APPLIED HYDROLOGY

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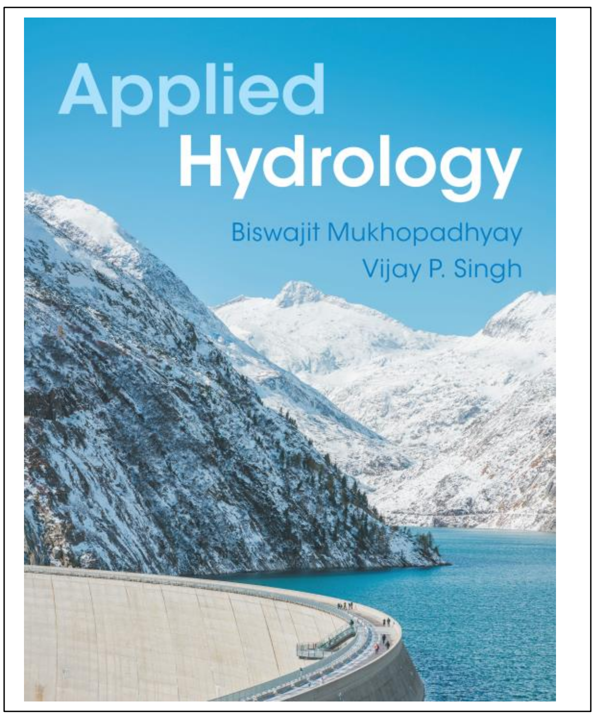
EXERCISES



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Chapter 1

Applied Hydrology in the Twenty First Century

Exercise 1.1. Figure 1.5 shows subbasin boundaries, designated as catchments with numbers, reaches with names, and junctions shown by solid triangles of the drainage basin drained by Mahoning Creek which is a tributary of Alleghany River in Pennsylvania. Develop a schematic basin model of the system. Develop a flow chart showing the elements contributing flows at each junction. Consider two types of flows: (1) direct runoff from a catchment and (2) channel flow.

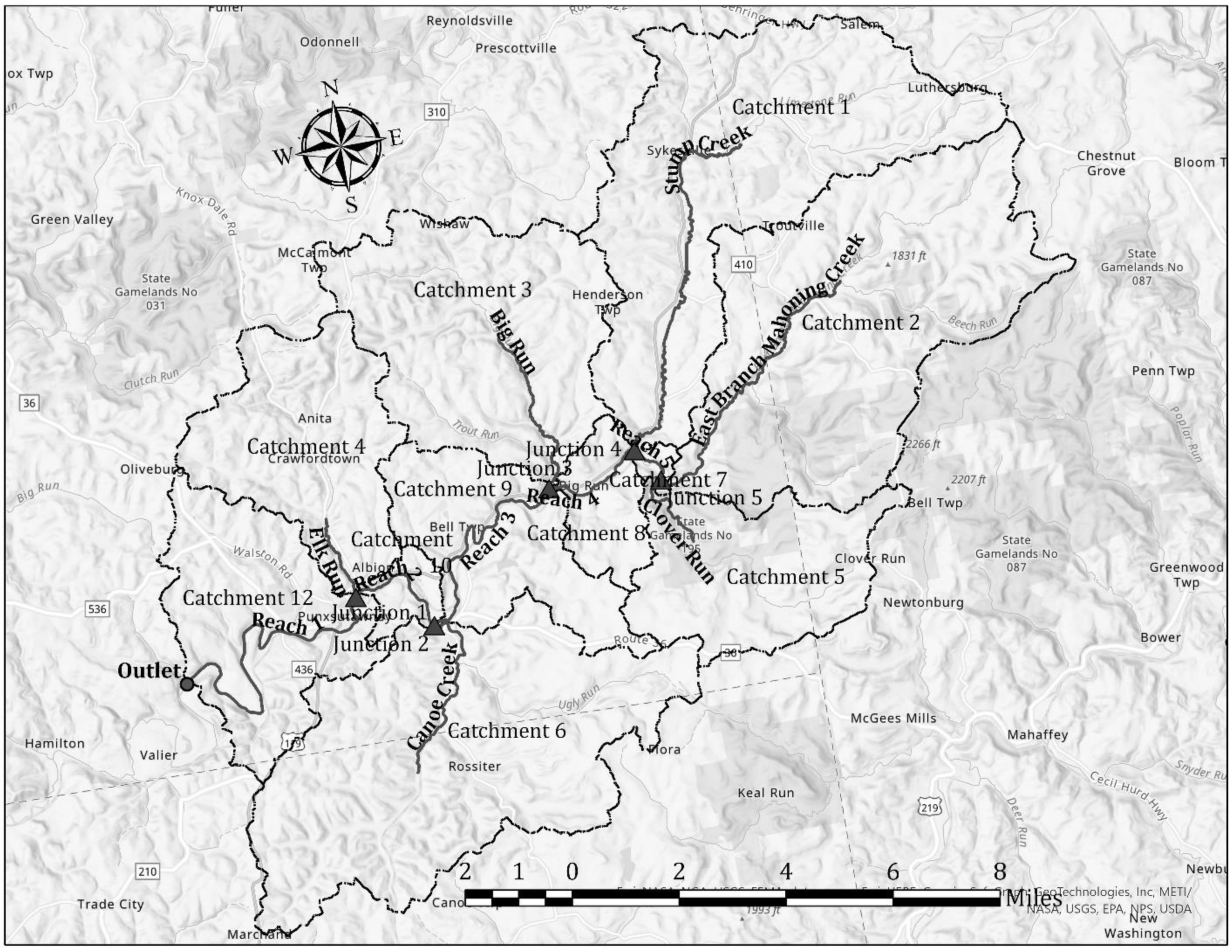

Figure 1.5 Drainage basin of Mahoning Creek, Pennsylvania, USA.

