Hydrology and Floodplain Analysis

Solutions Manual

4^{th} Edition

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Solutions Chapter 1

1.1. A lake with a surface area of 525 acres was monitored over a period of time. During a one-month period the inflow was 30 cfs, the outflow was 27 cfs, and a 1.5-in. seepage loss was measured. During the same month, the total precipitation was 4.25 in. Evaporation loss was estimated as 6.0 in. Estimate the storage change for this lake during the month.

525 ac

$$\left.\begin{array}{l} I = 30 \text{ cfs} \\ O = 27 \text{ cfs} \end{array}\right\} \text{During 1 month}$$

GW = 1.5 in.

P = 4.25 in.

E = 6 in.

$\Delta s = ?$

$P + I - O - GW - E = \Delta s \rightarrow$

4.25 in. +

$$\frac{(30-27)\ \text{ft}^3/\text{sec} \bullet 2.3 \bullet 10^{-5}\ \text{acres}/\text{ft}^2 \bullet 12\ \text{in}/\text{ft} \bullet 3{,}600\ \text{sec}/\text{hr} \bullet 24\ \text{hr}/\text{d} \bullet 30\ \text{d}/1\text{m} \bullet 1\text{m}}{525\ \text{ac}}$$

-1.5 in. – 6 in. = 4.25 in. + 4.09 in. – 1.5 in. -6 in. = 0.84 in.

Storage change in units of volume

$\Delta s = 0.84 \text{ in} \bullet (1/12)\text{ft/in} \bullet 525 \text{ ac} = 36.75 \text{ ac - ft}$

1.2. Clear Lake has a surface area of 708,000 m^2 (70.8 ha). For a given month the lake has an inflow of 1.5 m^3/s and an outflow of 1.25 m^3/s. A +1.0 m storage change or increase in lake level was recorded. If a precipitation gage recorded a total of 22.5 cm for this month, determine the evaporation loss (in cm) for the lake. Assume that seepage loss is negligible.

$E = -\Delta s + P + I - O - GW$

$= -(1m)(100\ cm/m) + 22.5\ cm$

$+ (1.5\ m^3/s)(3600\ s/hr)(24\ hr/day)(30\ day)(100\ cm/m) / (708{,}000\ m^2)$

$- (1.25\ m^3/s)(3600\ s/hr)(24\ hr/day)(30\ day)(100\ cm/m) / (708{,}000\ m^2)$

$= -100\ cm + 22.5\ cm + 549.2\ cm. - 457.6\ cm$

$\boxed{E = 14.1\ cm}$

1.3. Table P1.3 lists rainfall data recorded at a USGS gage for the storm of September 1, 1999. The basin area is 205 acres. Using these data, develop a rainfall hyetograph. (in/hr vs. t) in 5-min intervals and determine the time period with the highest intensity rainfall.

The recorded rainfall was reported as cumulative volume. To develop a hyetograph, the change in volume is divided by the change in time. Referring to Fig. P1.3, it can be seen that rainfall was recorded in 5 minute intervals from time 1610 to 1730 so the hyetograph will have 5 minute increments.

i_1 = (0.10 in – 0 in) (60 min/hr) / (5 min) = 1.2 in /hr

i_2 = (0.40 in – 0.10 in) (60 min/hr) / (5 min) = 3.60 in/hr

i_3 = (0.60 in – 0.40 in) (60 min/hr) / (5 min) = 2.40 in/hr

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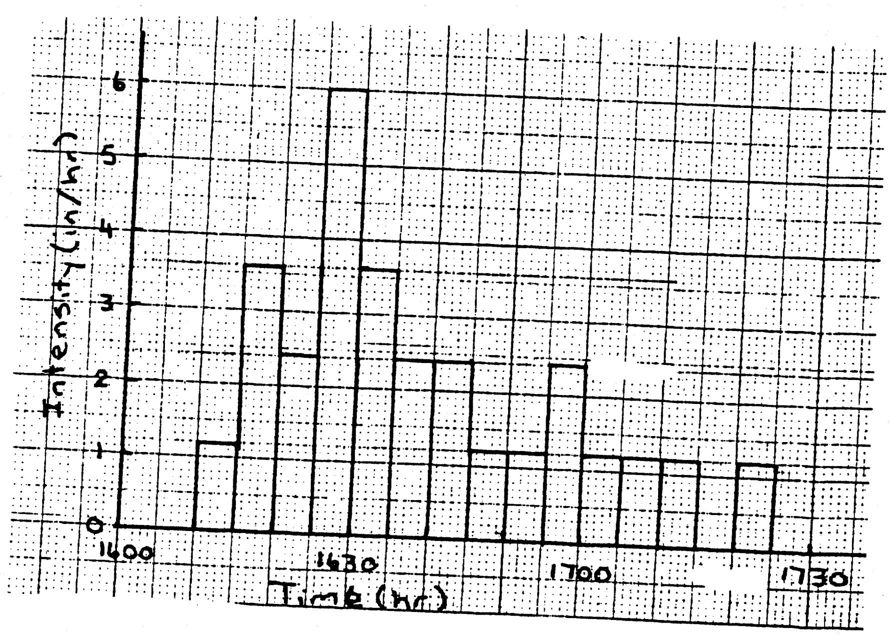
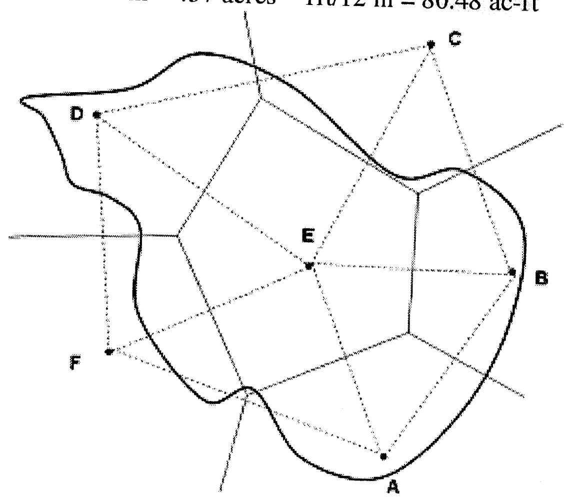
The remaining ordinates are found and plotted as shown below. It can easily be seen that the highest intensity occurred from 1625 to 1630.



1.4 A watershed of 437 ac with six rainfall gages can be divided into Thiessen polygons with the the listed data in the accompanying table. Using the total storm rainfall depths listed below; find the average rainfall over the watershed in ac-ft.

Gage	Rainfall (in)	Area (ac)	A_i / A_r	$(P_i)(A_i/A_r)$ (in)
A	2.2	81	0.185	0.41
B	3.22	67	0.153	0.49
C	0.71	17	0.039	0.03
D	2.49	89	0.204	0.51
E	0.88	153	0.350	0.31
F	6.72	30	0.069	0.46
	Σ=	437	1.000	2.21 in

2.21 in * 437 acres * 1ft/12 in = 80.48 ac-ft



1.5. A small urban watershed has four rainfall gages as located in Fig. P1.5. Total rainfall recorded at each gage during a storm event is listed in the table below. Compute the mean areal rainfall for this storm using (a) arithmetic averaging and (b) the Thiessen method.

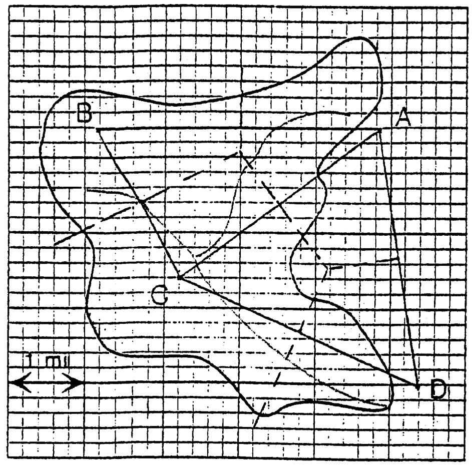
a) Arithmetic Average:

$$\frac{2.92+3.01}{2} = 2.965 \text{ in}$$

b) 25 squares = 1 mi^2

A= 64 squares = 2.56 mi^2
B= 78 squares = 3.12 mi^2
C= 148 squares = 5.92 mi^2
D= 36 squares = 1.44 mi^2

