Chapter 1-Answer Key

CONCEPT CHECK

1.1 What is the hydrologic cycle? What are the pathways that precipitation falling onto the land surface of the Earth is dispersed to the hydrologic cycle?

ANSWER:

The hydrologic cycle is a continuous process in which water is evaporated from water surfaces and the oceans, moves inland as moist are masses, and produces precipitation if the correct vertical lifting conditions exist.

A portion of precipitation (rainfall) is retained in the soil near where it falls and returns to the atmosphere via evaporation (the conversion of water to water vapor from a water surface) and transpiration (the loss of water vapor through plant tissue and leaves). Combined loss is called evapotranspiration and is a maximum value if the water supply in the soil is adequate at all times. Some water enters the soil system in infiltration which is a function of soil moisture conditions and soil and may reenter channels later as interflow or may percolate to recharge the shallow ground water. The remaining portion of precipitation becomes overland flow or direct runoff which flows generally in a down-gradient direction to accumulate in local streams that then flow into rivers.

1.2 Who is responsible for the first recorded rainfall measurements? Describe the technique used to obtain these measurements.

ANSWER:

The first recording was obtained in the seventeenth century by Perrault. He obtained his data by comparing measured rainfall to the estimated flow in the Seine River to show how the two were related.

1.3 Explain the difference between humidity and relative humidity.

ANSWER:

Humidity is a measure of the amount of water vapor in the atmosphere and can be expressed in several ways. Specific humidity is a mass of water vapor in a unit mass of moist air while relative humidity is a ratio of the air's actual water vapor content compared to the amount of water vapor at saturation for that temperature.

1.4 Explain how air masses are classified. Where are these types of air masses located?

ANSWER:

They are classified in two ways: the source from which they are generated, land (continental) or water (maritime), and the latitude of generation (polar or tropical).
These air masses are present in the United States. The Continental polar emanates from Canada and passes over the northern United States. The maritime polar air mass also comes southward from the Atlantic Coast of Canada and affects the New England states. Another maritime polar comes from the Pacific and hits the extreme northwestern states. The maritime tropical air masses come from the Pacific, the Gulf of Mexico and the Atlantic (these affect the entire Southern United States). Continental tropical air masses from only during the summer. They originate in Texas and affect the states bordering the north.

1.5 List seven major factors that determine a watershed's response to a given rainfall.

ANSWER:

Drainage Area
Channel Slope
Soil Types
Land Use
Land Cover
Main Channel and tributary characteristics-channel morphology
The shape, slope and character of the floodplain

PROBLEMS

1.6 A lake with a surface area of 1050 acres was monitored over a period of time. During a one-month period the inflow was 33 cfs, the outflow was 27 cfs, and a 1.5-in. seepage loss was measured. During the same month, the total precipitation was 4.5 in. Evaporation loss was estimated as 6.0 in. Estimate the storage change for this lake during the month.

ANSWER:

A = 1050 acres
T = 1 month
I = 33 cfs
O = 27 cfs
G = 1.5 in.
P = 4.5 in.
E = 6 in.

I-O+P-G-E = ΔS

First convert inflow and outflow into inches

$$\text{Inflow} = \frac{33\frac{ft^3}{s}\cdot\frac{1ac}{43560ft^2}\cdot\frac{12in}{1ft}\cdot\frac{3600s}{1hr}\cdot\frac{24hr}{1day}\cdot\frac{30days}{1month}\cdot 1month}{1050acres} = 22.4\text{ in.}$$

$$\text{Outflow} = \frac{27\frac{ft^3}{s}\cdot\frac{1ac}{43560ft^2}\cdot\frac{12in}{1ft}\cdot\frac{3600s}{1hr}\cdot\frac{24hr}{1day}\cdot\frac{30days}{1month}\cdot 1month}{1050acres} = 18.4\text{ in.}$$

ΔS = 22.4 in. - 18.4 in. + 4.5 in. - 1.5 in. – 6 in. = **1 in.**

ΔS in volume = $1in.\cdot\frac{1ft}{12in.}\cdot 1050acres$ = **87.5 ac-ft**

1.7 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 24 cm for this month, determine the evaporation loss (in cm) for the lake. Assume that seepage loss is negligible.

ANSWER:

$A = 708{,}000\ m^2$

$I = 1.5\ \frac{m^3}{s}$

$O = 1.25\ \frac{m^3}{s}$

$\Delta S = 1$ m

P = 24 cm

T = 1 month

$E = I - O + P - \Delta S$

Convert everything to centimeters

$\Delta S = 100$cm

$$\text{Inflow} = \frac{1.5\frac{m^3}{s}\cdot\frac{100cm}{1m}\cdot\frac{3600s}{hr}\cdot\frac{24hr}{1day}\cdot\frac{30days}{1month}\cdot 1month}{708{,}000m^2} = 549.2\text{ cm}$$

$$\text{Outflow} = \frac{1.25\frac{m^3}{s}\cdot\frac{100cm}{1m}\cdot\frac{3600s}{hr}\cdot\frac{24hr}{1day}\cdot\frac{30days}{1month}\cdot 1month}{708{,}000m^2} = 457.6\text{ cm}$$

E = 549.2 cm - 457.6 cm + 24cm – 1 00cm = **15.6cm**

1.8 In a given month, a watershed with an area of $1500m^2$ received 100cm of precipitation. During the same month, the loss due to evaporation was 15cm. Ignore losses due to transpiration and infiltration due to ground water. What would be the average rate of flow measured in a gage at the outlet of the watershed in m^3/day?

ANSWER:

$A = 1500\,m^2$

$P = 100cm$

$E = 15cm$

Here precipitation is the inflow I-E = O

O = 100cm-15cm = 85cm in 1 month over an area of $1500m^2$, so

$$O = \frac{85cm}{1month} \cdot \frac{1day}{24hr} \cdot \frac{1m}{100cm} \cdot 1500m^2 = 4.92\text{E-}4\ \frac{m^3}{s} = \mathbf{42.5}\frac{m^3}{day}$$

1.9 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 ground water. How much runoff reached the river for the year (in cm)?

ANSWER:

A = 2500 km^2

P = 130 cm

R = 30 m^3/sec

Assuming $\Delta S = 0$ in the span of the year

ET+G = P-R

Convert R to cm

$$R = \frac{30\frac{m^3}{s}\cdot\frac{100cm}{1m}\frac{3600s}{1hr}\cdot\frac{24hr}{1day}\cdot\frac{365days}{1year}\cdot 1year}{2500km^2\cdot(\frac{1000m}{1km})^2} = \mathbf{37.8\ cm\ is\ runoff}$$

ET + G = 130 cm - 37.8 cm = **92.2 cm**

1.10 Using the data from problem 1.9, what is the runoff coefficient?

ANSWER:

$$\text{Runoff coefficient} = R/P = \frac{37.8cm}{130cm} = \mathbf{0.29}$$

1.11 Plot Eq. (1–4) 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 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