Exercise 1.2. Figure 1.6 shows subbasin boundaries, designated as catchments with numbers, reaches with blue lines, and junctions shown by solid red triangles of the drainage basin drained by Upper San Joaquin River in California. Develop a schematic basin model of the system. Develop a flow chart showing the elements contributing flows at each junction. Consider two types of flows: (1) direct runoff from a catchment and (2) channel flow.

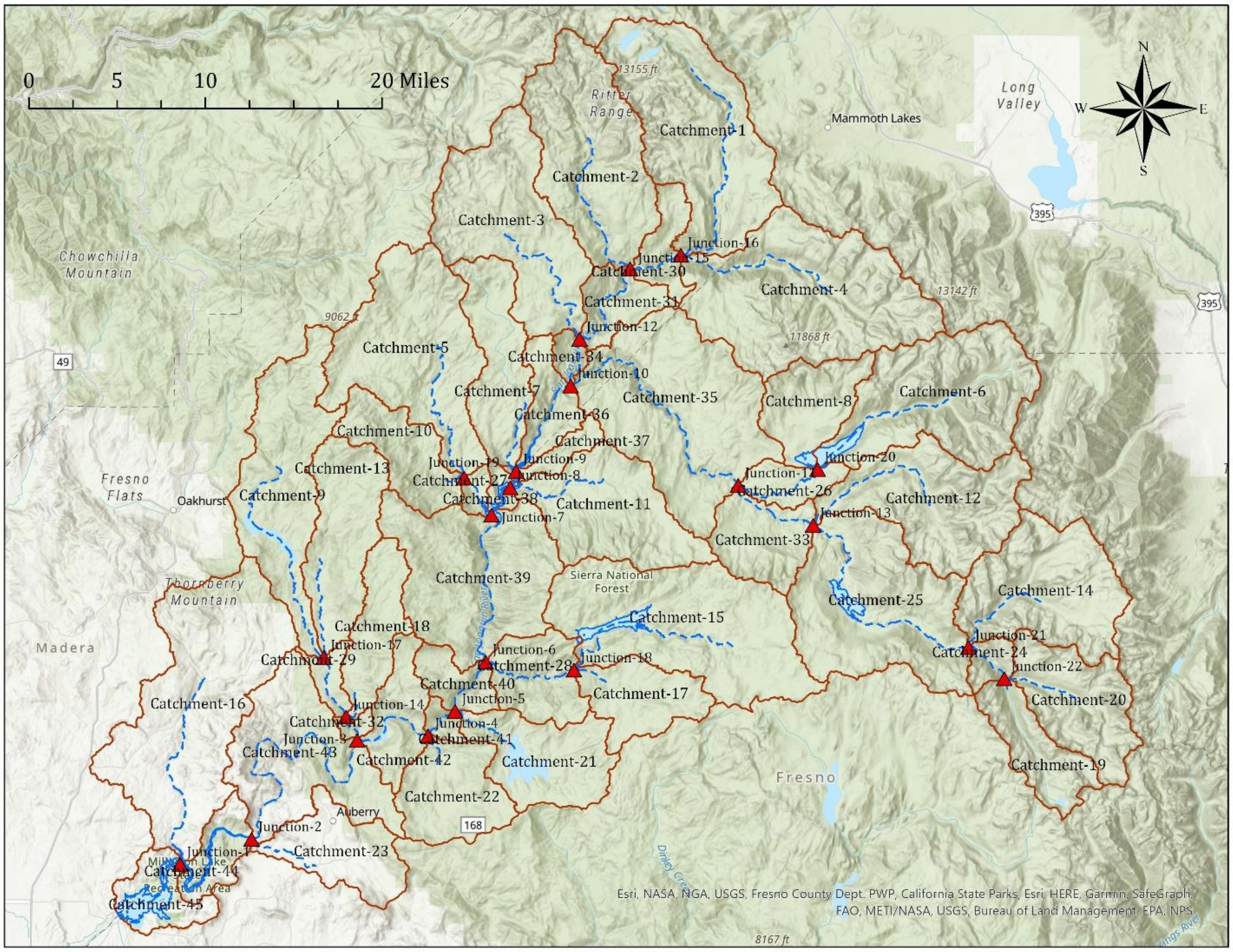

Figure 1.6 Drainage basin of Upper San Joaquin River, California, USA.