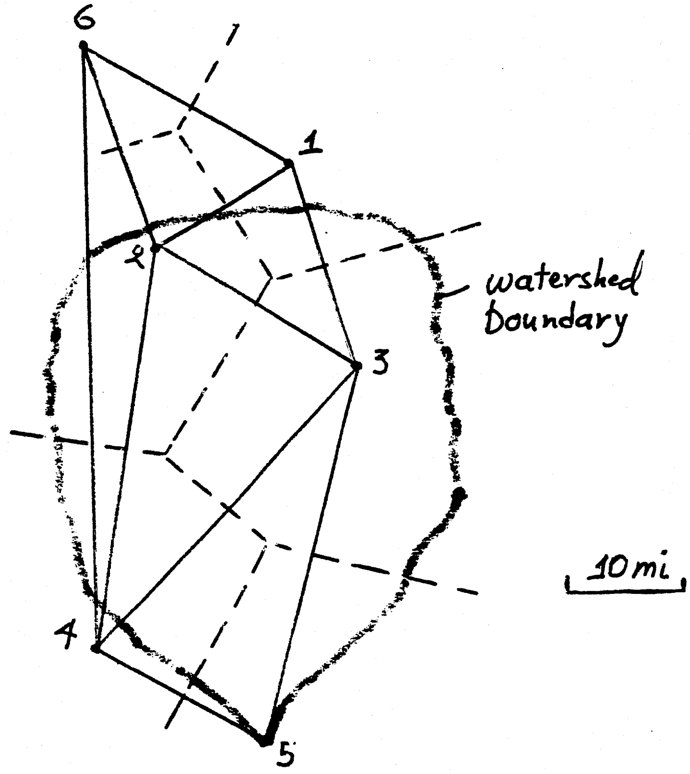
Area of Watershed → 13.04 mi^2



Gage	Area (mi^2)	Area (%)	Rainfall (in.)	Weighted Rainfall (in)
A	2.56	19.6	3.26	0.639
B	3.12	23.9	2.92	0.698
C	5.92	45.4	3.01	1.366
D	1.44	11.1	3.05	0.338
Sum	13.04	100		3.041

Answer = 3.041 (in)

1.6. Mud Creek has the watershed boundaries shown in Fig. P1.6. There are six rain gages in and near the watershed, and the amount of rainfall at each one during a storm is given in the accompanying table. Using the Thiessen method and a scale of 1 in. = 10 mi, determine the mean rainfall of the given storm.



Gage	Area (mi^2)	Area (%)	Rainfall (cm)	Weighted Rainfall (cm)
1	55.6	5	5.5	0.275
2	266.7	23.5	4.5	1.058
3	466.7	41.2	4	1.648
4	200	17.6	6.2	1.091
5	144.4	12.7	7	0.889
6	0	0	2.1	0
SUM	1133.4	100		4.961

1.7. Plot Eq. (1.6) as a graph (e_s vs. T) for a range of temperatures from –30°C to 40°C and a range of pressures from 0 mb to 70 mb. The area below the curve represents the unsaturated air condition. Using this graph, answer the following:

a) Select two saturated and two unsaturated samples of air from the dataset of pressure and temperature given below:

Pressure (mb) : {10, 20, 30}

Temperature (°C) : {10, 20, 30}

b) Let A and B be two air samples, where A: (T = 30°C, P = 25 mb) and B: (T = 30°C, P = 30 mb). For each sample, determine the following:

i) Saturation vapor pressure

ii) Dew point

iii) Relative humidity

c) Suppose both samples A and B are cooled to 15°C. What would be their relative humidity? What would be their dew point temperature?

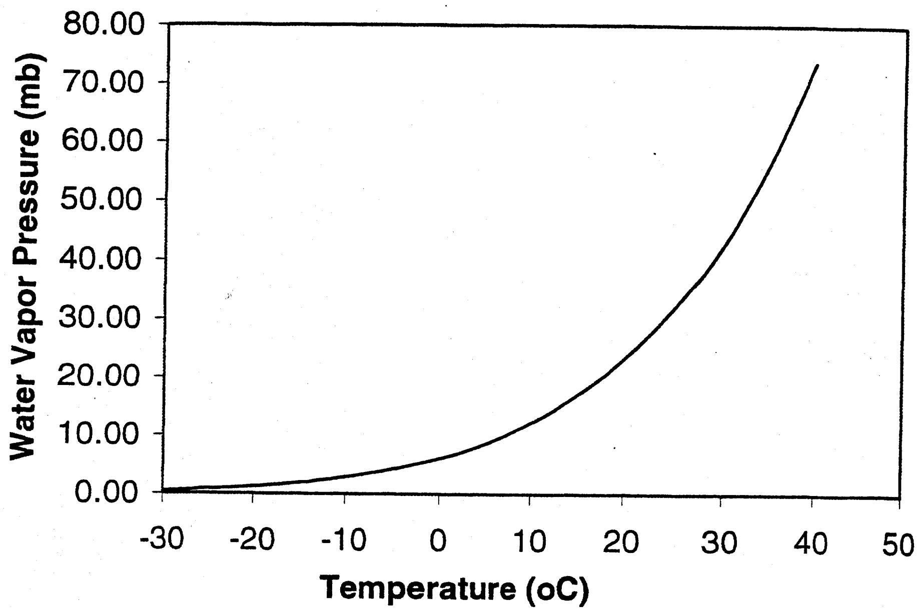
1.7. (cont.)

a) Saturated samples of air: T = 10° C, P = 20 mb

T = 10° C, P = 30 mb

Unsaturated samples of air: T = 10°C , P = 10 mb

T = 20°C, P = 20 mb



b) A = (T = 30°C , P = 25 mb)

B = (T = 30°C , P = 30 mb)

i) Saturation Vapor Pressure is a function of temperature.

For both samples A & B, T = 30°C

So $e_{sa} = e_{sb} = 42.41$ mb

ii) Dew point is a measure of the water vapor pressure.

For sample A, e_a = 25 mb $\longrightarrow T_d = 21.14$°C

For sample B, e_b = 30 mb $\longrightarrow T_d = 24.14$°C

iii) Relative humidity is the ratio of the actual vapor pressure to saturation vapor pressure

1.7 (cont.)

Sample A: (25/ 42.41) • 100 = 59%   Sample B: (30/42.41) • 100 = 71%

c) In 15°C, both samples have become saturated:

Their relative humidity is 100%.

After condensation begins, the temperature and the dew point are the same.

So, $T = T_d = 15°C$

1.8. The gas constant R has the value 2.87×10^6 cm^2/s^2 °K for dry air, when pressure is in mb. Using the ideal gas law ($P = \rho RT$), find the density of dry air at 25°C with a pressure of 950 mb. Find the density of moist air at the same pressure and temperature if the relative humidity is 65%.

(a) Rearranging the equation to solve for P gives:

$$\rho = P/RT$$

$$= \frac{(950 \text{ mb})\ (100 \text{ Nt/m}^2)}{(2.87 * 10^6 \text{ cm}^2 \text{ s}^{-2}\ {}^0\text{K}^{-1})\ (298.16\ {}^0\text{K})\ \text{mb}}$$

$1\text{mb} = 100 \text{ Pa} = 100 \text{ Nt/m}^2$

$1 \text{ Nt/m}^2 = 1\text{Kg m} / \text{m}^2 \text{s}^2$

$$\boxed{\rho = 1.11 \text{ Kg} / \text{m}^3}$$

(b) The density of moist air can be found using Eq. 1.4. Since we know the relative humidity, we can find e. (See Appendix C for values of e_s.)

$$H = 100\ (e/e_s)$$

$$65 = 100\ (e/31.72 \text{ mb})$$

$$e = 20.62 \text{ mb}$$

Substituting this into Eq. 1.4 gives:

$$\rho_m = (p/RT)\ (1 - .378\ e/P)$$

$$= \rho_d\ (1 - 0.378\ e/P)$$

$$= (1.11 \quad \text{Kg/m}^3)\ [\ 1 - (0.378)(20.62 \text{ mb})/950 \text{ mb})]$$

$$\boxed{\rho_m = 1.10 \text{ Kg/ m}^3}$$

moist air lighter than dry air!

1.9. At a weather station, the air pressure was measured to be 101.1 kPa, the air temperature was 22°C, and the dew point temperature was 18°C. Calculate the corresponding vapor pressure, relative humidity, specific humidity, and air density. First compute e and e_s.

Air Pressure = 101.1 kPa = 1011 mbar

Air Temp = 22° C = 295 K

T_d = 18° C

Note: 100 Pa = 1 millibar.