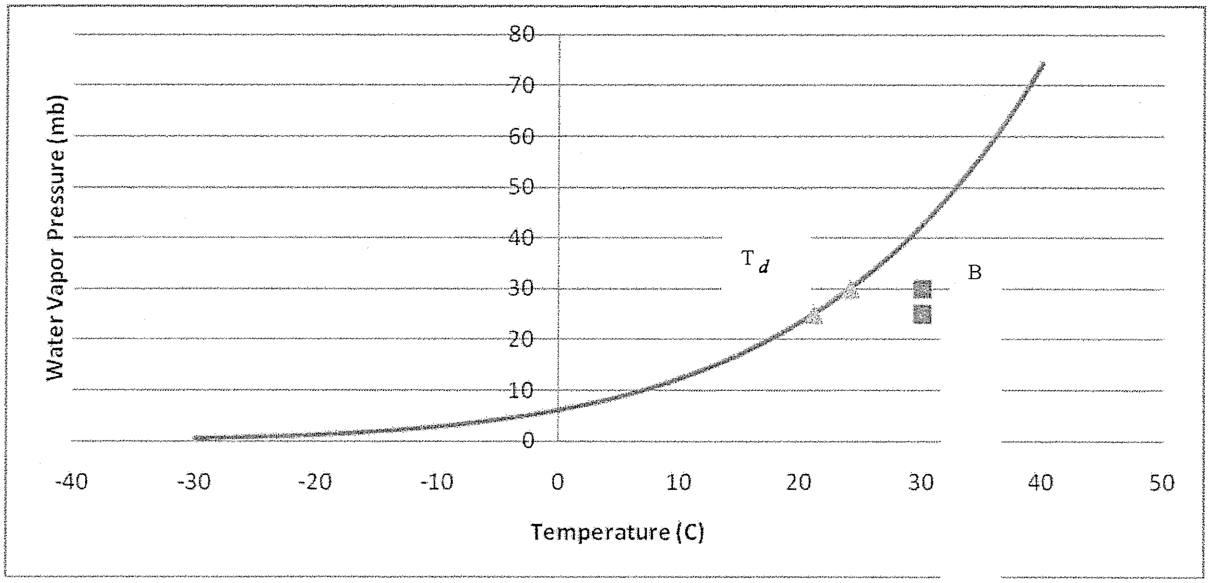
(ii) Dew point

(iii) Relative humidity

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

1.11 cont'

ANSWER:



The graph can be made using a program like Excel

Equation (1–4): $e = 2.7489\times10^{8}\exp\left(\left(\dfrac{-4278.6}{(T_d+242.79)}\right)\right)$

a) Saturated samples of air: **$T = 10^\circ$ C, P = 20 mb**

$T = 10^\circ$ C, P = 30 mb

Unsaturated samples of air: **$T = 10^\circ$ C, P = 10 mb**

$T = 20^\circ$ C, P = 20 mb

b) A = ($T = 30^\circ$ C, P = 25 mb)

B = ($T = 30^\circ$ C, P = 30 mb)

i. Saturation Vapor Pressure is a function of temperature. For both samples A and B, $T = 30^\circ$ C so

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

ii. Dew point is a measure of water vapor pressure

For sample A, $e_a = 25\text{mb} \rightarrow T_d =$ **21.14° C**

For sample B, $e_b = 25\text{mb} \rightarrow T_d =$ **24.14° C**

1.11 cont'

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

$$\text{Sample A} = \frac{25}{42.41}\cdot 100 = 59\%, \quad \text{Sample B} = \frac{30}{42.41}\cdot 100 = \mathbf{71\%}$$

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

$T = T_d = \mathbf{15^\circ C}$

1.12 The gas constant R has the value $2.87 \times 10^6\ \mathrm{cm^2/s^2\,°K}$ 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 1050 mb. Find the density of moist air at the same pressure and temperature if the relative humidity is 65 percent.

ANSWER:

$R = 2.87 \times 10^6\ \mathrm{cm^2/s^2\,°K}$

$T = 25°C$

$P = 1050$ mb

Note: 1 mb = 100 Pa = 100 Nt/m^2 = 100 kg/m·s^2

a) Rearrange for ρ gives

$$\rho = \frac{P}{RT} = \frac{1050mb \cdot \left(00Nt/m^2 \big/ 1mb\right)\left(1kg/m \cdot s^2 \big/ 1Nt/m^2\right)}{2.87\times10^6\ cm^2 \cdot s^{-2} \cdot K^{-1} \cdot 298K} \cdot \left(\frac{100cm}{1m}\right)^2 = \mathbf{1.23\ kg/m^3}$$

b) The density of moist air can be found using the equation $\rho_m = \frac{P}{RT}(1-0.378e/P)$ Since we know the relative humidity, we can find e. (See Appendix C for values of e_s at 25° C (need to convert from kN/m^2 to mb)

At 25° C $e_s = 31.72$ mb

$H = 100e/e_s$

$65 = 100e/31.72$

$e = 20.62$ mb

Substituting this into equation gives

$$\rho_m = \frac{P}{RT}(1-0.378e/P) = \rho_d\,(1-0.378e/P)$$

1.12 cont'

$$1.23\ \text{kg/m}^3\left(1-\frac{0.378\cdot 20.62mb}{1050mb}\right)= \mathbf{1.22\ kg/\ m^3}$$

Moist air is lighter than dry air!

1.13 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.

ANSWER:

Air Pressure = 101.1 kPa = 1011mb

Air Temp = 22°C = 295K

$T_d = 18°C$

Note: 100 Pa = 1 mb

-Vapor Pressure

$$e = 2.7489\times10^8 \exp\left(\left(\frac{-4278.6}{(T_d + 242.79)}\right)\right)$$

$$e = 2.7489\times10^8 \exp\left(\left(\frac{-4278.6}{(18 + 242.79)}\right)\right) = \mathbf{20.60\ mb}$$

$$e_s = 2.7489\times10^8 \exp\left(\left(\frac{-4278.6}{(22 + 242.79)}\right)\right) = \mathbf{26.40\ mb}$$

-Relative Humidity

$H = 100e/e_s = 100\cdot 20.60/26.40 = 100\cdot 0.78 = \mathbf{78\%}$

-Specific Humidity

$$q = \frac{0.622e}{P - 0.378e} = \frac{0.622\cdot 20.6}{1011-(0.378\cdot 20.6)} = \mathbf{0.0128\ kg\ water/kg\ moist\ air}$$

-Air Density

$$\rho_m = \left(\frac{P}{RT}\right)\left(1 - \frac{0.378e}{P}\right) = \left(\frac{1011}{(2.87\times10^3)(295)}\right)\cdot\left(1 - \frac{(0.378\cdot 20.6)}{1011}\right)$$

$= 1.18\times10^{-3}\ g/cm^3 = \mathbf{1.2\ kg/m^3}$

1.14 What are the three main mechanisms for generation of vertical air motion?

ANSWER:

The three mechanisms for the generation of vertical air motion are:

-convective: due to intense heating of air at the ground which leads to expansion and vertical rise of air

-cyclonic: associated with the movement of large air-mass systems, as in the case of warm or cold fronts

-orographic: due to mechanical lifting of moist air masses over the windward side of mountain ranges

1.15 Describe the naming system for describing basic clouds.

ANSWER:

The names of basic clouds have the following roots:

-cirrus: feathery or fibrous clouds

-stratus: layered clouds

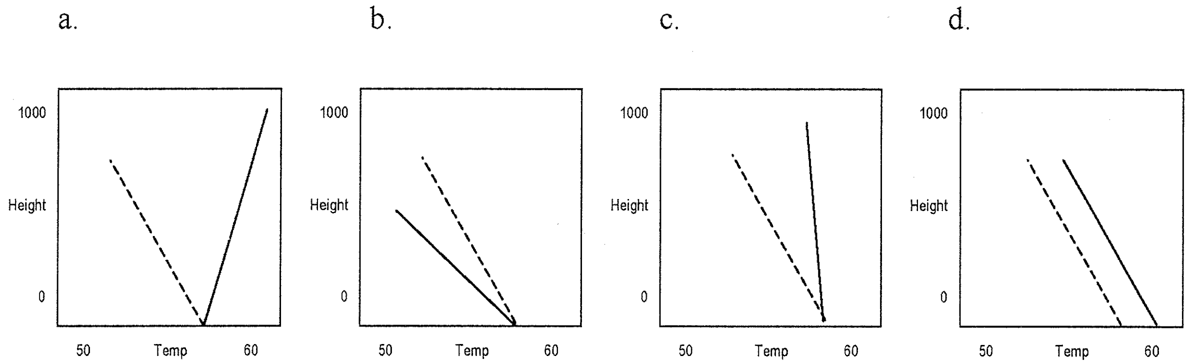
-cumulus: towering, puffy clouds

-alto: middle-level clouds

-nimbus: rain clouds

The second aspect of cloud classification is by height. An example is "cumulonimbus."

