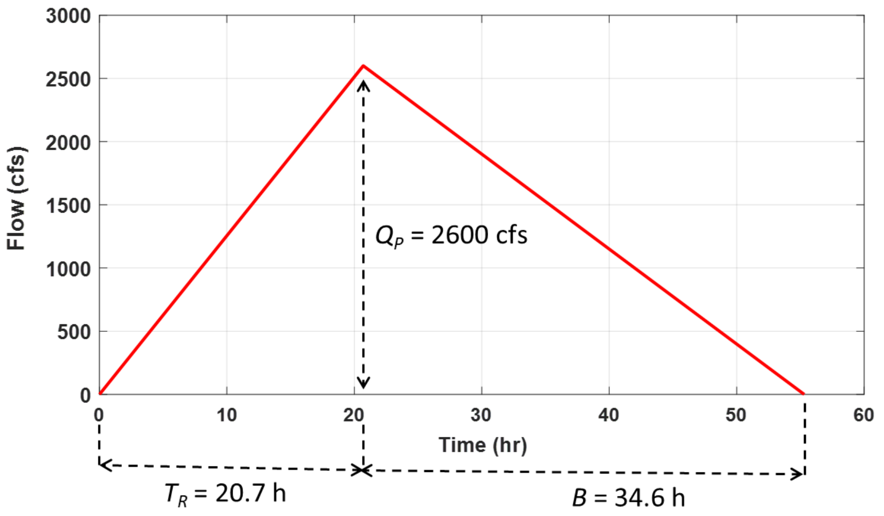
The peak flow is

$$Q_P = \frac{484A}{T_R} = \frac{484 \times 111}{20.7} = 2600 \text{ cfs}$$

The time of fall is

$$B = 1.67T_R = 1.67 \times 20.7 = 34.6 \text{ hr}$$

We have all the information needed to compute the SCS triangular hydrograph. The UH is shown to the side.



P.10 ■ Solution

For straight row crop in soil group B, *CN* is equals 86. For good pasture in soil group B, the *CN* is 61. Using these *CN* values and the given area data, we obtain the weighted curve number

$$\overline{CN}_{II} = \frac{400\times 86 + 100\times 61}{400+100} = 81.0$$

Correcting this to antecedent moisture condition III, we obtain

$$\overline{CN}_{III} = \frac{\overline{CN}_{II}}{0.427+0.00573\overline{CN}_{II}} = \frac{81.0}{0.427+0.00573\times 81.0} = 90.9$$

The retention parameter *S* is then

$$S = \frac{25,400}{CN} - 254 = \frac{25,400}{90.9} - 254 = 25.43 \text{ mm}$$

Using the standard SCS-CN equation, the runoff *Q* is given by

$$Q = \frac{(P-0.2S)^2}{P+0.8S} = \frac{(P-0.2\times 25.43)^2}{P+0.8\times 25.43}$$

$$\therefore Q = \frac{(P-5.09)^2}{P+20.3} \;\; ; \;\; P \geq 5.09 \text{ mm}$$

We can use this formula to compute the runoff for the two stormy days specified in the problem statement. For the first day, with a precipitation of 100 mm,

$$Q = \frac{(100-5.09)^2}{100+20.3} = 74.88 \text{ mm}$$

For the second day, with a precipitation of 90 mm,

$$Q = \frac{(90-5.09)^2}{90+20.3} = 65.36 \text{ mm}$$

The total runoff is Q = 74.88 + 65.36 = 140.2 mm.

P.11 ■ Solution

The appropriate area × *CN* products are computed below; curve numbers can be gleaned from Table 1.

Land use	Soil group	% Area	CN	Area × CN
Cultivated – Good bunding	C	55 × 0.5 = 27.5%	76	2090
	D	55 × 0.5 = 27.5%	79	2173
Waste land	C	45 × 0.5 = 22.5%	85	1913
	D	45 × 0.5 = 22.5%	88	1980

The weighted *CN* follows as

$$\overline{CN}_{II} = \frac{\Sigma(\text{Area}\times\text{CN})}{100} = \frac{2090+2173+1913+1980}{100} = 81.6$$

Converting this CN_{II} to Antecedent Moisture Condition III,

$$\overline{CN}_{III} = \frac{\overline{CN}_{II}}{0.427+0.00573\overline{CN}_{II}} = \frac{81.6}{0.427+0.00573\times 81.6} = 91.2$$