- Vapor Pressure

  $e = 2.7489 \times 10^8 \exp(-4278.6/(T_d + 242.79))$

  $e = 2.7489 \times 10^8 \exp(-4278.6/(18 + 242.79)) = \underline{20.60 \text{ mbar}}$

  $e_s = 2.7489 \times 10^8 \exp(-4278.6/(\text{AIR TEMP.} + 242.79)) = \underline{26.40 \text{ mbar}}$

- Relative Humidity

  $H = e/e_s \times 100\% = 20.60/26.40 = 0.78 \times 100 = \underline{78\%}$

- Specific Humidity

  $q = 0.622\, e/(P - 0.378\, e) = 0.622 \bullet 20.6/(1011 - 0.378 \bullet 20.6)$

  $q = \underline{0.0128 \text{ kg water/ kg moist air}}$

- Air Density

  $\rho_m = P/RT\,(1 - 0.378\, e/P)$

  $= [1011/(2.87 \cdot 10^3 \cdot 295)] \bullet [1 - (0.378 \bullet 20.60/1011)]$ $\cancel{mb}\ g\text{-}\cancel{K} / \cancel{mb}\ cm^3\text{-}\cancel{K}$

  $= 1.20 \times 10^{-3}\ g/cm^3 = \underline{1.2\ kg/m^3 = \rho_m}$

1.10. A small swimming pool (15ft x 20ft x 4ft) is suspected of having a leak out the bottom. Measurements of rainfall, evaporation, and water level are taken daily for 10 days as given below. Estimate the average daily leakage out of the swimming pool in ft^3/day. Assume the pool is 4 ft (48 in.) deep on day 1.

Day #	Evaporation (in.)	Rain (in.)	Level (in.)
1	0.5		48 (initial)
2	0.1	0.8	
3	0.5		
4	0.1	2.8	
5	0.5		
6	0.5		
7	0.1	2.4	
8	0.5		
9	0.5		
10	0.5		41 (ending)

During the 10 days =

Evaporation = 3.8 in

Precipitation = 6 in

If there would be no leakage, the final level of the swimming pool would be:

$$(48 + 6 - 3.8) \text{ in} = 50.2 \text{ in}$$

Due to the leakage,

$$(50.2 - 41) \text{ in} = 9.2 \text{ in are lost over 10 days}$$

Leakage = 0.92 in/ day = .077 ft/day

15 x 20 x .077 ft/day = <u>23 ft^3/day</u>

1.11. In a given year, a watershed with an area of 2500 km^2 received 130 cm of precipitation. The average rate of flow measured in a gage at the outlet of the watershed was 30 m^3/sec. Estimate the water losses due to the combined effects of evaporation, transpiration, and infiltration due to groundwater. How much runoff reached the river for the year (in cm)? What is the runoff coefficient?

$ET + G = P - R - \Delta S$

Assuming water level stays the same between $t = 0$ and $t = 1$, then $\Delta S = 0$

$ET + G = 130\text{ cm} - 30\text{ m}^3\text{/s (over 1 year)}$

$$ET + G = 130\text{ cm} - \frac{(30\text{ m}^3\text{/s})(86{,}400\text{ s/day})(365\text{ day/yr})(100\text{cm/m})}{(2500\text{ km}^2)(1000\text{ m/km})^2}$$

$ET + G = 130\text{ cm} - 37.84\text{ cm}$

$ET + G = 92.1\text{ cm}$

R = Runoff = 37.84 cm leftover from runoff

R/P = 37.84 cm/ 130 cm

$\boxed{R/P = .29}$

1.12. The incremental rainfall data in the table were recorded at a recording rainfall gage on a small urban parking lot of 1 ac. Be careful to use a 0.5 hr time step and record intensity in cm/hr.

a) Plot the rainfall hyetograph.

b) Determine the total storm rainfall depth (inches).

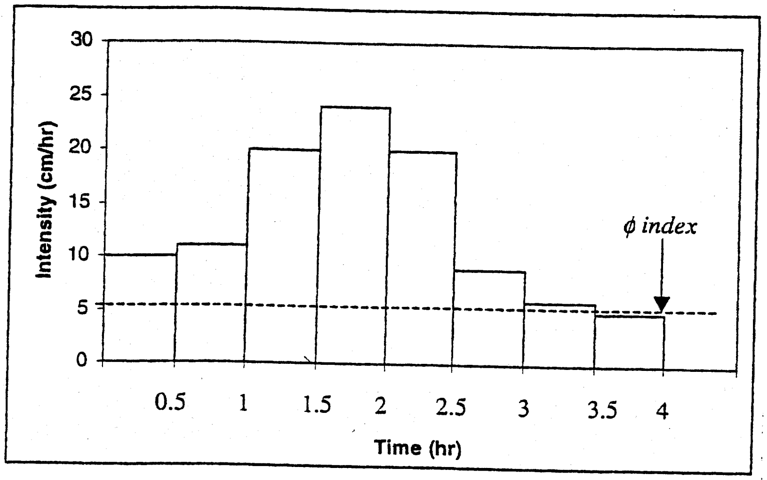
c) If 100% of the rainfall occurs as runoff and the time base of a triangular hydrograph (flow rate vs time) is 3 hr, find the peak flow of the hydrograph in cfs. Be careful with units.

Hint: (first find the volume of rainfall, then equate it to the area under the hydrograph)

TIME (hr)	RAINFALL (cm)
0	0
0.5	5.0
1.0	5.5
1.5	10.0
2.0	12.0
2.5	10.0
3.0	4.5
3.5	3.0
4.0	2.5
4.5	0

1.12. (cont.)

a) The hyetograph ordinates are found by dividing the incremental rainfall by the time interval



Time (hr)	Rainfall Intensity (cm/hr)
0 - 0.5	10
0.5 - 1	11
1 - 1.5	20
1.5 - 2	24
2 - 2.5	20
2.5 - 3	9
3 - 3.5	6
3.5 - 4	5
4 - 4.5	0

b) The total volume of rainfall is found by summing the incremental rainfall.

Volume = 52.5 cm over the watershed

c) $(10-\phi)\bullet 0.5+(11-\phi)\bullet 0.5+(20-\phi)0.5+(24-\phi)\bullet 0.5+(20-\phi)\bullet 0.5+(20-\phi)\bullet 0.5+(9-\phi)\bullet 0.5+(6-\phi)\bullet 0.5+(5-\phi)\bullet 0.5=30.5$

$\Longrightarrow (10-\phi)+(11-\phi)+(20-\phi)+(24-\phi)+(20-\phi)+(9-\phi)+(6-\phi)+(5-\phi)=61$

TRIAL AND ERROR

Assume $\phi=5 \Rightarrow 5+6+15+19+15+4+1=65>61$

Assume $\phi=5.57 \Rightarrow 4.45+5.43+14.43+18.43+14.43+3.43+0.43=61.01$

So ϕ index $=5.57$ cm/hr

1.13.

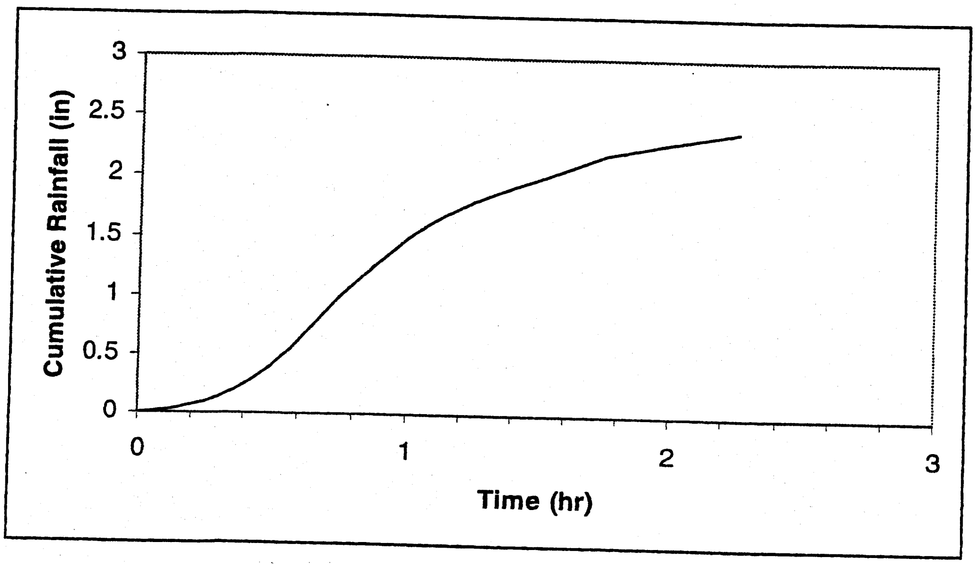
For the rainfall record provided below, plot cumulative rainfall (P) and gross rainfall hyetograph (in./hr) using Δt = 15min = 0.25 hr.