1.16 Below are three different atmospheric systems. The dashed line represents the dry adiabatic lapse rate where as the solid line represents the dry ambient lapse rate. Label whether the atmosphere is stable, unstable, or neutral:



ANSWER:

a. stable

b. unstable

c. stable

d. neutral

1.17 Hurricane Katrina was the most devastating hurricane in United States history. Referring to http://www.hpc.ncep.noaa.gov/. Find the information concerning total rainfall during Hurricane Katrina, answer the following questions:

(a) What category event was Hurricane Katrina when it made landfall?

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

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

(c) What finally halted the path of the hurricane?

ANSWER:

a. Category 3
b. Florida received the greatest cumulative rainfall of 16.43 in.
c. The lowest central pressure was 902 mb.
d. It was absorbed into a developing extratropical cycle when it reached Pennsylvania. (Acceptable alternative: It transformed into extratropical low pressure as it moved eastward from the Great Lakes over the Tennessee Valley.)

1.18 A watershed of 465 ac with six rainfall gages can be divided into Thiessen polygons with the listed data in the accompanying table. Using the total storm rainfall depths listed, find the average rainfall over the watershed in ac-ft.

Gage	Rainfall (in.)	Area (ac)
A	2.20	90
B	3.22	77
C	0.71	17
D	2.49	89
E	0.88	162
F	6.72	30

ANSWER:

$A_t = 465$ ac

Gage	Rainfall, P_i (in.)	Area, A_i (ac)	A_i/A_t	$P_i \times A_i/A_t$ (in.)
A	2.2	90	0.194	0.43
B	3.22	77	0.166	0.53
C	0.71	17	0.037	0.03
D	2.49	89	0.191	0.48
E	0.88	162	0.348	0.31
F	6.72	30	0.065	0.44
SUM		**465**	**1.001**	**2.22 in**

$$2.22\text{ in.} \times 465ac \cdot {}^{1ft}\!/_{12in.} = \mathbf{86.0\ ac\text{-}ft}$$

1.19 A small urban watershed has four rainfall gages as located in Fig. P1–19. 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.

Gage	Rainfall (in.)
A	3.26
B	2.92
C	3.01
D	3.05

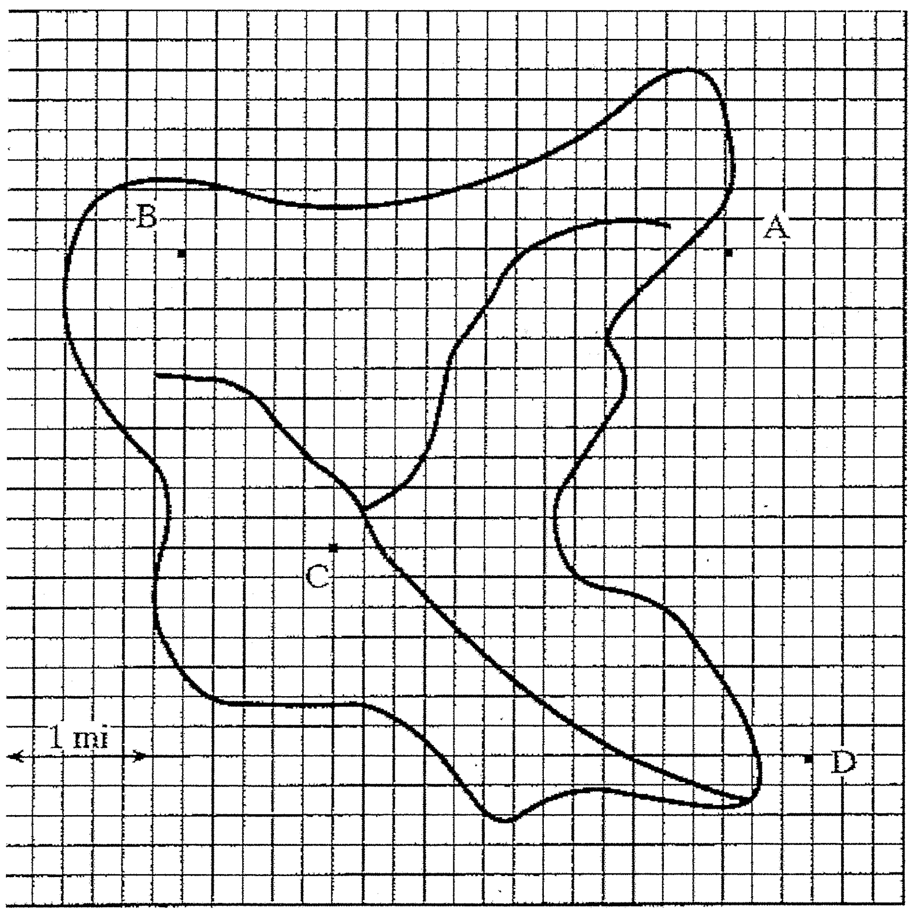


Fig. P1-19

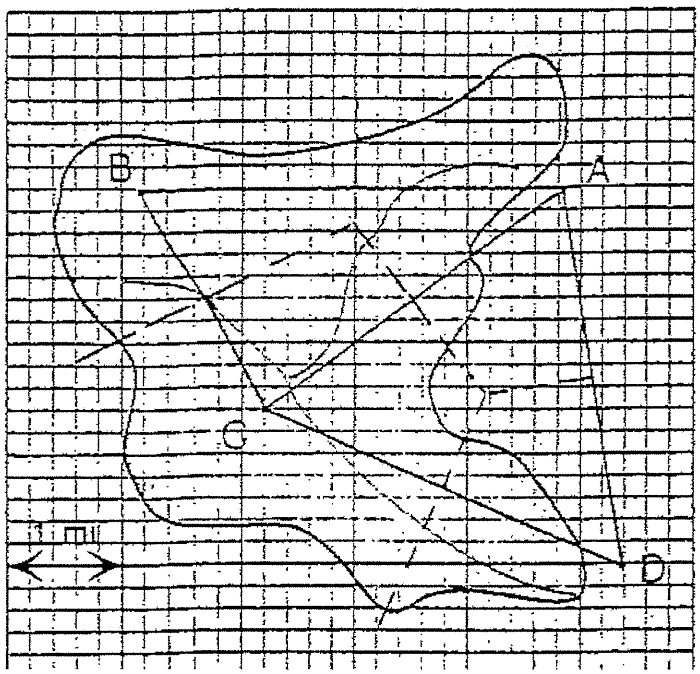
ANSWER:

a)

To calculate the arithmetic average only the gages that are present in the watershed boundary need to be taken into account which in this case are B and C:

Arithmetic Average: $\dfrac{2.92+3.01}{2}$ = **2.96 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: (2.56 + 3.12 + 5.92 + 1.44) mi^2 = 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	1.336
D	1.44	11.1	3.05	0.338
SUM	**13.04**	**100**		**3.04**

1.19 cont'

Weighted Rainfall is calculated using: rainfall x area % (in decimals)

Rainfall = 3.04 in

1.20 Mud Creek has the watershed boundaries shown in Fig. P1–20. 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 Number	**Rainfall (cm)**
1	5.5
2	4.5
3	4.0
4	6.2
5	7.0
6	2.1