Chapter 2

Review of Mathematics

Exercise 2.1. A polynomial is a special kind of mathematical expression given as

$$P(x)=a_n x^n + a_{n-1}x^{n-1} + a_{n-2}x^{n-2} + \ldots + a_2 x^2 + a_1 x + a_0 \tag{2.1}$$

If a_n is not equal to zero, then the polynomial has degree n. The **roots**, sometimes called zeros or **solutions**, of a polynomial $P(x)$ are the values of x for which $P(x)$ is equal to zero. Any polynomial with degree n has n complex roots. Finding roots of a polynomial is sometimes called solving the polynomial. A quadratic equation $ax^2 + bx + c = 0$ has two roots (when a second-degree polynomial is written to show equality to zero it becomes an equation). It always represents a parabolic curve.
Derivative of the function $f'(x)$ evaluated at the point of tangency gives the slope of the tangent *T.*
Once the slope of the tangent line is known its equation can be written in one-**point form**.
Tangent to a curve $y = f(x)$ at (x_0, y_0) is given by

$$y - y_0 = \frac{dy}{dx}(x - x_0) \tag{2.2}$$

With the information given above do the following:

(1) Find the equation of the tangent (T) to the curve, $f(x) = x^3 - 2x^2 + 4$ at (2,4). Using Excel plot $f(x)$, $f'(x)$, and *T.*

(2) Find the derivatives of the following three functions at their roots: (i) $f(x) = 2x^2 + 3x - 5$; (ii) $g(x) = 4x^2 - 12x + 9$; (iii) $h(x) = 4x^2 - 4x + 5$. Using Excel plot the curves and their derivatives, and the tangents at the roots. What are the distinctive characteristics of the roots of these three polynomials?

Exercise 2.2. Find the derivatives, $\frac{dy}{dx}$ *of* (1) $x^3 - xy^2 + 3y^2 + 2 = 0$ (2) given $x = a(\theta - sin\,\theta)$ and $y = a(1 + \cos\theta)$.

Exercise 2.3. Construct the Taylor polynomial of degree 7 approximating the function $f(x) = sin\,x$ for x near 0. Plot the actual sine function and Taylor's polynomial using Excel. Compare the value of the Taylor approximation with the true value of $f(x)$ at $x = \pi/3$.

Exercise 2.4. Determine, from the first principles, the Laplace transform of the function e^{at}, where a is a constant. Plot the original function and the transformed function in Excel.

Exercise 2.5. Consider a rectangular pulse of size *1/k* that occurs at time $t = 0$ and which has a pulse width of *k,* i.e., the area of the pulse is 1. Sketch this function and derive the Laplace transform of this function.

Exercise 2.6. Derive the Laplace transform of unit step function. What would be the result if instead of a unit step input signal of height 1, the height is a unit? Now consider again the unit step function but delayed by time T instead of occurring at $t = 0$. What is the Laplace transform of this function?

Exercise 2.7. The convolution theorem states that if $F_1(s)$ and $F_2(s)$ are the Laplace transforms of $f_1(t)$ and $f_2(t)$ then the product of the two functions $F_1(s)$ and $F_2(s)$ is the convolution of $f_1(t)$ and $f_2(t)$. Using this theorem find the inverse transform of

$$\frac{1}{(s+2)(s+5)} \tag{2.3}$$

Exercise 2.8. Using integrating factor, solve the following two differential equations both of which are variants of decay equation. Also, check your solution for the second equation by separating the variables and then solving the equation.

$$\frac{dN}{dt} = -kN;\ N(t=0) = N_0 \tag{2.4}$$

$$L\frac{dQ}{dt} = -kQ + W \tag{2.5}$$

Exercise 2.9. A certain bacterium is observed in a stream that undergoes a biochemical reaction whereby it grows with time. During a monitoring program it was observed that after one hour the number of bacteria in the culture was 1.5 times the original measurement at the start of monitoring. Determine the time necessary for the number of bacteria to triple. During the same monitoring, a biochemical water quality parameter was observed to become 75% of the original amount at the same time the bacteria culture was measured. Determine the time when this constituent will be vanishingly small. Both these observations can be modeled using the differential equation of growth and decay.

Exercise 2.10. A 12-volt battery is connected to a series circuit in which the inductance is ½ H and resistance is 10 Ω. Determine the current in the circuit as a function of time if switch is turned on at $t = 0$, i.e., the initial current was zero in the circuit.

Exercise 2.11. In an RL electric circuit with L = 4 H and R = 12 Ω, the voltage varies according to $E(t) = 60 \sin 30t$. Determine the current.

Exercise 2.12. In a right-angled triangle *ABC,* let leg b = 121.56 m and the angle A = 25°21'40", and the maximum absolute error in determining the leg b is $|\Delta * b|$ = 0.05 m, and the maximum absolute error in determining the angle A is $|\Delta * A| = 12''$. Determine the maximum absolute error in calculating the leg a from the formula $a = b = \tan A$.

Exercise 2.13. Solve the following system of equations using the method of determinant.

$$\begin{cases} \quad\quad 4x_2 + 3x_3 = -2 \\ -2x_1 + 5x_2 - 2x_3 = 1 \\ 3x_1 + 4x_2 \quad 5x_3 = 6 \end{cases}$$

Exercise 2.14. Solve the following system of equations using the method of matrix inversion.

$$\begin{cases} x_1 + x_2 + x_3 = 2 \\ x_1 + x_3 = 0 \\ 2x_1 - x_2 = 2 \end{cases}$$

Exercise 2.15. The fundamental equation of hydrology is given by the equation expressing conservation of mass, also known as the **continuity equation** represented by a differential equation $\frac{dS}{dt} = I(t) - O(t)$, where I is the input in the system, O is the output from the system and S is the change in the storage in the system. To visualize the physical meaning of this equation, see Figure 1.1., where the drainage basin is the system and consider rainfall as the input to the system, river runoff coming out at the outlet of the basin is the output from the system, and the water that is stored in the system is S. Ignore the water that is evaporated. For given physiographic features of a drainage basin system, the storage is a function of the input and output and their changes with time. This can be mathematically expressed as

$$S = f\left(I, I^{(1)}, I^{2}, \ldots, I^{m}, O, O^{(1)}, O^{(2)}, \ldots, O^{(n)}\right)$$

where the superscripts denote the order of the time derivatives of input and output. Derive an expression giving output as a function of input by eliminating the storage term. The equation that will result is known as the **general hydrologic system** (GHS) model first proposed by Chow and Kulandaiswamy (1971)[1].