TIME (min)	0	15	30	45	60	75	90	105	120	135
P (in.)	0	0.1	0.4	1.0	1.5	1.8	2.0	2.2	2.3	2.4

TIME (hr)	0	1	2	3	4	5	6	7	8	9	10	11	12
Q (cfs)	0	100	200	400	800	700	550	350	250	150	100	50	0

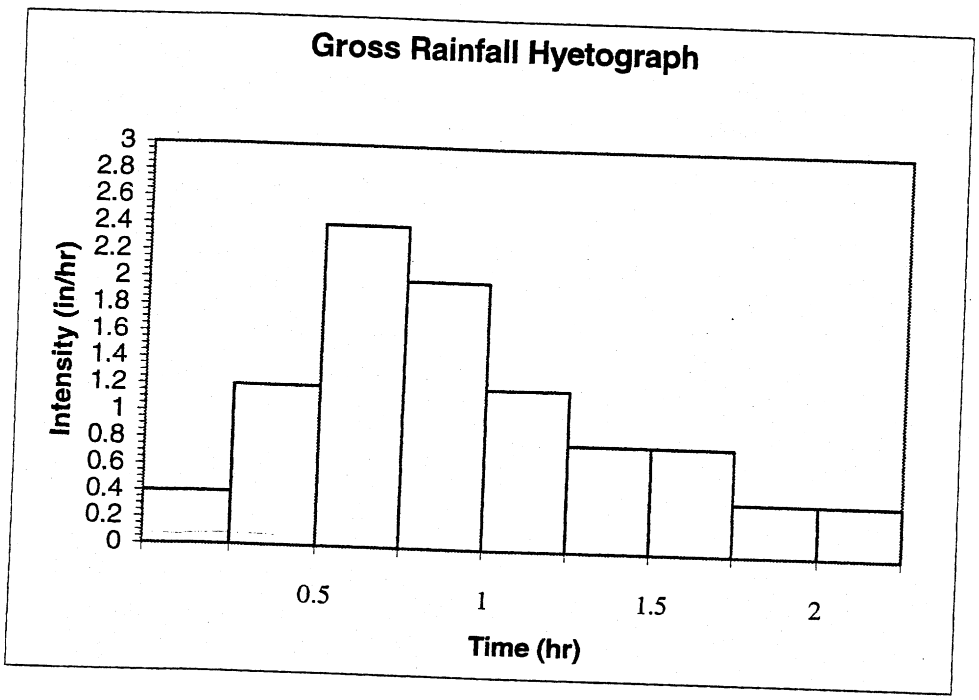
1.13. (cont.)

Time (hr)	Cumulative Rainfall (in)
0	0
0.25	0.1
0.5	0.4
0.75	1
1	1.5
1.25	1.8
1.5	2
1.75	2.2
2	2.3
2.25	2.4



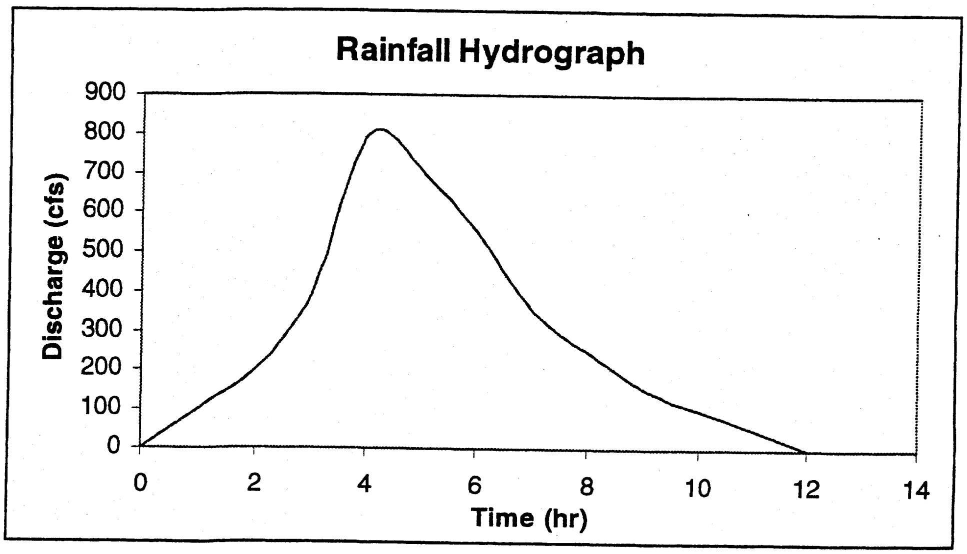
1.13. (cont.)

Time (hr)	Gross Rainfall Intensity (in/hr)
0 - 0.25	(0.1-0) / 0.25 = 0.4
0.25 - 0.5	(0.4-0.1) / 0.25 = 1.2
0.5 -0.75	2.4
0.75 - 1	2
1 - 1.25	1.2
1.25 -1.5	0.8
1.5 - 1.75	0.8
1.75 - 2	0.4
2 -2.2.5	0.4



Problem 1.14 utilizes the rainfall from problem 1.13.

1.14. If the gross rainfall of problem 1.13 falls over a watershed with area of 1600 acres, find the volume that was left to infiltration (assume evaporation can be neglected) based on the volume under the hydrograph.



$$P_{NET} = \frac{\text{Direct Runoff (area under hydrograph)}}{\text{Area of Watershed}}$$

Direct Runoff $\approx 0 + 100 + 200 + 400 + 800 + 700 + 550 + 350 + 250 + 150 + 100 + 50 + 0$

$= 3650$ cfs –hr ~3650 ac – in.

$$P_{NET} = \frac{3650 \text{ ac- in}}{1600 \text{ ac}} = 2.28 \text{ in.}$$

Volume of Infiltration = (2.4 – 2.28) in. = 0.12 in over the watershed

1.15. The following questions refer to Fig. 1.8, the IDF curve for Houston, Texas.

a) What is the return period of a storm that recorded 3.1 in./hr for 2 hr in Houston, Texas?

b) What amount of rain (in.) would have to fall in a 6-hr period to be considered a 100-yr storm in Houston?

c) What is the return period of a storm that lasts 1 hr and records 3.5 in. of rainfall?

d) Develop and plot a 6-hr, 100-yr storm design rainfall using 1-hr time steps (see Fig 1.8). Assume the maximum hourly value occurs between hour 3 and 4.

1) Find the rainfall intensity for a 1-hr duration and plot the rainfall intensity in inches/hr between the hours of 3 and 4 on a bar graph.

2) Then, find the rainfall intensity for a 2-hr duration; multiply the intensity by the duration of rain to get the volume. Plot the difference between the 2-hr duration volume and the 1-hr duration volume for hour 2 to 3 on a bar graph.

3) Continue in the same way for the 3-hr duration, plotting the new intensity to the right of the maximum (hour 4–5). (Find the 3-hr volume and subtract the 2-hr volume)

4) Then, find the rainfall intensity for a 6-hr duration and the respective volume. Plot the remaining volume (6-hr minus 3-hr) over the 3 hours, assuming equal distribution between them, with two bars to the left and one on the right of the maximum (time intervals 0–1, 1–2, and 5–6).

a) More than 100 –year storm

b) 1.36 in/hr • 6 hr = 8.16 in

c) ~ 25 yr. storm

d) 1 – hr. duration: 1 hr • 4.4 in/hr = 4.4 in

2 – hr. duration: 2 hr • 2.85 in/hhr = 5.7 in

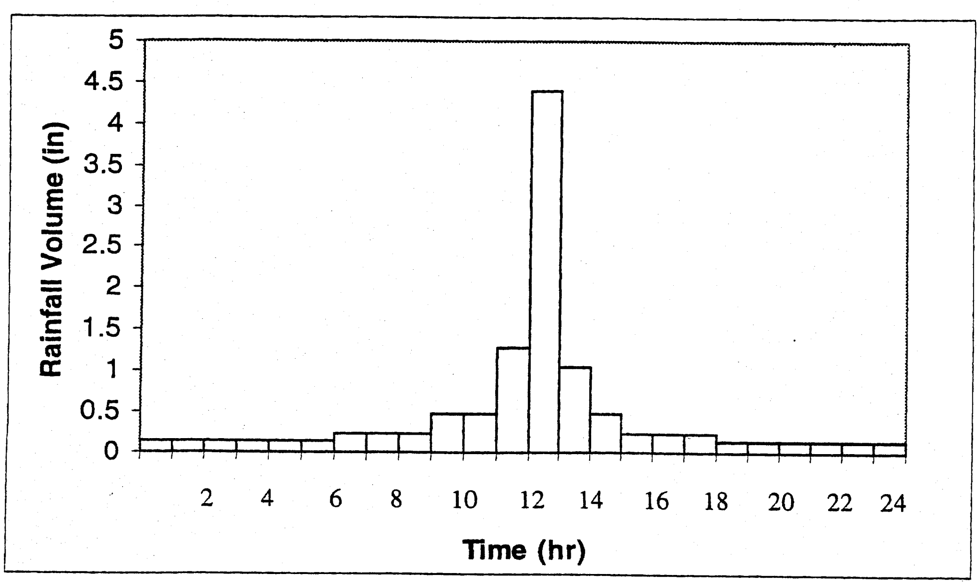
3 – hr duration: 3 hr • 2.25 in/hr = 6.75 in

6 – hr duration: 6 hr • 1.36 in/hr = 8.16 in

1.15. (cont.)