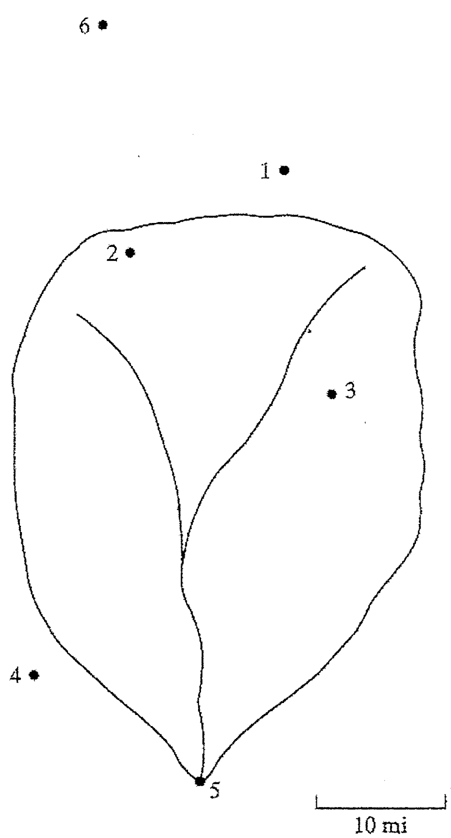
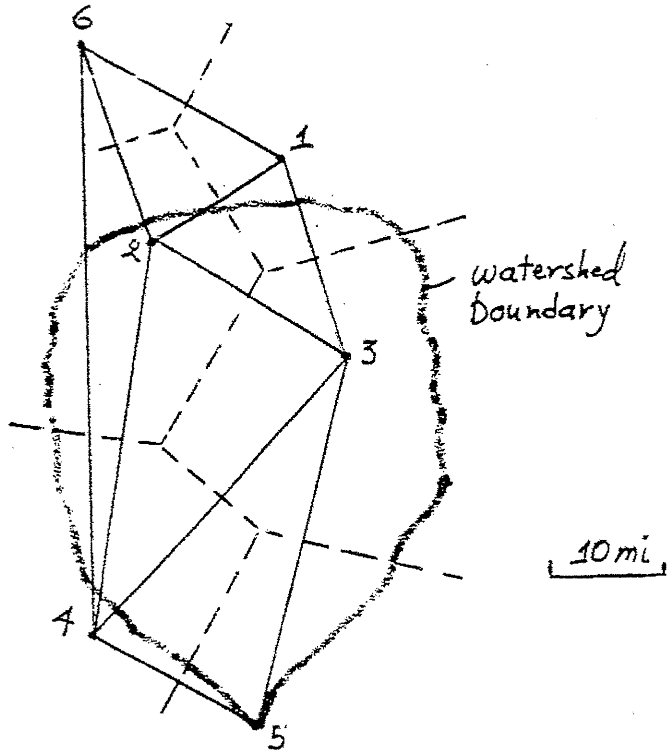


Fig. P1-20

1.20 cont'

ANSWER:



Gage	Area (sq mi)	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**		**4.96**

Answer: **4.96 cm**

1.21 Table P1–21 lists rainfall data recorded at a USGS gage for the storm of September 1, 1999. The basin area is 2050 acres. Using these data, develop a rainfall hyetograph (in./hr vs. *t*) in 15-min. intervals and determine the time period with the highest intensity rainfall.

Time (hr)	**Accumulated Rainfall (in.)**	**Discharge (cfs)**
16:05	0	0
16:20	0.4	5
16:35	1.4	600
16:50	1.9	1110
17:05	2.3	1300
17:20	2.5	1380
17:35	2.6	1350
17:50		1280
18:05		1110
18:20		790
18:35		460
18:50		240
19:05		110
19:20		59
19:35		35
19:50		20
20:05		12
20:20		7
20:35		4
20:50		2

Table P1–21.

1.21 cont'

ANSWER:

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 the table P1-21, it can be seen that rainfall was recorded in 15 min. intervals from time 1605 to 1750 so the hyetograph will have 15 min increments.

15:50→16:05 = 0 in./hr

i_1 = (0.4 in. - 0 in.) (60 min/hr) / (15min) = 1.6 in./hr

i_2 = (1.40 in. - 40 in.) (60 min./hr) / (15min) = 4.0 in./hr

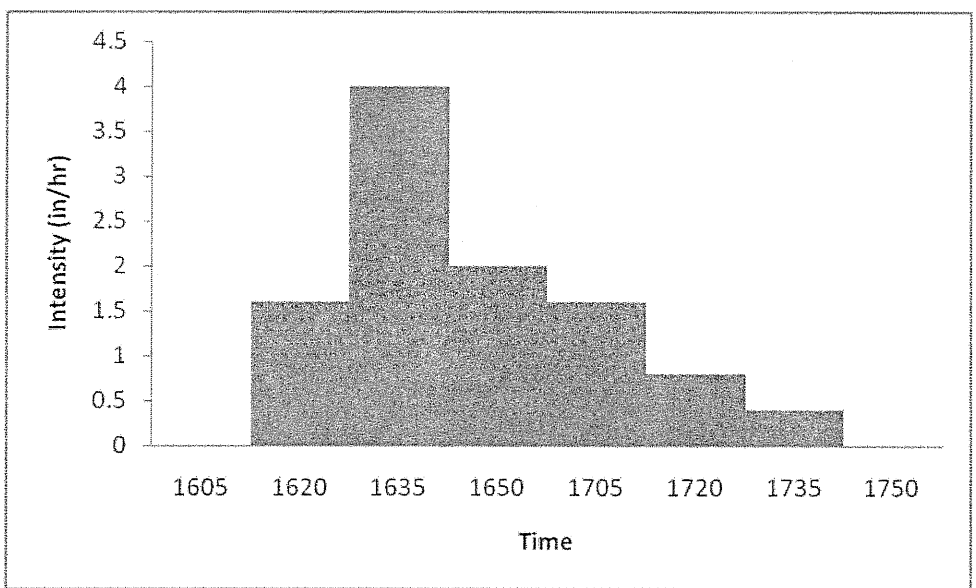
i_3 = (1.90 in. - 1.40 in.) (60 min/hr) / (15min) = 2.0 in./hr

i_4 = (2.30 in. - 1.90 in.) (60 min/hr) / (15min) = 1.6 in./hr

i_5 = (2.50 in. - 2.30 in.) (60 min/hr) / (15min) = 0.8 in./hr

i_6 = (2.60 in. - 2.50 in.) (60 min/hr) / (15min) = 0.4 in./hr

i_7 = rain ends = 0 in./hr



The period of highest intensity begins at 1635 with 4 in./hr.

Hyetograph can be plotted using a program such as Excel.

Problems 1.22 and 1.23 refer to the hydrologic data used in Problem 1.21.

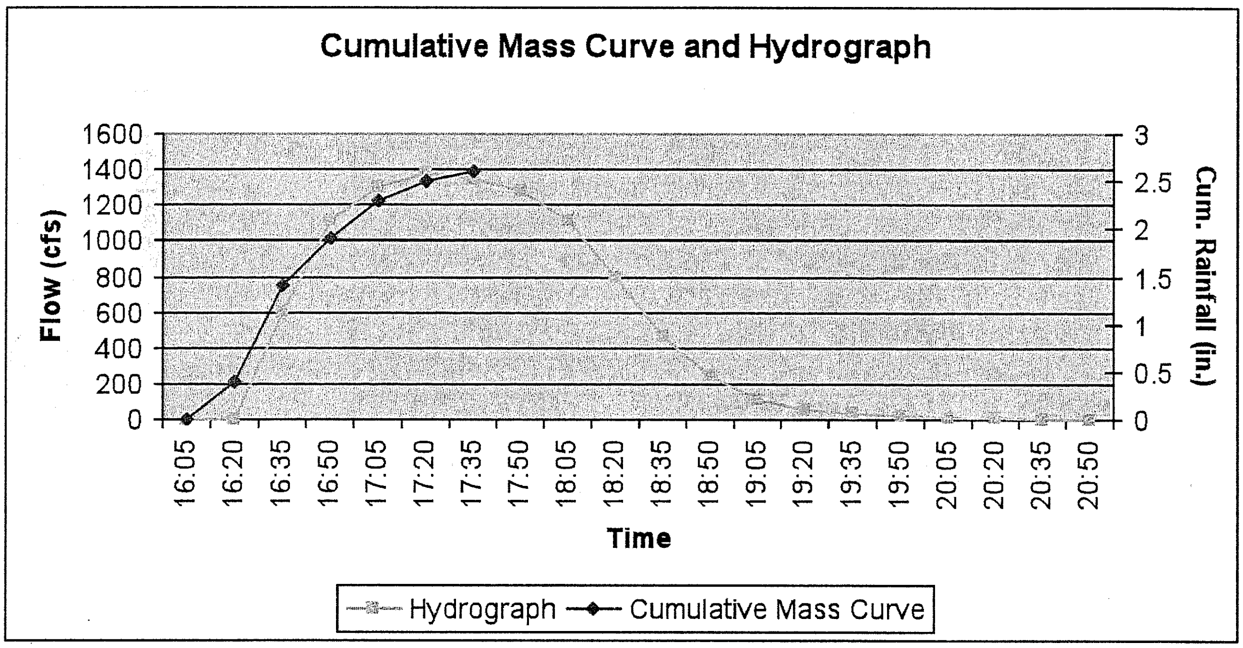
1.22 (a) Plot the cumulative mass curve for rainfall and the hydrograph (flow rate vs. time) on the same graph using two scales.