[1] Chow, V. T. and Kulandaiswamy, V. C. (1971). General hydrologic system model. *Journal of the Hydraulics Division*, *Proceedings of the American Society of Civil Engineers*, 97 (6), 791-804.

Chapter 3

Statistical Hydrology

Exercise 3.1. A very limited set of values for peak annual flow of Missouri River at St. Charles, Missouri, is available as given in Table 3.12. How can you construct a cumulative frequency distribution to have reasonably reliable estimates of various quartiles?

Table 3.12 *Annual peak flow of Missouri River at St. Charles, Missouri*

Date of peak flow	**Peak discharge (ft^3/s)**
6/10/2001	305000
5/15/2002	350000
5/12/2003	156000
3/7/2004	211000
1/6/2005	247000
5/4/2006	137000
5/13/2007	303000
9/16/2008	353000
6/19/2009	289000
5/18/2010	317000
5/28/2011	279000
3/24/2012	192000
6/2/2013	409000
6/11/2014	193000
6/20/2015	344000
12/30/2015	471000
5/5/2017	515000
3/20/2021	334000

Exercise 3.2. Table 3.13 gives the historical record of one-day maximum rainfall total for a year in Houston, Texas from 1921 to 2009. What is the recurrence interval of 5 inches (127 mm) of one day rain in Houston? What is the probability of having 5 inches of one day rainfall in Houston in any random year?

Table 3.13 *One day maximum rainfall totals in Houston, Texas for a given year from 1921 to 2009*

Date/year	Rainfall (mm)	Rainfall (in)	Date/year	Rainfall (mm)	Rainfall (in)	Date/year	Rainfall (mm)	Rainfall (in)
April 18, 2009	130.8	5.15	September 19, 1979	224.3	8.83	October 07, 1949	252.7	9.95
September 13, 2008	205.2	8.08	November 26, 1978	77.5	3.05	November 16, 1948	106.4	4.19
May 28, 2007	85.3	3.36	April 20, 1977	91.9	3.62	May 20, 1947	97.8	3.85
June 19, 2006	236.0	9.29	June 15, 1976	146.1	5.75	June 08, 1946	137.2	5.40
July 17, 2005	82.8	3.26	June 09, 1975	123.2	4.85	August 27, 1945	211.3	8.32
November 17, 2004	85.3	3.36	October 31, 1974	93.5	3.68	May 02, 1944	88.4	3.48
October 09, 2003	80.3	3.16	July 07, 1973	179.6	7.07	November 01, 1943	158.8	6.25
August 15, 2002	140.2	5.52	April 27, 1972	157.5	6.20	July 04, 1942	88.6	3.49
June 05, 2001	216.7	8.53	September 10, 1971	67.3	2.65	June 11, 1941	97.8	3.85
November 18, 2000	66.8	2.63	May 21, 1970	107.2	4.22	November 24, 1940	85.1	3.35
May 12, 1999	65.3	2.57	December 05, 1969	71.1	2.80	July 12, 1939	131.8	5.19
September 11, 1998	149.1	5.87	May 10, 1968	161.3	6.35	May 06, 1938	127.0	5.00
January 27, 1997	104.1	4.10	December 09, 1967	64.0	2.52	October 16, 1937	90.4	3.56
June 25, 1996	83.8	3.30	April 14, 1966	131.6	5.18	May 24, 1936	100.6	3.96
December 17, 1995	106.2	4.18	May 22, 1965	69.3	2.73	December 07, 1935	125.7	4.95
October 17, 1994	199.6	7.86	December 10, 1964	82.8	3.26	January 26, 1934	56.1	2.21
October 20, 1993	178.3	7.02	June 21, 1963	68.6	2.70	July 22, 1933	70.6	2.78
November 01, 1992	78.2	3.08	November 27, 1962	69.9	2.75	August 14, 1932	71.1	2.80
May 08, 1991	108.2	4.26	June 18, 1961	143.0	5.63	April 19, 1931	70.4	2.77
1990	–	–	June 26, 1960	166.9	6.57	October 06, 1930	112.3	4.42
August 01, 1989	217.9	8.58	July 24, 1959	101.1	3.98	April 13, 1929	163.3	6.43
March 17, 1988	47.8	1.88	September 07, 1958	67.8	2.67	October 16, 1928	74.7	2.94