Interval	Rainfall Volume (in)
12-13	4.4
11-12	1.3
13-14	6.75 - 5.7 = 1.05
10-11	(8.16 - 6.750) / 3 = 0.47
9-10	0.47
14-15	0.47
8-9	(9.6 - 8.16) / 6 = 0.24
7-8	0.24
6-7	0.24
15-16	0.24
16-17	0.24
17-18	0.24
5-6	(11.4 - 9.6) / 12 = 0.15
4-5	0.15
3-4	0.15
2-3	0.15
1-2	0.15
0-1	0.15
18-19	0.15
19-20	0.15
20-21	0.15
21-22	0.15
22-23	0.15
23-24	0.15

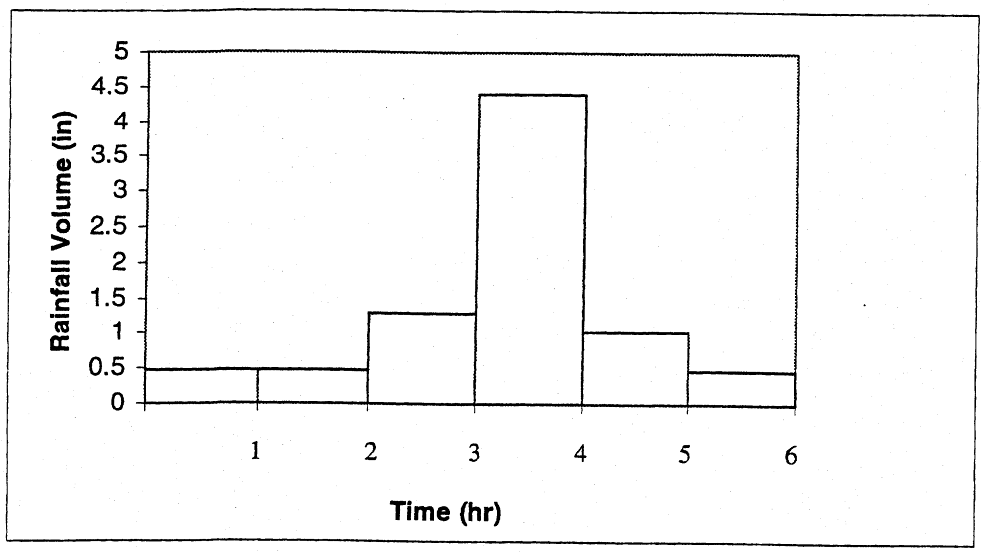
24 – hr, 100 –yr storm design rainfall



1.15. (cont.)

Interval	Rainfall Volume (in)
3-4	4.4
2-3	5.7 - 4.4 = 1.3
4-5	6.75 - 5.7 = 1.05
1-2	(8.16 - 6.75) / 3 = 0.47
0-1	0.47
5-6	0.47

6 – hr, 100 – yr storm design rainfall



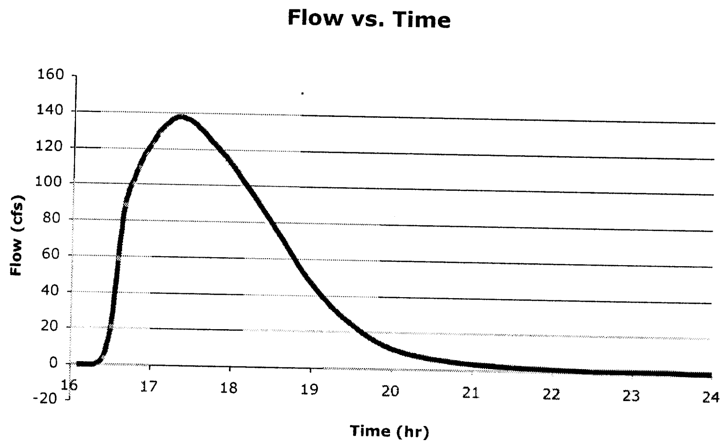
Problems 1.16 and 1.17 refer to the hydrologic data used in Problem 1.3.

1.16.

a) Plot the cumulative mass curves for rainfall and the hydrograph (flow rate vs. time) on the same graph.

b) Compute the volume of infiltration loss for the storm, neglecting ET by subtracting the volume of gross rainfall from the volume under the hydrograph.

(a)



(b) Convert flow rate (cfs) into inches and determine cumulative runoff.

For example use trapezoid method: (5cfs • 22cfs • 0.5) • (5min • 60s • 12in)/(43560ft^2 • 205acres) = 0.00544in   Repeat for all values and find cumulative runoff.

From either the plot or the data, we get:

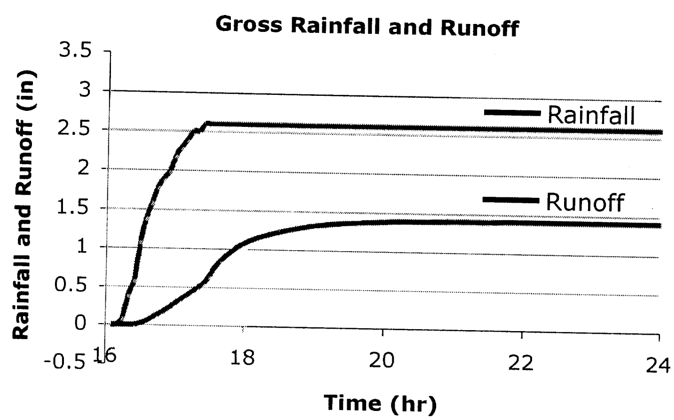
RF_T = 2.60 in

RF_N = 1.41 in

(2.60 in – 1.41 in) = 1.19 in

1.19in • 205acres / 12in =

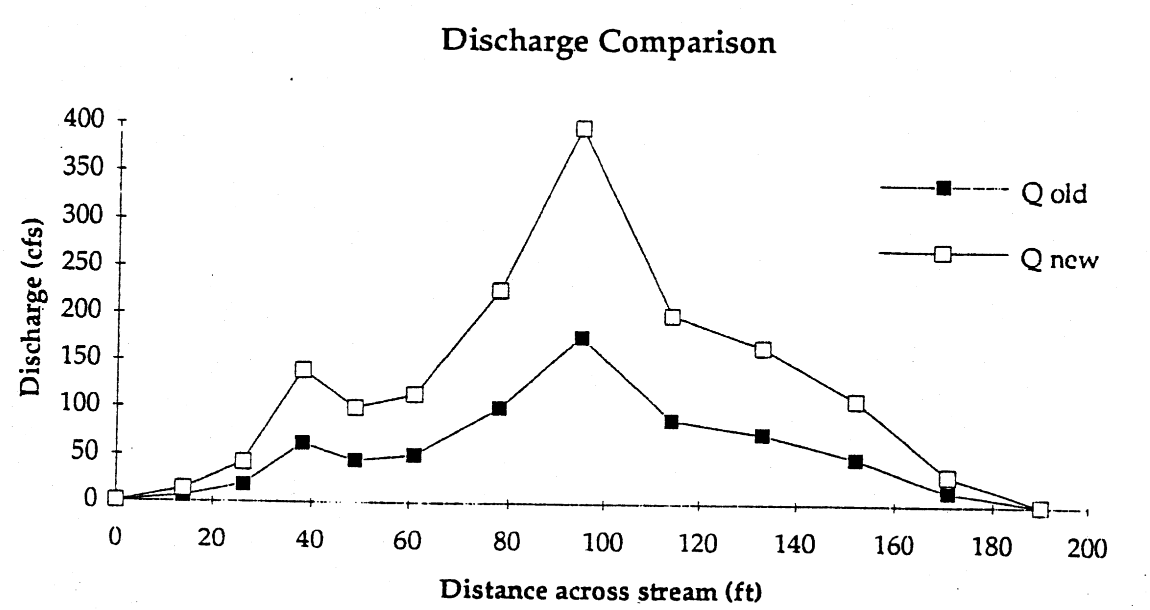
20.3 acre-ft



1.18. Rework Example 1.5, increasing the mean velocity and the depth by 50%. On one plot, graph the original discharge from the example and the newly calculated discharge for each station.