(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.

ANSWER:

a) Cumulative mass curve and hydrograph.

The cumulative mass curve is the accumulated rainfall vs. time and the hydrograph is flow vs. time. All the information is available in the table P1-20.



The graphs can be created using a program such as Excel.

b) Volume of infiltration loss from the storm.

The total volume can be found using the flow. The flow multiplied by the time increment can give the volume in that increment in cfs-hr. These volumes can then be added up to give the total volume under the hydrograph.

1.22 cont'

$$i_1 = 0\ \text{cfs} \times 15\text{min}\frac{1\text{hr}}{60\,\text{min}} = 0\ \text{cfs-hr}$$

$$i_2 = 5\ \text{cfs} \times 15\text{min}\frac{1\text{hr}}{60\,\text{min}} = 1.25\ \text{cfs-hr}$$

$$i_3 = 600\ \text{cfs} \times 15\text{min}\frac{1\text{hr}}{60\,\text{min}} = 150\ \text{cfs-hr}$$

Time (hr)	**Flow (cfs)**	**Volume Under Hydrograph (cfs-hr)**
16:05	0	0
16:20	5	1.25
16:35	600	150
16:50	1110	277.5
17:05	1300	325
17:20	1380	345
17:35	1350	337.5
17:50	1280	320
18:05	1110	277.5
18:20	790	197.5
18:35	460	115
18:50	240	60
19:05	110	27.5
19:20	59	14.75
19:35	35	8.75
19:50	20	5
20:05	12	3
20:20	7	1.75
20:35	4	1
20:50	2	0.5
		2468.5

Total volume under hydrograph = 2468.5 cfs-hr.

Assume 1 cfs-hr $\approx$ 1 ac-in., so 2468.5 cfs-hr = 2468.5 ac-in.

To get the volume of runoff in inches, divide the volume by area 2468.5 ac-in. / 2050 ac = 1.20 in. = RF_N

To get the loss from infiltration, subtract the runoff from precipitation (RF_T = 2.6 in. from cumulative rainfall)

$RF_T - RF_N$ = infiltration loss

1.22 cont'

2.60 in. - 1.20 in. = 1.40 in.

To obtain the value in ac-ft: $1.40 \text{ in.} \cdot \frac{1\text{ft}}{12\text{in}} \cdot 2050\text{acres} = \mathbf{239.2\ ac\text{-}ft}$

Alternate solution:

Convert cfs-hr into inches.

$$\left(\frac{2468.5 ft^3 \cdot hr}{s}\right)\left(\frac{3600s}{hr}\right)\left(\frac{ac}{43{,}560 ft^2}\right)\left(\frac{1}{2050ac}\right)\left(\frac{12in.}{ft}\right) = 1.19 \text{ in. runoff } (\mathrm{RF}_N)$$

$\mathrm{RF}_T - \mathrm{RF}_N$ = infiltration loss

2.60 in. – 1.19 in. = 1.41 in. infiltration loss

Convert inches to ac-ft.

$$1.41 in. \cdot \frac{1 ft}{12 in.} \cdot 2050 ac = \mathbf{240.9\ ac\text{-}ft}$$

1.23 What is the runoff coefficient for the September 1, 1999, storm, where Coeff. = R/P?

ANSWER:

$RF_N = 1.20$ in

$RF_T = 2.60$ in

Runoff coefficient = $RF_N / RF_T = 1.20/2.60 = \mathbf{0.46}$

(Using $RF_N = 1.19$ in. gives same rounded answer.)

1.24 The following questions refer to Fig. 1–15, 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?

(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 hours 3 and 4.

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

(ii) 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.

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

(iv) 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 to the right of the maximum (time intervals 0–1, 1–2, and 5–6).

1.24 cont'

ANSWER:

a. More than 100 yr storm

b. 1.36 in/hr $\cdot$ 6 hr = 8.16 in.

c. $\approx$25 yr. storm

d. (i) - (iv) the rainfall intensities can be found using the IDF curve (Fig 1-8) for the following times (1,2,3,6). To find the volume you multiply by the hour. All the parts have been plotted on one graph.

(i) Interval 3-4

1 hr duration: 1hr $\cdot$ 4.4 in./ hr = 4.4 in.

Rainfall intensity between hours three and four for an one hour duration is 4.4 in./hr so 4.4 inches is the maximum volume for the 6hr 100 yr storm.

(ii) Interval 2-3

2 hr duration: 2hr $\cdot$ 2.85 in./ hr = 5.7 in.

5.7 - 4.4 = 1.3 in.

(iii) Interval 4-5

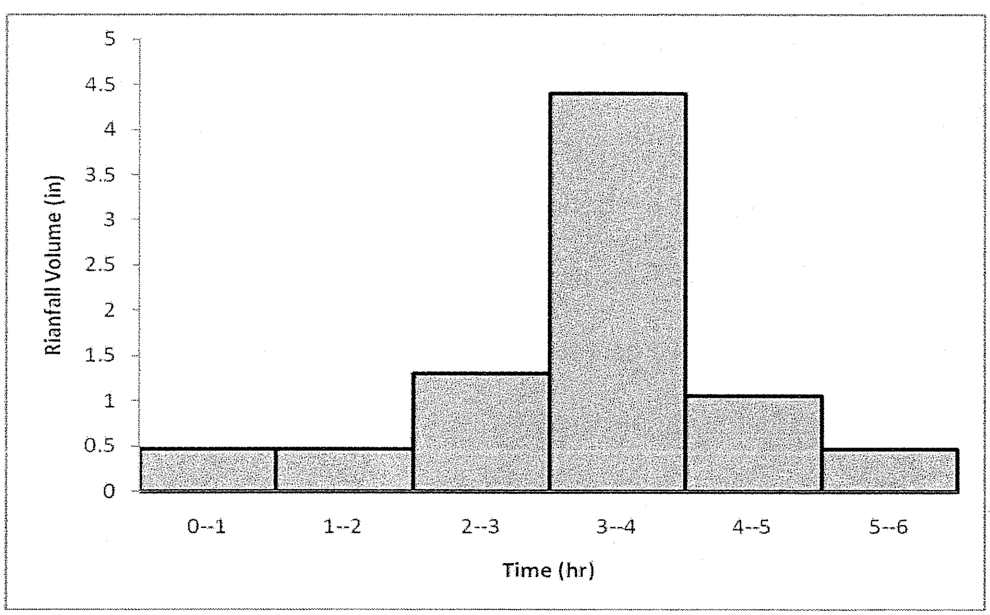
3 hr duration: 3hr $\cdot$ 2.25 in./ hr = 6.75 in.

6.75 - 5.7 = 1.05

(iv) Intervals, 1-2,0-1 and 5-6

6 hr duration: 6hr $\cdot$ 1.36 in./ hr = 8.16 in.