Date/year	Rainfall (mm)	Rainfall (in)	Date/year	Rainfall (mm)	Rainfall (in)	Date/year	Rainfall (mm)	Rainfall (in)
July 07, 1987	66.8	2.63	October 14, 1957	137.7	5.42	December 06, 1927	61.5	2.42
June 04, 1986	123.4	4.86	January 21, 1956	42.2	1.66	March 10, 1926	82.0	3.23
November 11, 1985	108.7	4.28	February 04, 1955	66.0	2.60	November 05, 1925	132.6	5.22
August 14, 1984	106.2	4.18	October 05, 1954	72.4	2.85	December 19, 1924	59.2	2.33
May 21, 1983	74.2	2.92	August 29, 1953	85.6	3.37	December 10, 1923	112.0	4.41
May 13, 1982	91.4	3.60	February 01, 1952	98.6	3.88	March 25, 1922	186.9	7.36
May 03, 1981	240.8	9.48	March 26, 1951	87.6	3.45	June 22, 1921	79.5	3.13
January 20, 1980	58.4	2.30	January 01, 1950	81.8	3.22			

Exercise 3.3. A couple in Houston has purchased a house which is situated within the 100-year floodplain of Buffalo Bayou and they have a mortgage from their bank for 30 years. What is the probability that their house will be inundated by a 100-year flood flow from Buffalo Bayou during the mortgage life, assuming they will not pay off their mortgage before the end of 30 years?

Exercise 3.4. During design of a flood control dam, a design storm needs to be selected in order to be 95 percent sure that it is not exceeded in a 50-year period. What should be the return period of the design storm? If the hydraulic structure to be designed would be a minor bridge over a creek, what should be the return period of a storm that is expected to exceed in a 25-year period?

Exercise 3.5. What is the chance that exactly three 50-year floods will occur in a 100-year period? What is the chance that three or more will occur? What is the chance that it will be exceeded twice or more in the next 10 years?

Exercise 3.6. What is the chance that a 100-year flood will be exceeded in the 50-year economic lifetime of a relatively minor flood control project?

Exercise 3.7. The data used in the calculation of the normal distribution curves shown in Figure 3.10 are given in Table 3.14. Prove that normal distribution is an acceptable model for the mean annual river flow at this station on Potomac River and fit the observed CDF to the theoretical cdf. Determine the confidence limits of the mean and standard deviation of the mean annual discharge of Potomac River at this gauging station.

Table 3.14 *Mean annual discharge* (ft^3/s) *of Potomac River at Point of Rocks, Maryland*

Year	**1896**	**1897**	**1898**	**1899**	**1900**	**1901**	**1902**	**1903**	**1904**	**1905**	**1906**
Discharge (ft^3/s))	5,633	11,760	9,566	12,550	6,394	12,220	14,680	13,740	6,374	6,580	9,258
Year	**1907**	**1908**	**1909**	**1910**	**1911**	**1912**	**1913**	**1914**	**1915**	**1916**	**1917**
Discharge (ft^3/s))	13,890	14,000	6,427	7,749	6,497	11,170	7,929	10,250	9,693	10,370	7,881
Year	**1918**	**1919**	**1920**	**1921**	**1922**	**1923**	**1924**	**1925**	**1926**	**1927**	**1928**
Discharge (ft^3/s))	9,367	8,386	10,550	7,035	8,159	5,028	13,720	6,925	7,970	11,480	12,020
Year	**1929**	**1930**	**1931**	**1932**	**1933**	**1934**	**1935**	**1936**	**1937**	**1938**	**1939**
Discharge (ft^3/s))	8,546	6,492	4,917	6,922	12,660	4,856	10,670	13,440	12,670	8,692	9,002
Year	**1940**	**1941**	**1942**	**1943**	**1944**	**1945**	**1946**	**1947**	**1948**	**1949**	**1950**
Discharge (ft^3/s))	9,108	7,317	6,744	13,480	6,849	8,925	8,828	5,220	7,867	13,210	8,543
Year	**1951**	**1952**	**1953**	**1954**	**1955**	**1956**	**1957**	**1958**	**1959**	**1960**	**1961**
Discharge (ft^3/s))	13,030	11,010	10,840	4,665	11,350	7,056	7,767	10,100	4,642	10,310	9,338
Year	**1962**	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**
Discharge (ft^3/s))	9,068	7,089	7,888	7,595	4,876	8,779	8,907	4,366	9,133	11,900	15,840
Year	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**
Discharge (ft^3/s))	15,680	10,240	11,880	8,154	8,565	13,210	12,790	12,770	5,364	8,958	10,180
Year	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**
Discharge (ft^3/s))	15,010	7,060	10,650	9,544	7,786	8,806	7,121	9,585	6,896	13,140	14,970
Year	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Discharge (ft^3/s))	6,668	18,750	11,410	15,970	4,613	7,424	6,757	4,015	17,930	14,580	9,606
Year	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Discharge (ft^3/s))	7,072	8,749	8,958	7,514	10,620	11,360	9,115	9,637	10,740	7,008	9,224
Year	**2017**	**2018**	**2019**	**2020**	**2021**						
Discharge (ft^3/s))	7,637	15,580	17,360	7,985	9005.00						

Exercise 3.8. The histogram data of annual flows of Sabarmati River in the state of Gujrat in India is given in Table 3.15. Compute the first four product moments. Determine the parameters of normal, log normal, and gamma distributions. Using the derived parameters generate the pdf and cdf of each of these three distributions, using both Excel and the equations given in the text. From visual examination of the plots, comment on the distribution that fits the observed data best.