Referring to the Solution Table for Example 1.9, we can revise the depth and velocity columns by the prescribed 50% to get the following table and graph:

Meas. station	Dist. across stream (ft)	Width Δ W (ft)	Depth D (ft)	New depth D (+50%) ft	Mean vel. v (ft/sec)	New area Δ W * D2	Q - old (cfs)	Q - new from D2 (cfs)
A	0	7	0	0	0	0	0	0
B	14	13	1.1	1.7	0.6	21.5	6.2	13.8
C	26	12	2.6	3.9	0.9	46.8	19.0	42.8
D	38	11.5	3.5	5.3	2.3	60.4	62.0	139.5
E	49	11.5	3.2	4.8	1.8	55.2	44.5	100.2
F	61	14.5	3.1	4.7	1.7	67.4	50.8	114.3
G	78	17	3.9	5.9	2.3	99.5	100.8	226.7
H	95	18	4.2	6.3	3.5	113.4	176.9	398.0
I	114	19	3.3	5.0	2.1	94.1	89.0	200.3
J	133	19	2.9	4.4	2.0	82.7	73.8	166.1
K	152	19	2.1	3.2	1.8	59.9	49.1	110.4
L	171	19	1.4	2.1	0.8	39.9	14.1	31.7
M	190	9.5	0	0	0	0	0	0



1.19. Assume that stations B through L in Example 1.5 have all become 0.2 ft deeper. In addition, a tributary has joined the stream and added approximately 500 cfs to the flow in the channel. Calculate the new discharge amounts for each station by altering the depths and adding the tributary's contribution across the channel in proportion to the modified discharge distribution. Assume velocity distribution remains unchanged.

Meas. Station	Distance across stream (ft)	Width ΔW (ft)	Depth D (ft)	New Depth D2 (ft)	Mean Velocity (ft/sec)	New Area ΔW*D2 (ft^2)	Q without tributary (cfs)	%Q	%Q *500 tributary (cfs)	Total Q (cfs)
A	0	7	0	0	0	0	0	0	0	0
B	14	13	1.1	1.3	0.43	16.9	7.267	0.01	5	12.27
C	26	12	2.6	2.8	0.61	33.6	20.496	0.028	14	34.5
D	38	11.5	3.5	3.7	1.54	42.55	65.527	0.09	45	110.53
E	49	11.5	3.2	3.4	1.21	39.1	47.311	0.065	32.5	79.81
F	61	14.5	3.1	3.3	1.13	47.85	54.0705	0.074	37	91.07
G	78	17	3.9	4.1	1.52	69.7	105.944	0.145	72.5	178.44
H	95	18	4.2	4.4	2.34	79.2	185.328	0.254	127	312.33
I	114	19	3.3	3.5	1.42	66.5	94.43	0.13	65	159.43
J	133	19	2.9	3.1	1.34	58.9	78.926	0.108	54	132.93
K	152	19	2.1	2.3	1.23	43.7	53.751	0.074	37	90.75
L	171	19	1.4	1.6	0.53	30.4	16.112	0.022	11	27.11
M	190	9.5	0	0	0	0	0	0	0	0
SUM							729.1625	1	500	1229.16

1.20. Hurricane Katrina was the most devastating hurricane in United States history. Referring to http://www.hpc.ncep.noaa.gov/tropical/rain/katrina2005.html concerning total rainfall during Hurricane Katrina, answer the following questions:

a) Which state experienced the most cumulative rainfall during Hurricane Katrina?

a) Florida received the greatest cumulative rainfall of 16.43 in.

b) What was the lowest central pressure recorded during the hurricane?

b) The lowest central pressure was 902 mbar.

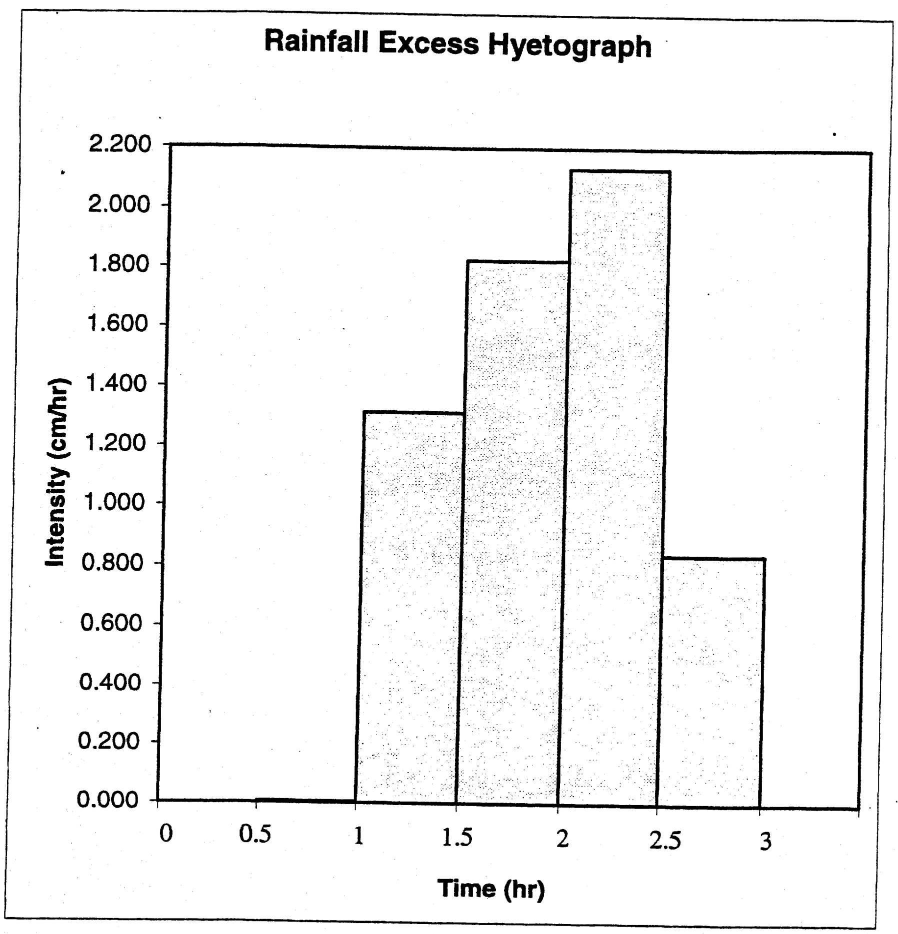
c) What finally halted the path of the hurricane?

c) It was absorbed into a developing extratropical cyclone when it reached Pennsylvania.

1.21. Using the rainfall below and a Horton infiltration curve with the parameters $k = 0.1$ hr^{-1}, $f_c = 0.5$ cm/hr, and $f_o = 0.7$ cm/hr, determine and graph the excess rainfall that would occur. Assume that the initial loss for the watershed is 0.5 cm, calculate the excess rainfall as an average over half-hour intervals, and refer to Example 6.1 for guidance.

The volume of rainfall for the first half hour is 1 • ½ = 0.5 cm. This will fill the depression storage of the watershed. Thus infiltration begins at 30 min.

Time Interval (hr)	Rainfall (cm/hr)	Infiltration Capacity at the start of interval (cm/hr)	Average Infiltration Capacity (cm/hr)	Rainfall Excess (cm/hr)
0-0.5	1			0.000
0.5-1	0.7	0.700	0.695	0.005
1-1.5	2	0.690	0.686	1.314
1.5-2	2.5	0.681	0.677	1.823
2-2.5	2.8	0.672	0.668	2.132
2.5-3	1.5	0.664	0.660	0.840
3-3.5	0.5	0.656	0.652	0.000



1.22. Using Fig. 1.19, find the daily evaporation from a shallow lake with the following characteristics:

Mean daily temperature = 25.6°C,

Daily solar radiation = 550 cal/cm^2,

Mean daily dew point = 4.4°C,

Wind movement (6 in. above pan) = 5.5 ft/s.

The chart has been constructed for units of °F, cal/cm^2, mi/ day, and in so the given measurement must be converted to the proper units.

$$25.6^{\circ}\text{C} = (25.6)(1.8) + 32 = 78^{\circ}\text{F}$$

$$4.4^{\circ}\text{C} = (4.4)(1.8) + 32 = 40^{\circ}\text{F}$$

$$5.5 \text{ ft/s} = (5.5 \text{ ft/s})(3600\text{s/hr})(24 \text{ hr/day})(1 \text{ mi}/5{,}280 \text{ ft}) = 90 \text{ mi/day}$$

Enter the chart at the point where T = 78°F and radiation = 550. Project a horizontal line to Td = 40°F. Next project a vertical line to v = 90 mi/day intersects the vertical line projected down from the entry point.

$$\boxed{E = 0.24 \text{ in.}}$$

1.23. A class A pan is maintained near a small lake to determine daily evaporation (see table below). The level in the pan is observed every day, and water is added if the level falls near 7 in. For each day the difference in height level is calculated between the current and previous day, and the precipitation value is from the current day. Determine the daily lake evaporation if the pan coefficient is 0.70.