(8.16 - 6.75)/3 = 0.47



The graph can be created using programs such as Excel

1.25 Given the stream section shown in Fig. P1-25 and the following measurements, calculate the total discharge throughout the section (Table P1-25).

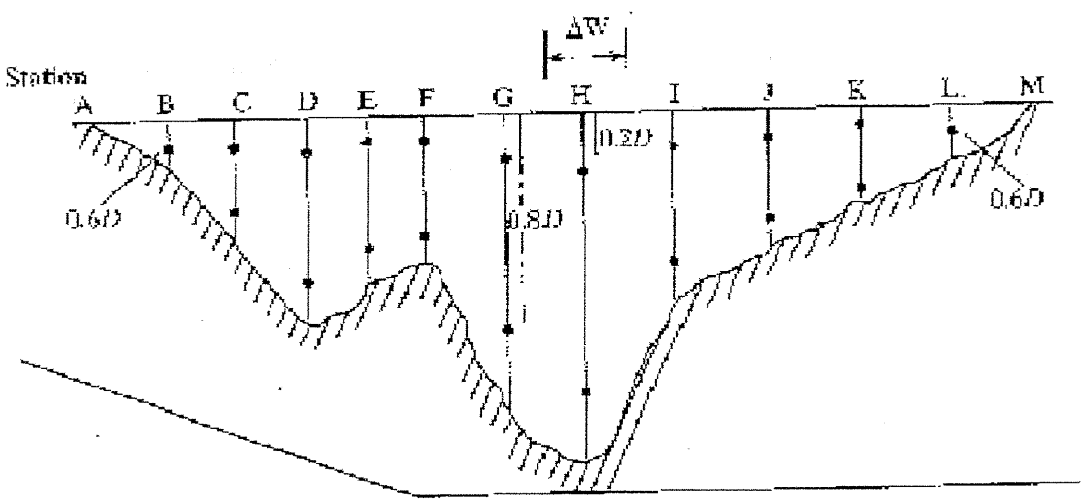


Fig P1-25

Measurement Station	Distance Across Stream (ft)	Depth D (ft)	Mean Velocity v (ft/sec)
A	0	0	0
B	14	1.1	0.43
C	26	2.6	0.61
D	38	3.5	1.54
E	49	3.2	1.21
F	61	3.1	1.13
G	78	3.9	1.52
H	95	4.2	2.34
I	114	3.3	1.42
J	133	2.9	1.34
K	152	2.1	1.23
L	171	1.4	0.53
M	190	0	0

Table P1-25

ANSWER:

The distance represents the distance along the top of the stream. The depth and the velocity are measured directly in the field.

To find the discharge the width needs to be found:

The distance points mark the middle of each width division across the stream; accordingly, the width is measured as halfway to the next and halfway back to the previous station.

For example station F:

$$\Delta W = 0.5 \times (61 - 49) + 0.5(78 - 61) = 14.5$$

The discharge is calculated as the depth times the width mean velocity summed across the stream: $Q_1 = \sum_{i=1}^{n} (\Delta W_i \cdot D_i \cdot v_i)$

The calculations are summarized in the following table

Station	Distance Across Stream (ft)	Depth D (ft)	Mean Velocity v (ft/sec)	Width ΔW(ft)	Area ΔW×D(ft^2)	DischageQ (cfs)
A	0	0	0	7	0	0.00
B	14	1.1	0.43	13	14.3	6.15
C	26	2.6	0.61	12	31.2	19.03
D	38	3.5	1.54	11.5	40.25	61.99
E	49	3.2	1.21	11.5	36.8	44.53
F	61	3.1	1.13	14.5	44.95	50.79
G	78	3.9	1.52	17	66.3	100.78
H	95	4.2	2.34	18	75.6	176.90
I	114	3.3	1.42	19	62.7	89.03
J	133	2.9	1.34	19	55.1	73.83
K	152	2.1	1.23	19	39.9	49.08
L	171	1.4	0.53	19	26.6	14.10
M	190	0	0	0	0	0.00

1.26 Assume that stations B through L in problem 1–25 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.

ANSWER:

Station	Dist. Across stream (ft)	Width ΔW(ft)	Old Depth D (ft)	New depth D2 (ft)	Mean vel., v (ft/sec)	New Area (ft^2) (ΔW* D2)	New Q without tributary (cfs)	%Q	%Q*500 (cfs)	Total Q (cfs)
A	0	7	0	0.0	0	0	0.0	0	0	0
B	14	13	1.1	1.3	0.43	16.9	7.3	0.01	5	12.3
C	26	12	2.6	2.8	0.61	33.6	20.5	0.028	14	34.5
D	38	11.5	3.5	3.7	1.54	42.6	65.5	0.09	45	110.5
E	49	11.5	3.2	3.4	1.21	39.1	47.3	0.065	32.5	79.8
F	61	14.5	3.1	3.3	1.13	47.9	54.1	0.074	37	91.1
G	78	17	3.9	4.1	1.52	69.7	106.0	0.145	72.5	178.5
H	95	18	4.2	4.4	2.34	79.2	185.5	0.254	127	312.3
I	114	19	3.3	3.5	1.42	66.5	94.3	0.13	65	159.4
J	133	19	2.9	3.1	1.34	58.9	79.0	0.108	54	133
K	152	19	2.1	2.3	1.23	43.7	53.8	0.074	37	90.8
L	171	19	1.4	1.6	0.53	30.4	16.1	0.022	11	27.1
M	190	19	0	0.0	0	0	0.0	0	0	0
SUM							**729.1625**	**1**	**500**	**1229.16**

The new flow rate (without tributary) is found using this equation:

$$Q_i = \sum_{i=1}^{n} (\Delta W_i \cdot D2_i \cdot v_i)$$

1.27 The incremental rainfall data in the table were recorded at a rainfall gage on a small urban parking lot of 1 acre. 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 percent 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.

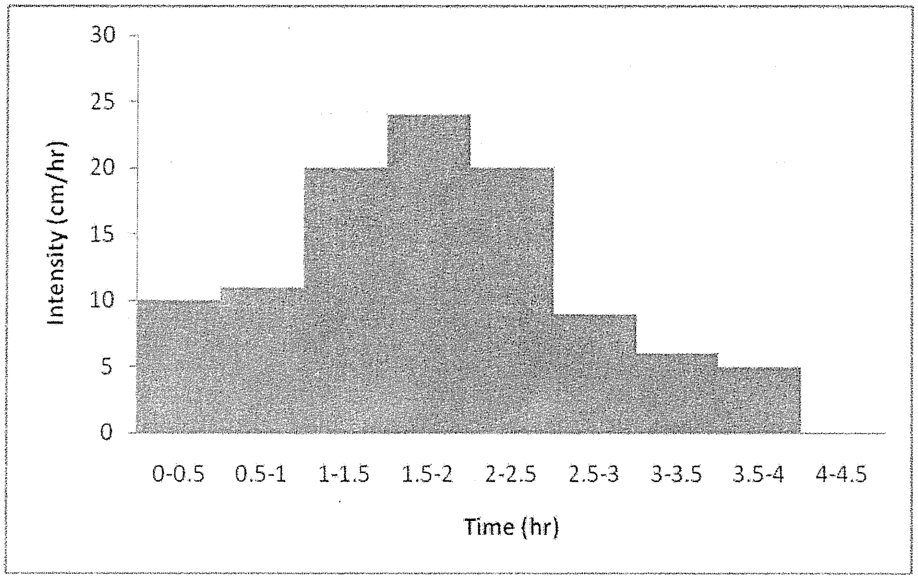
Time (hr)	**Rainfall (cm)**
0	0
0.5	5.0
1.0	5.5
1.5	10.0
2.0	12.0
2.5	10.0
3.0	4.5
3.5	3.0
4.0	2.5
4.5	0

ANSWER:

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

1.27 cont'



The graph can be created using programs such as Excel.