Table 3.15 *Histogram data for mean annual flow of Sabarmati River, Gujrat, India*

Discharge range (m^3/s)	**Average (m^3/s)**	**Frequency**	**Discharge range (m^3/s)**	**Average (m^3/s)**	**Frequency**
100-200	150	6	200-300	250	9
300-400	350	11	400-500	450	9
500-600	550	9	600-700	650	9
700-800	750	19	800-900	850	6
900-1,000	950	6	1,000-1,100	1,050	1
1,100-1,200	1,150	5	1,200-1,300	1,250	2
1,300-1,400	1,350	3	1,400-1,500	1,450	0
1,500-1,600	1,550	2	1,600-1,700	1,650	0
1,700-1,800	1,750	1			

Exercise 3.9. As discussed in Chapter 4, Gumbel distribution or Extreme Value Type I distribution has been widely used for frequency analysis of rainfall AMS or PDS. The pdf of this distribution is given as

$$f(x) = \frac{1}{a}\exp\left[-\left(\frac{x-c}{a}\right) - \exp\left(-\frac{x-c}{a}\right)\right] \quad x \geq c \tag{3.1}$$

Estimate the parameters of the distribution by the method of moments.

Exercise 3.10. Annual peak discharge values in Trinity River recorded at downtown Dallas for 118 water years are given in Table 3.16 (USGS Gauge 08057000). The flow in this river has been regulated by the U.S. Army Corps of Engineers since 1913. Do the following.

1) Conduct a *t*-test to determine if there is any trend.
2) Determine autocorrelation and thereby determine whether the annual flood flows at this location can be considered random events.
3) Fit three probability distributions to the data: (1) lognormal (2) three-parameter gamma (this is called Pearson III or P III distribution) and (3) three-parameter gamma after log transformation (this is called log Pearson Type III or LP III distribution). These are discussed in detail in the Section on flood frequency analysis in Chapter 5. For the present exercise follow the instructions given below.

A) Use Excel

Excel has two functions that can be used for this purpose.

(1) For lognormal distribution use the function LOGNORMAL.DIST (*x*, mean, standard deviation, TRUE/FALSE). The *x* indicates the variable but do not use log-transformed discharge values. Excel computes it internally. But you need to calculate the mean and standard deviation of the set after you do logarithmic transformation of all values in the set. Select FALSE as the fourth argument of the function to get the density function and then select TRUE to get the cumulative probability distribution.

(2) For gamma distribution use the function GAMMA.DIST (*x*, alpha, beta, TRUE/FALSE). Now for using this Excel function for three-parameter gamma distribution an additional step needs to be performed. The three-parameter gamma distribution is given as

$$f(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)}(x-\gamma)^{\alpha-1}\exp\left(-\frac{x-\gamma}{\beta}\right) \tag{3.2}$$

α, β, and γ are known as shape, scale, and location parameters, respectively. These parameters can be obtained from either product moments or L moments. The important point to notice here is that the location parameter does nothing more than shifting the *x* values by an amount of γ. Thus, in order to use Excel's two parameter gamma distribution function to obtain P III or LP III distribution, all *x* values must be shifted by γ. Finally, for LP III, just convert the *x* values to logarithms (use either log10 or ln).

B) **Use HEC-SSP**

Under HEC-SSP create a new project and select import data from USGS and select Texas and gauge 08057000 and the type of data which in this case will be annual peaks. After the data are imported HEC-DSS, select the Distribution Fitting Analysis option. Select the analytical functions after selecting the moment method [Product Moment (PM) or L Moment (LM) or Maximum Likelihood Estimation (MLE)].

Table 3.16 *Annual peak flow through Trinity River at downtown Dallas, Texas*

Date	Discharge (ft^3/s)	Date	Discharge (ft^3/s)	Date	Discharge (ft^3/s)
3/27/1904	7630	3/26/1943	21300	8/20/1983	9010
5/23/1905	22600	5/2/1944	22700	3/24/1984	13000
5/18/1906	21400	3/31/1945	52900	4/29/1985	12400
6/8/1907	10200	6/2/1946	38900	6/2/1986	19600
5/25/1908	184000	12/13/1946	34000	5/30/1987	12400
10/26/1908	8220	2/27/1948	46300	6/2/1988	8650
4/10/1910	5800	5/18/1949	82500	5/17/1989	58700
8/30/1911	8600	5/4/1950	28800	5/3/1990	82300
4/4/1912	8680	6/17/1951	9350	5/25/1991	11700
5/7/1913	5300	4/23/1952	7570	12/21/1991	62200