Pan Evaporation = Drop in water level in the pan + Amount of Rainfall

Lake Evaporation = Pan evaporation • coefficient

Day	Rainfall (in.)	Water Level (in.)	Pan Evaporation (in.)	Lake Evaporation (in.)
1	0	8	0	0
2	0.23	7.92	8 - 7.92 + 0.23 = 0.31	0.7 * 0.31 = 0.217
3	0.56	7.87	0.61	0.427
4	0.05	7.85	0.07	0.049
5	0.01	7.76	0.1	0.070
6	0	7.58	0.18	0.126
7	0.02	7.43	0.17	0.119
8	0.01	7.32	0.12	0.084
9	0	7.25	0.07	0.049
10	0	7.19	0.06	0.042
11	0	7.08 (refill)	0.11	0.077
12	0.01	7.91	0.1	0.070
13	0	7.86	0.05	0.035
14	0.02	7.8	0.08	0.056

1.24. Given an initial rate of infiltration equal to 1.25 in./hr and a final capacity of 0.25 in./hr, use Horton's equation (Eq. 1.20) to find the infiltration capacity at the following times: t = 10 min, 15 min, 30 min, 1 hr, 2 hr, 4 hr, and 6 hr. You may assume a time constant $k = 0.25\ \text{hr}^{-1}$.

Substituting the given values into Horton's equation gives:

$$F = 0.25\ \text{in/hr} + (1.0\ \text{in/hr})(e^{-0.25t})$$

Solving this equation for the given values of t gives:

T (hr)	F (in/hr)
1/6	1.21
1/4	1.19
1/2	1.13
1	1.03
2	0.86
4	0.62
6	0.47

1.25. Determine a Horton equation to fit the following times and infiltration capacities.

TIME (hr)	*f* (in./hr)
1	3.17
2	2.60
6.5	1.25
∞	0.60

Horton's Equation : $f = f_c + (f_o - f_c)\, e^{-kt}$

At $t = \infty$, $f = 0.6 = f_c + (f_o - f_c)e$

$f_c = 0.6$

At $t = 1$ hr, $f = 3.17 = 0.6 + (f_o - 0.6)\, e^{-k}$

At $t = 2$ hr, $f = 2.60 = 0.6 + (f_o - 0.6)\, e^{-2k}$

Solve for f_o From t= 1 hr equation:

$$f_o = \frac{3.17 - 0.6}{e^{-k}} + 0.6$$

Substitute into the t = 2hr equation:

$0.6 + (2.57/ e^{-k})\, e^{-2k} = 2.60$

$2.57\, e^{-k} = 2.00$

$e^{-k} = 2/ 2.57 = 0.78$

$k = 0.25$

Use the values above and plug into the equation for $t = 1$ hr.

1.26. A 5-hr storm over a 15-ac basin produces a 5-in. rainfall: 1.2 in./hr for the first hour, 2.1 in./hr for the second hour, 0.9 in./hr for the third hour, and 0.4 in./hr for the last two hours. Determine the infiltration that would result from the Horton model with k = 1.1 hr^{-1}, f_c = 0.2 in./hr, and f_o = 0.9 in./hr. Plot the overland flow for this condition, in in./hr vs. t.

K = 1.1 hr^{-1}

f_c = 0.2 in/hr

f_o = 0.9 in/hr

$f = f_c + (f_o - f_c)\, e^{-kt}$

t = 0, $f = 0.2 + (0.9 - 0.2)e^{o} = 0.9$ in/hr

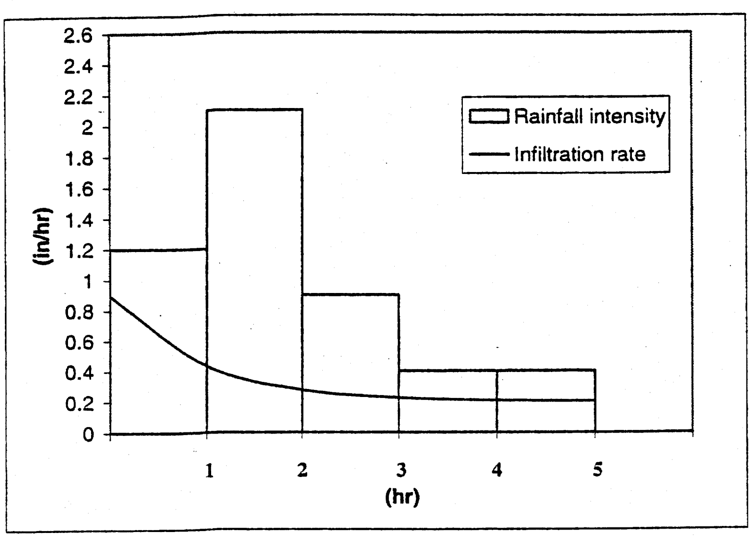
t = 1, $f = 0.2 + (0.9 - 0.2)e^{-1.1} = 0.43$ in/hr

t = 2, $f = 0.2 + (0.9 - 0.2)e^{-2.2} = 0.28$ in/hr

t= 3, $f = 0.2 + (0.9 - 0.2e^{-3.3} = 0.23$ in/hr

t = 4, $f = 0.2 + (0.9 - 0.2)e^{-4.4} = 0.21$ in/hr

t = 5, $f = 0.2 + (0.9 - 0.2)e^{-5.5} = 0.203$ in/hr



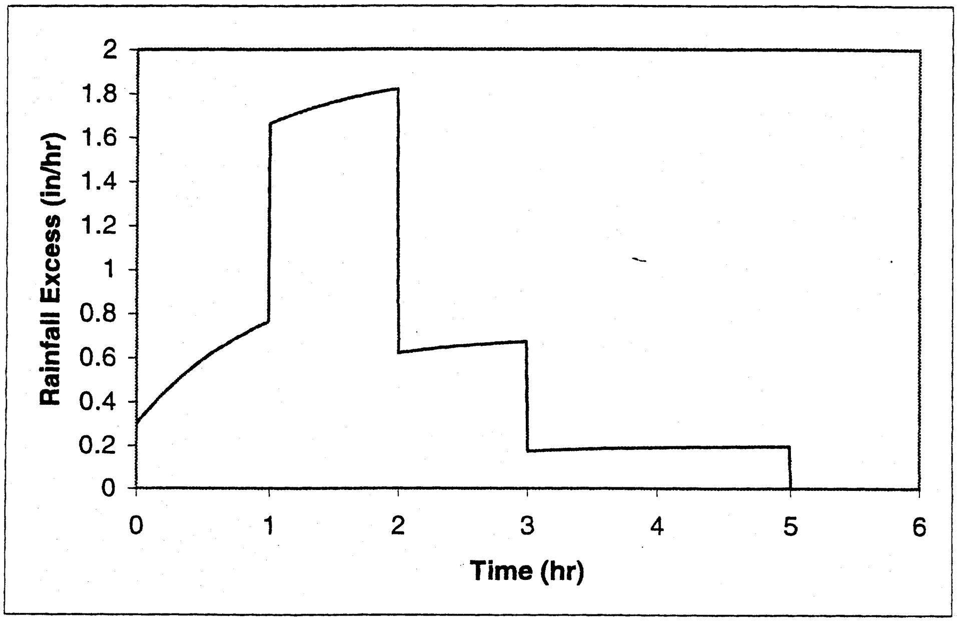
1.26. (cont.)

Infiltration Volume = $\int^5_0 (0.2 + 0.7e^{-1.1t})\, dt =$

$0.2\,[t]^5_0 + (0.7/ -1.1)\,[e^{-1.16}]^5_0 =$

$1 + (-0.636) \bullet (0.004 - 1) =$

$1 + 0.663 = 1.633$ in over the watershed



1.27. A plot of the infiltration curve obtained using Horton's equation is shown in Fig. P1.27. Prove that $k = (f_o - f_c)/F'$ if F' is the area between the curve and the f_c line. Find the area by integration over time, as time approaches infinity.

A point is chosen on the curve such that at $t = t_1$, $f \approx f_c$. The area F' is equal to the area under the curve above the line f_c from $t = 0$ to $t = t_o$. this area may be found by integration as follows:

$$F' = \int_0^{ta} [f_c + (f_o - f_c)e^{-kt}]\ dt - \int_0^{ta} f_c\, dt$$

$$= \int_0^{ta} (f_o - f_c)\, e^{-kt}\ dt$$

$$F' = (f_o - f_c)\,(-1/k)\,(e^{-kta}) - (f_o - f_c)\,(-1/k)$$

As $t_a \longrightarrow \infty$, $e^{-kta} \longrightarrow 0$, therefore:

$$F' = 1/k\,(f_o - f_c)$$

$$K = (f_o - f_c)\,/F'$$

1.28. Determine the ϕ index of Figure P1.28 if the runoff depth was 5.6 in. of rainfall over the watershed area.

TRIAL AND ERROR

$$(0.4-\phi)\bullet 6+(0.5-\phi)\bullet 2+(0.7-\phi)\bullet 4+(0.9-\phi)\bullet 2+(0.3-\phi)\bullet 4+(0.2-\phi)\bullet 2=5.6$$

ASSUME $\phi=0.3$ in/hr

$0.1 \bullet 6 + 0.2 \bullet 2 + 0.4 \bullet 4 + 0.6 \bullet 2 = 3.8 < 5.6$

ASSUME $\phi=0.2$ in/hr

$0.2 \bullet 6 + 0.3 \bullet 2 + 0.5 \bullet 4 + 0.7 \bullet 2 + 0.1 \bullet 4 = 5.6$

So ϕ index = 0.2 in/hr

1.29. Compute the ϕ index for the rainfall of problem 1.13 using the results from problem 1.14 and plot the rainfall excess hyetograph.