The retention parameter *S* is

$$S = \frac{25,400}{\overline{CN}} - 254 = \frac{25,400}{91.2} - 254 = 24.51 \text{ mm}$$

Using the standard SCS-CN equation, the runoff *Q* is expressed as

$$Q = \frac{(P-0.2S)^2}{P+0.8S} = \frac{(P-0.2\times 24.51)^2}{P+0.8\times 24.51}$$

$$\therefore Q = \frac{(P-4.90)^2}{P+19.6} \;;\; P \geq 4.90 \text{ mm}$$

For a day with rainfall P = 15 cm = 150 mm, the runoff depth is

$$Q = \frac{(150-4.90)^2}{150+19.6} = 124.1 \text{ mm}$$

Since the watershed covers an area of 550 ha = 550×10^4 m^2, the runoff volume becomes

$$V = \left(550\times10^4 \text{ m}^2\right)\times\left(0.124 \text{ m}\right) = \boxed{682{,}000 \text{ m}^3}$$

P.12 ■ Solution

Part 1: The weighted CN calculations are tabulated below.

Land use	Soil group	% Area	CN	Area × CN
Residential (65% imperviousness)	B	0.35 × 0.5 = 17.5%	85	1488
	C	0.4 × 0.5 = 20.0%	90	1800
	D	0.25 × 0.5 = 12.5%	92	1150
Commercial and business (85% imperv.)	B	0.35 × 0.25 = 8.75%	92	805
	C	0.4 × 0.25 = 10%	94	940
	D	0.25 × 0.25 = 6.25%	95	594
Lawns and parks in good condition	B	0.35 × 0.25 = 8.75%	61	534
	C	0.4 × 0.25 = 10%	74	740
	D	0.25 × 0.25 = 6.25%	80	500

The weighted CN is calculated as

$$\overline{CN}_{II} = \frac{\left(\begin{array}{c}1488+1800+1150+805+940\\+594+534+740+500\end{array}\right)}{100} = 85.5$$

The retention parameter S is

$$S = \frac{25{,}400}{\overline{CN}_{II}} - 254 = \frac{25{,}400}{85.5} - 254 = 43.08 \text{ mm}$$

The runoff associated with 150 mm of rainfall is

$$Q = \frac{(P-0.2S)^2}{P+0.8S} = \frac{(150-0.2\times43.08)^2}{150+0.8\times43.08} = \boxed{108.4 \text{ mm}}$$

Part 2: The updated curve number calculations are tabulated below.

Land use	Soil group	% Area	CN	Area × CN
Residential (65% imperviousness)	B	0.35 × 0.5 = 17.5%	85	1488
	C	0.4 × 0.5 = 20.0%	90	1800
	D	0.25 × 0.5 = 12.5%	92	1150
Good pasture	B	0.35 × 0.25 = 8.75%	61	538
	C	0.4 × 0.25 = 10%	74	740
	D	0.25 × 0.25 = 6.25%	80	500
Lawns and parks in good condition	B	0.35 × 0.25 = 8.75%	61	534
	C	0.4 × 0.25 = 10%	74	740
	D	0.25 × 0.25 = 6.25%	80	500

The weighted CN is now

$$\overline{CN}_{II} = \frac{\left(\begin{array}{c}1488+1800+1150+538+740\\+500+534+740+500\end{array}\right)}{100} = 79.9$$

The retention parameter S is

$$S = \frac{25{,}400}{\overline{CN}_{II}} - 254 = \frac{25{,}400}{79.9} - 254 = 63.9 \text{ mm}$$

The runoff associated with 150 mm of rainfall is

$$Q=\frac{(P-0.2S)^2}{P+0.8S}=\frac{(150-0.2\times 63.9)^2}{150+0.8\times 63.9}=\boxed{93.62\text{ mm}}$$

Clearly, the conversion of good pasture into a commercial area caused the runoff to vary from 93.6 mm to 108.4 mm, which corresponds to a nearly 16% increase.

References

- BEDIENT, P., HUBER, W., and VIEUX, B. (2013). *Hydrology and Floodplain Analysis – International Edition*. 5th edition. Upper Saddle River: Pearson.
- SUBRAMANYA, K. (2008). *Engineering Hydrology*. 3rd edition. New Delhi: Tata McGraw-Hill.

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