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

$0 + 5 + 5.5 + 10 + 12 + 10 + 4.5 + 3 + 2.5 + 0 = 52.5$ cm

(52.5 cm)(1 in. / 2.54 cm) = 20.669 in. $\approx$ 20.7 in.

c. The volume of rainfall in ac-in. is found by multiplying the rainfall in inches by the watershed size.

Volume = 20.7 in. $\times$1 ac = 20.7 ac-in. $\approx$ 20.7 cfs-hr

This volume is the area under a hydrograph. Because the hydrograph is triangular this becomes a geometry problem:

$A = \frac{1}{2}bh$ 20.7 cfs-hr $= \frac{1}{2}\cdot 3\cdot h$ where h will be the peak flow in cfs

h = 13.8 cfs

Alternate solution:

$$(20.7 ac\cdot in)\left(\frac{1ft}{12in.}\right)\left(\frac{43{,}560ft^2}{ac}\right)\left(\frac{1hr}{3600s}\right) = 20.9 \text{ cfs-hr}$$

$$20.9 \text{ cfs-hr} = \frac{1}{2}\cdot 3\cdot h$$

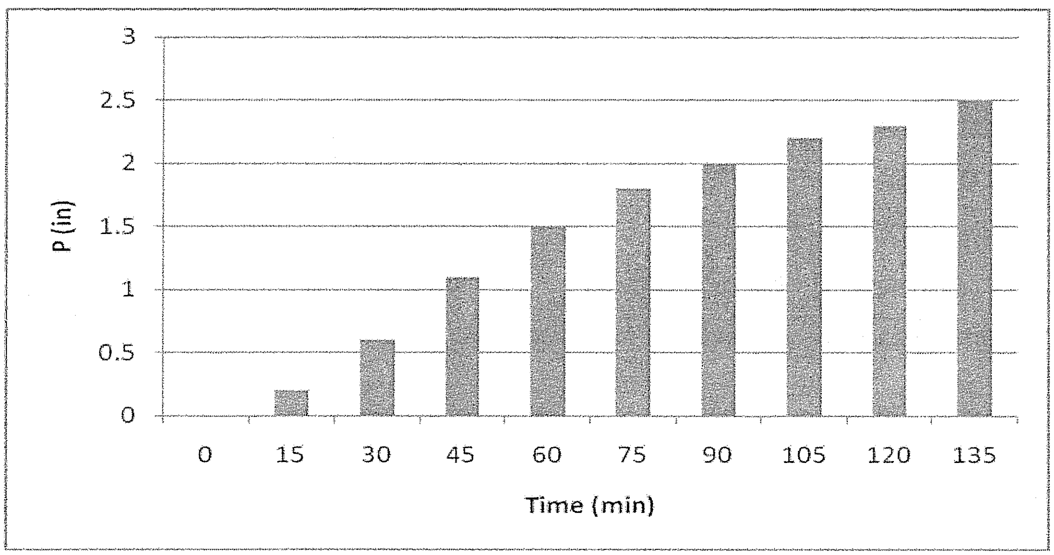
h = 13.9 cfs

1.28 For the rainfall record provided below, plot cumulative rainfall (P) and gross rainfall hyetograph (in./hr) using $\Delta t = 15 \text{ min} = 0.25 \text{ hr}$.

Time (min)	0	15	30	45	60	75	90	105	120	135		
P (in.)	0	0.2	0.6	1.1	1.5	1.8	2.0	2.2	2.3	2.5		
Time (hr)	1	2	3	4	5	6	7	8	9	10	11	12
Q (cfs)	100	200	500	800	700	550	450	250	150	100	75	0

ANSWER:

Cumulative rainfall (P)

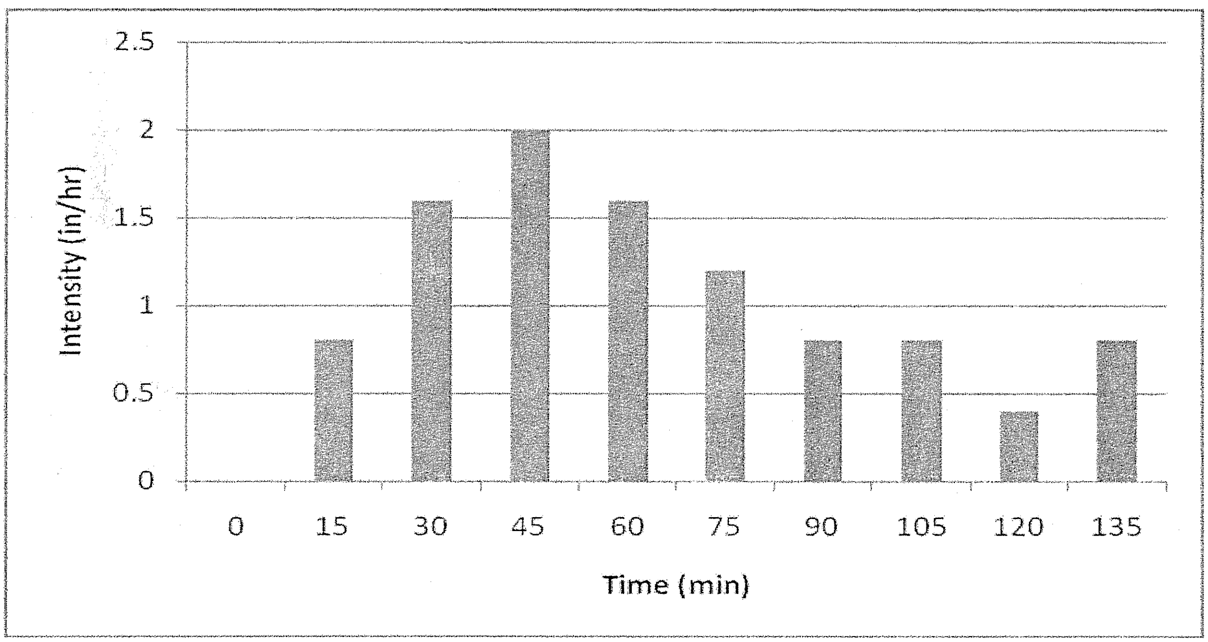


The graph can be created using a program such as Excel.

1.28 cont'

Gross rainfall hyetograph: First want to find incremental rainfall and then divide it by the time interval (.25)

Gross rainfall (in.)	**Intensity (in./hr)**
0	0
0.2	0.8
0.4	1.6
0.5	2
0.4	1.6
0.3	1.2
0.2	0.8
0.2	0.8
0.1	0.4
0.2	0.8



The graph can be created using a program such as Excel.

Problem 1.29 utilizes the rainfall from Problem 1.28.

1.29 If the gross rainfall of Problem 1.28 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.

ANSWER:

The area under the hydrograph can be found by multiplying Q by the time interval (1 hr) in order to obtain cfs-hr.

(100 + 200 + 500 + 800 + 700 + 550 + 450 + 250 + 150 + 100 + 75) cfs-hr = 3875 cfs-hr

Assume that 1 cfs-hr ≈ 1 ac-in

3875 cfs-hr = 3875 ac-in.

Then divide the volume by area in order to obtain the total runoff in inches

3875ac-in. /1600 ac = 2.4 in.

From the cumulative rainfall, total rainfall is 2.5 in so loss to infiltration is 2.5 - 2.4 = 0.1 in.

In terms of volume: 0.1*1600 = **160 ac-in.**

Alternate Solution:

$$\left(\frac{3875 ft^3 \cdot hr}{s}\right)\left(\frac{3600 s}{hr}\right)\left(\frac{12 in.}{ft}\right)\left(\frac{1 ac}{43{,}560 ft^2}\right) = 3845 \text{ ac-in.}$$

3845 ac-in. / 1600 ac = 2.4 in.

2.5 in. – 2.4 in. = 0.1 in.