$P_{NET} = 2.28$ in

$2.28 = [(0.4 - \phi)+(1.2-\phi)+(2.4 - \phi) + (2 - \phi) + (1.2 - \phi) + (0.8 - \phi)+(0.8+ \phi)+ (0.4 - \phi)+ (0.4 - \phi)] \cdot 0.25$

$\Rightarrow\ 9.12 = [(0.4 - \phi)+(1.2-\phi)+(2.4-\phi)+(2-\phi)+(1.2-\phi)+(0.8-\phi)+(0.8-\phi)+(0.4-\phi)+(0.4-\phi)]$
(Equation 1)

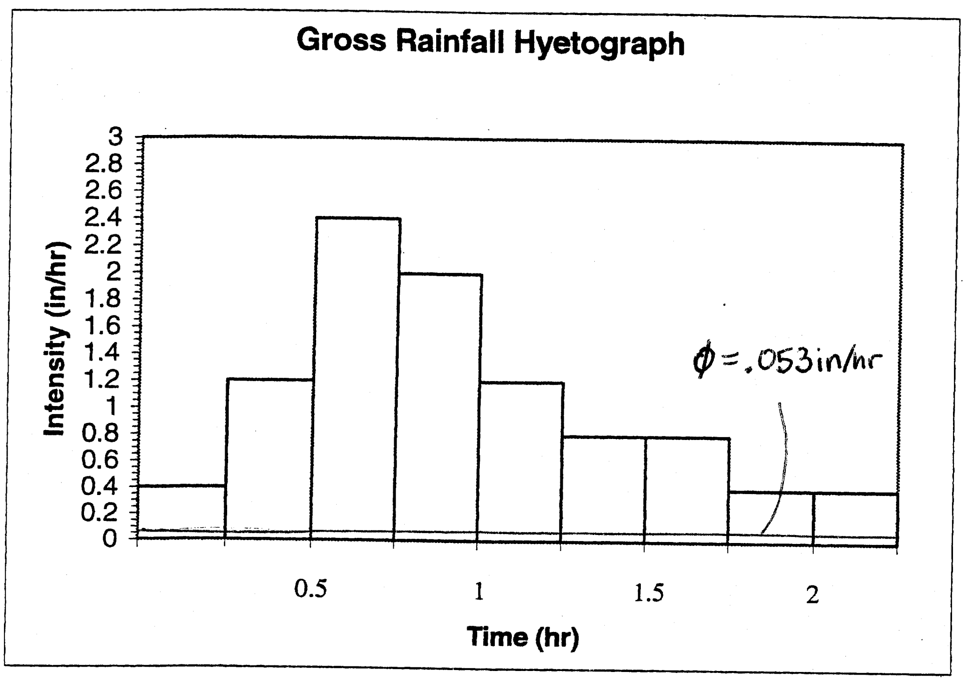
Trial and Error Method

For $\phi = 0.1$: $0.3+ 1.1 + 2.3 + 1.9 + 1.1 + 0.7 + 0.7 + 0.3 + 0.3 =$

$= 8.7 < 9.12 \Rightarrow \phi < 0.1$

Since ϕ is less than 0.4 in/hr (where 0.4 in/hr is the smallest rainfall intensity,) we can solve Equation 1 as a regular equation:

$9.12 = 9.6 - 9\phi$ $\qquad\qquad$ $\phi = 0.053$ in/hr



1.30. A sandy loam has an initital moisture content of 0.18, hydraulic conductivity of 7.8 mm/hr, and average capillary suction of 100 mm. Rain falls at 2.9 cm/hr and the final moisture content is measured to be 0.45. Plot the infiltration rate vs. the infiltration volume, using the Green and Ampt method of infiltration.

$\theta_i = 0.18$, $\theta_f = 0.45$

$K_s = 78$ mm/hr

$S_{av} = 100\text{mm} = -\Psi_F$ Avg Capillary Suction

Rain Intensity = 2.9 cm/hr (For 6 hours)

$M_D = \theta_f - \theta_i = 0.45 - 0.18 = 0.27$

$F_s = (S_{av} \cdot M_D) / ((I/K_s) - 1) = 100 \bullet (0.27) / (2.9/0.78 - 1)$ mm/ (cm/cm) = 9.93 mm

Until 9.93 mm has infiltrated, the rate of infiltration equals the rainfall intensity = 2.9 cm/ hr

$t = (1/2.9) \bullet (.993) = 0.34$ hr.

F (cm)	F (cm/hr)
1	2.89
2	1.83
3	1.48
4	1.31
5	1.20
6	1.13
7	1.08
8	1.04

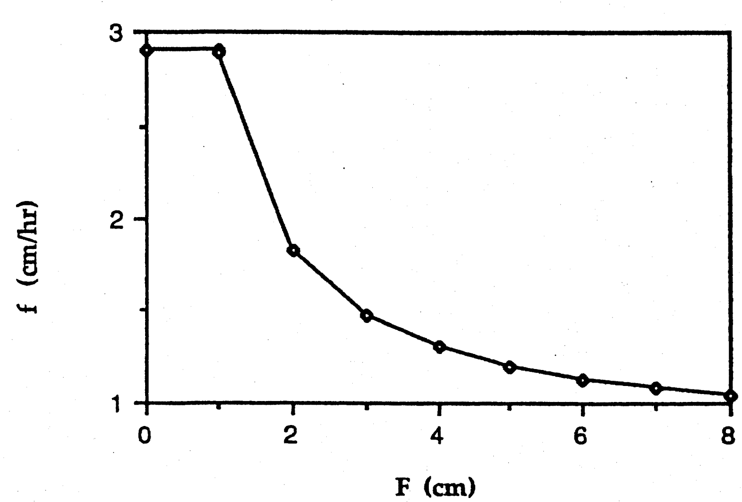
After Saturation:

$f = K_s (1 + S_{av} \bullet (M_d/F))$

$= 0.78 (1 + 10 \bullet (0.27 / F))$

$= 0.78 (1 + (2.7/F))$

Infiltration Rate vs. Infiltration Volume



1.31. Use the parameters given to graph the infiltration rate vs. the infiltration volume for the same storm for both types of soil. Prepare a graph using the Green-Ampt method, comparing all the curves calculated with both the lower- and upper-bound porosity parameters. The rainfall intensity of the storm was 1.5 cm/hr for several hours and the initial moisture content of all the soils was 0.15.

SOIL	POROSITY	CAPILLARY SUCTION (cm)	HYDRAULIC CONDUCTIVITY (cm/hr)
Silt loam	0.42–0.58	16.75	0.65
Sandy clay	0.37–0.49	23.95	0.10

$\theta_i = 0.15$ $S_{AV} = -\Psi_F$ Capillary Suction

Rain Intensity = 1.5 cm/hr

	SL	SC
K_S	0.65	0.10 cm/hr
S_{AV}	16.75	23.95 cm
θ_f	0.42- 0.58	0.37- 0.49

$M_d = \theta_f - \theta_i$

-Silty Loam: (SL)

$F_S = (S_{AV} \bullet M_d) /((I/ K_s) -1) = (16.75 \bullet M_d)/ ((1.5 \text{ cm/hr}/ 0.65 \text{ cm/hr}) -1) = 16.75 \bullet M_d/ 1.308$

With a Low Porosity,

$M_d = 0.42 - 0.15 = 0.27$

$F_s = 3.46$ cm

Saturation Time = Fs/I = 3.46 cm/ 1.5 cm/hr = 2.31 hr

With a High Porosity:

$M_d = 0.58- 0.15 = 0.43$

$F_s = 5.51$ cm

Saturation Time = 5.51 cm/ 1.5 cm/hr = 3.67 hr

1.31. (cont.)

Sandy Clay:

$F_s = (S_{AV} \bullet M_d) / ((I / K_s) - 1) = (23.95 \bullet M_d) / ((1.5/0.1) - 1) = 23.95 \bullet M_d / 14$

With a Low Porosity,

$M_d = 0.37 - 0.15 = 0.22$

$F_s = 0.38$ cm

Saturation Time $= 0.38$ cm / 1.5 cm/hr = 0.25 hr

With a High Porosity,

$M_d = 0.49 - 0.15 = 0.34$

$F_s = 0.58$ cm

Saturation Time $= 0.58$ cm/ 1.5 cm/hr = 0.39 hr

Plot the Infiltration Volume –vs.– The Infiltration Rate: $f = k_s (1 + S_{av} \bullet (M_d/F))$