Date	Discharge (ft^3/s)	Date	Discharge (ft^3/s)	Date	Discharge (ft^3/s)
12/6/1913	44500	5/16/1953	16600	2/26/1993	23600
6/12/1915	39600	5/12/1954	4640	10/20/1993	20400
4/3/1916	54700	5/20/1955	6010	5/9/1995	30500
5/29/1917	8600	5/2/1956	7320	9/1/1996	5970
4/20/1918	9710	5/26/1957	75300	2/13/1997	27600
11/9/1918	50300	4/27/1958	23200	3/17/1998	28100
5/12/1920	54000	6/23/1959	7590	12/4/1998	14800
4/7/1921	18200	10/5/1959	21400	6/11/2000	13200
4/27/1922	75100	6/26/1961	12200	2/17/2001	31200
6/12/1923	37900	9/9/1962	13200	3/20/2002	32400
12/15/1923	43100	4/29/1963	13200	10/19/2002	27200
5/11/1925	17700	9/22/1964	32600	6/10/2004	28900
4/23/1926	11500	2/9/1965	26900	11/18/2004	16100
4/21/1927	14000	5/1/1966	42100	3/20/2006	43800
4/6/1928	11200	6/1/1967	7800	6/28/2007	38700
12/18/1928	34800	3/21/1968	25000	3/19/2008	27600
5/14/1930	34200	5/8/1969	67000	9/14/2009	31100
12/6/1930	9210	4/26/1970	20000	9/9/2010	44200
1/24/1932	44000	8/15/1971	5650	5/3/2011	12600
3/7/1933	17500	12/10/1971	33400	1/26/2012	27500
3/2/1934	10000	6/4/1973	32900	1/10/2013	12200
5/20/1935	76700	5/6/1974	15100	12/22/2013	9630
9/28/1936	25900	2/2/1975	27000	5/29/2015	47300
10/26/1936	10100	4/20/1976	22400	11/28/2015	42100
2/19/1938	67500	3/28/1977	36800	1/16/2017	16300
4/19/1939	10800	5/28/1978	4540	9/22/2018	41100
6/16/1940	18100	5/4/1979	29800	10/16/2018	30000
6/12/1941	77000	9/30/1980	8480	3/18/2020	25600
4/26/1942	111000	6/17/1981	14600	5/17/2021	21700
		11/4/1981	37400		

From the HEC-SSP runs, determine the distribution that fits the data best and then generate the report for that distribution fitting. From the report determine the flood discharge values with 100-year and 500-year return periods.

Exercise 3.11. The AMS of 1 h rainfall at two contrasting climatic regions of the United States is given in Table 3.17. The data are from NOAA's precipitation frequency data server. Determine the product moments and L moments. Then determine the parameters of Extreme Value Type I (Gumbel) and Generalized Extreme Value distributions (see Chapter 4). Using the two sets of parameters fit these two distributions to AMS and determine which distribution fits the data better, using the Kolmogorov-Smirnov test at the 0.05 significance level.

Table 3.17 *AMS for 1 h rainfall at two climatically contrasting locations in the United States*

Mira Loma Space Center, Riverside, California		**Ft. Lauderdale International Airport, Florida**	
Date	**Rainfall depth (in)**	**Date**	**Rainfall depth (in)**
3/8/1968	0.95	8/14/1960	1.49
2/22/1969	0.34	5/3/1961	1.66
3/1/1970	0.43	6/15/1962	2.73
12/19/1970	0.3	3/3/1967	1.78
6/4/1972	0.41	10/9/1968	2.48
12/4/1972	0.52	10/30/1969	1.46
1/4/1974	0.24	3/8/1970	2
12/4/1974	0.44	12/22/1971	0.89
9/10/1976	0.36	11/7/1972	5.26
1/3/1977	0.43	11/18/1973	3.2
3/4/1978	0.68	6/24/1975	2.2
3/28/1979	0.43	6/24/1978	2.58
2/15/1980	0.78	4/25/1979	5.07
1/29/1981	0.43	4/10/1980	2.13
3/17/1982	0.29	7/2/1981	2.69
2/27/1983	0.79	5/23/1982	2.24
9/16/1984	0.43	9/28/1983	1.44
3/27/1985	0.28	2/21/1984	1.65
3/10/1986	0.39	10/7/1985	2.13
1/4/1987	0.45	3/26/1986	2.09
12/4/1987	0.55	10/12/1987	1.25
12/21/1988	0.27	5/17/1988	0.88
2/1/1990	0.28	5/10/1990	2.4
3/27/1991	0.32	6/9/1991	1.88
2/12/1992	0.55	1/1/1992	1.84
2/8/1993	0.89	6/3/1993	2
3/19/1994	0.26	8/28/1994	1.71
1/4/1995	0.96	9/7/1995	3.83
2/20/1996	0.47	6/9/1996	2.72
9/25/1997	0.21	8/9/1997	2.29
3/25/1998	0.37	5/28/1998	3.22

Mira Loma Space Center, Riverside, California		Ft. Lauderdale International Airport, Florida	
Date	Rainfall depth (in)	Date	Rainfall depth (in)
4/7/1999	0.52	6/26/1999	2.48
2/12/2000	0.57	9/26/2000	1.53
2/27/2001	0.26	3/19/2001	2.29
11/6/2001	0.29	12/9/2002	2.24
12/16/2002	0.44	5/27/2003	4.89
2/2/2004	0.32	2/1/2004	1.93
10/20/2004	0.73	7/9/2005	1.74
4/4/2006	0.35	6/1/2006	1.41
2/19/2007	0.38	6/29/2007	2.3
1/4/2008	0.29	10/4/2008	1.88
12/15/2008	0.31	12/17/2009	2.07
2/6/2010	0.56	9/6/2010	4.33

Chapter 4

Rainfall Measurements and Models

Exercise 4.1. Locations of six gauging stations within White Rock Creek watershed in Dallas are shown in Figure 4.54. A 24 h heavy rainfall occurred over much of Dallas on March 19, 2006 causing widespread flooding. Table 4.26 gives the rainfall data for the rain event. The distance (in miles) from the centroid of the watershed to the rain gauges shown in Figure 4.54 are as follows: Gauge 1 → 3.14; Gauge 2 → 3.04; Gauge 3 → 5.53; Gauge 4 → 6.92; Gauge 5 → 10.15; Gauge 6 → 11.55.