0.1 in.*1600 ac. = **160 ac-in.**

1.30 Rework Example 1 from the case study on Jones Creek for Subbasin C(see PowerPoint). The baseflow for Subbasin C is 200 cfs. In addition, the initial infiltration for the first hour is 1 in and a constant infiltration of 0.5 in thereafter. The storm hydrograph and rainfall hyetograph for Subbasin C are given in Figures P1-30a and P1-30b .

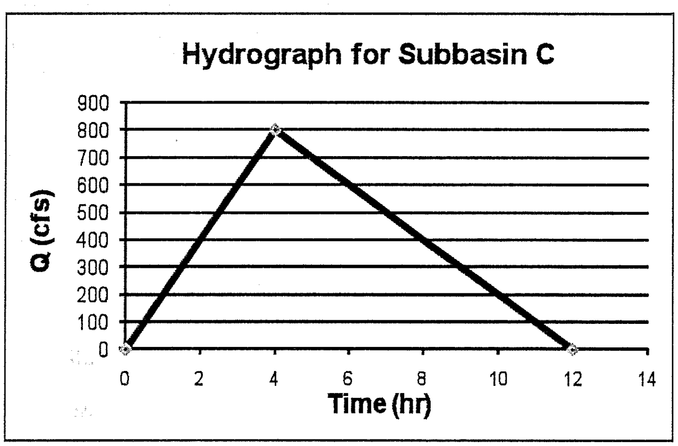


Fig P1-30 (a)

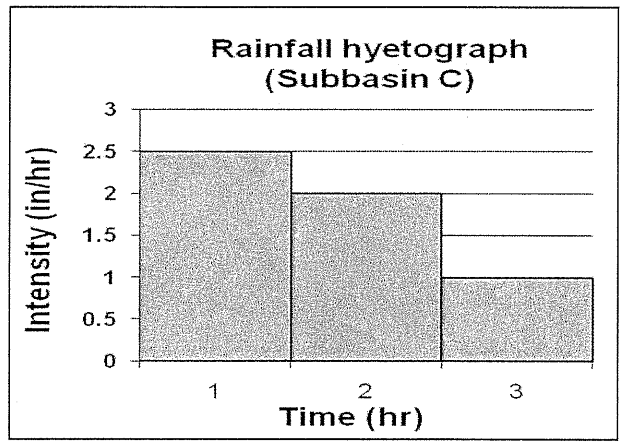
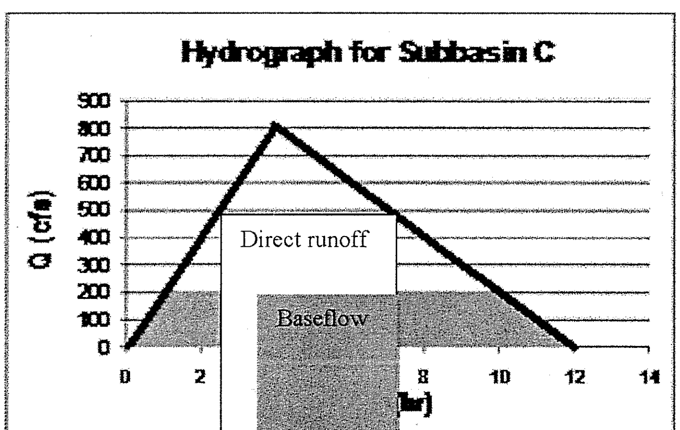


Fig P1-30 (a)

ANSWER:

First separate out the base flow:



Calculate the vol runoff:
DRO = Total R Flow

$$\text{Total Runoff} = \text{Area of triangle} = \frac{1}{2}(b)(h) = \frac{1}{2}\cdot 12hr\cdot 800cfs\,\frac{3600s}{1hr}\cdot\frac{1ac\cdot ft}{43{,}560\,ft^2} = 396.69 \text{ ac-ft}$$

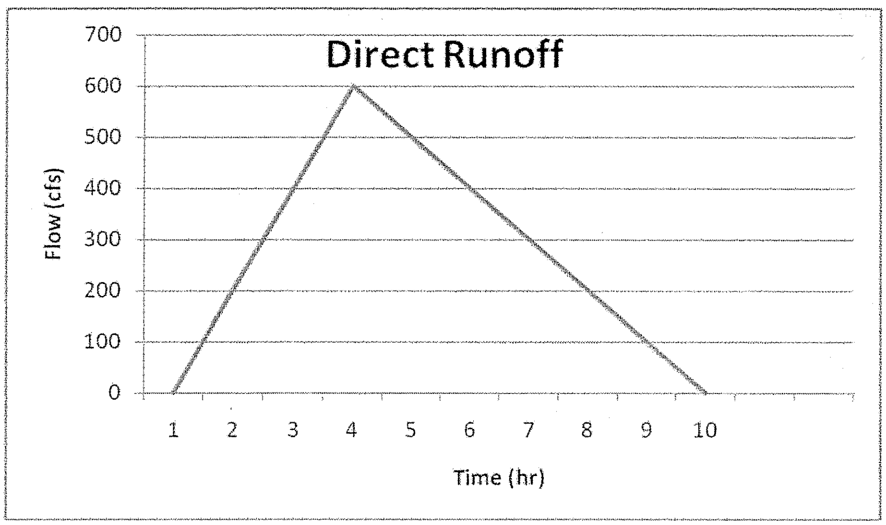
1.30 cont'

$$\text{Base Flow} = \text{Area of trapezoid} = \frac{1}{2}(b_1+b_2)(h) = \frac{12hr+10hr}{2}\cdot 200cfs\,\frac{3600s}{1hr}\cdot\frac{1ac\cdot ft}{43{,}560\,ft^2} =$$

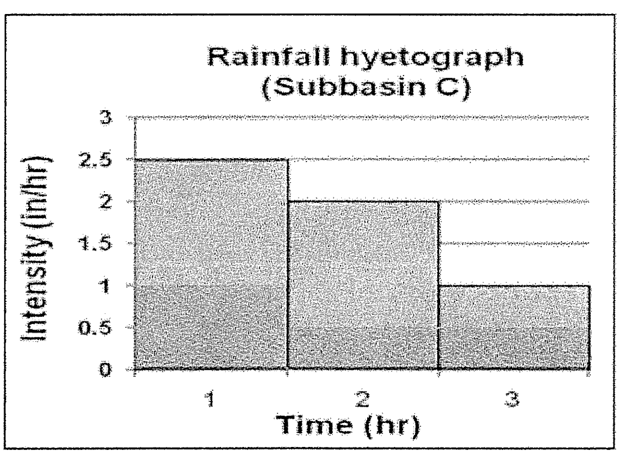
181.82 ac-ft

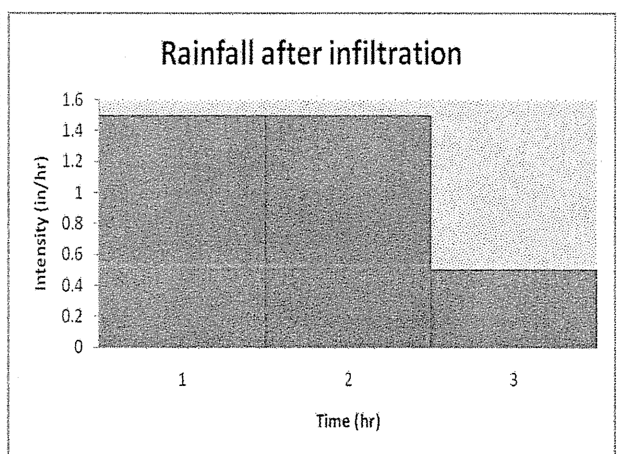
DRO = 396.69 ac-ft – 181.82 ac-ft
DRO = 214.87 ac-ft

The resulting hydrograph is:



Separate infiltration from the hyetograph





1.30 cont'

Place the hyetograph on the hydrograph