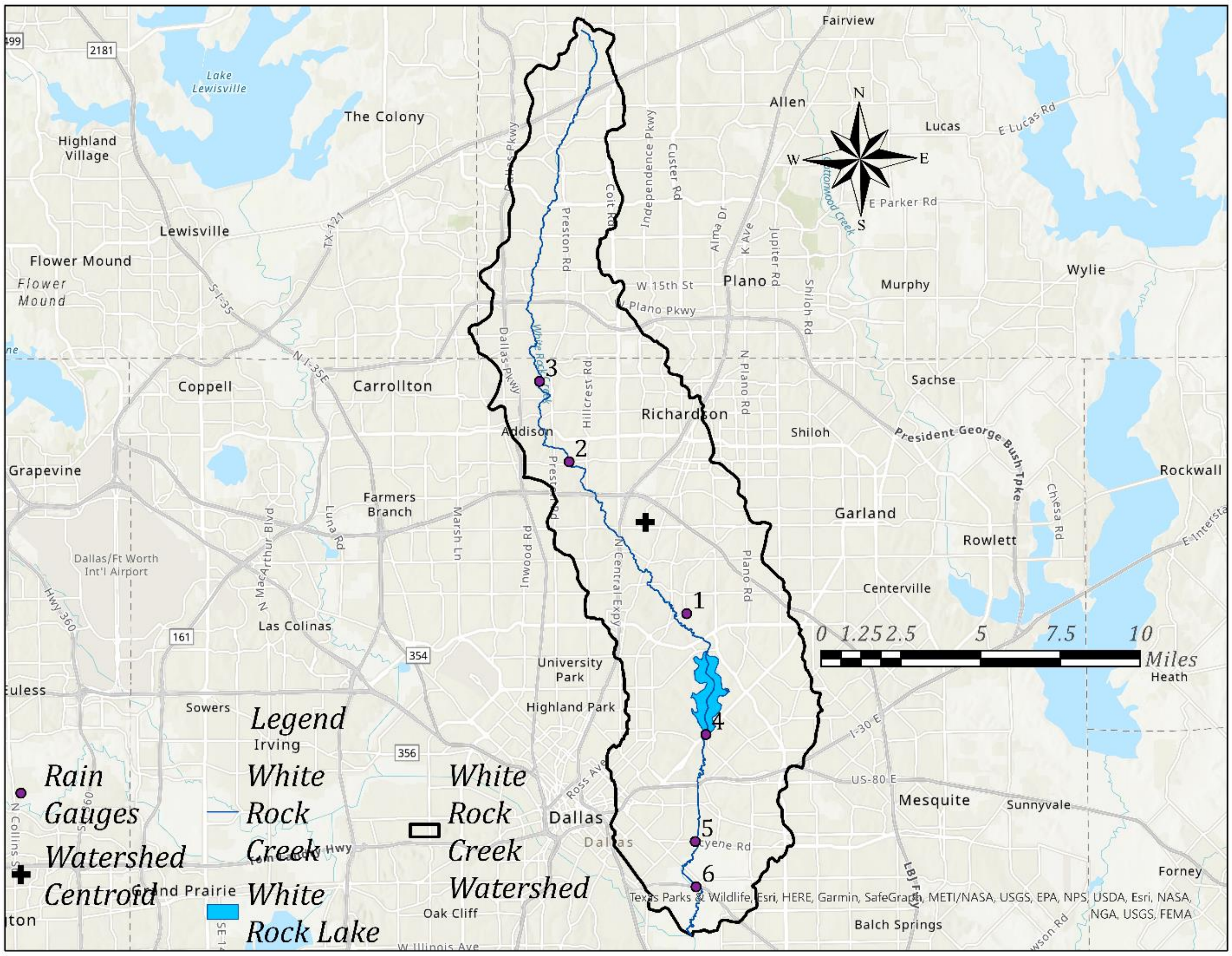

Figure 4.54 Rain gauges within the White Rock Creek watershed in Dallas, Texas, USA.

Table 4.26 *Rainfall data for March 19, 2006 rain event in White Rock Creek watershed, Dallas, Texas, USA*

	Incremental Rainfall (inches)					
Hour (h)	**Gauge 1**	**Gauge 2**	**Gauge 3**	**Gauge 4**	**Gauge 5**	**Gauge 6**
12:00 AM	0	0	0	0	0	0
1:00 AM	0	0	0	0	0	0

	Incremental Rainfall (inches)					
Hour (h)	**Gauge 1**	**Gauge 2**	**Gauge 3**	**Gauge 4**	**Gauge 5**	**Gauge 6**
2:00 AM	0.04	0.04	0.12	0	0	0
3:00 AM	0.2	0.35	0.39	0.12	0.12	0.16
4:00 AM	0.16	0.04	0.04	0.12	0.31	0.31
5:00 AM	0.63	0.28	0.28	0.51	0.08	0.08
6:00 AM	0.51	0.24	0.24	0.51	0.39	0.12
7:00 AM	0.71	0.24	0.2	0.31	0.47	0.39
8:00 AM	0.12	0.04	0.04	0.08	0.12	0.16
9:00 AM	0.28	0.08	0.08	0.2	0.08	0.04
10:00 AM	0.63	0.2	0.12	0.28	0.16	0.12
11:00 AM	0.04	0.08	0.08	0.04	0.08	0.08
12:00 PM	0.16	0.04	0	0.2	0.28	0.24
1:00 PM	0.35	0.2	0.16	0.43	0.35	0.47
2:00 PM	2.8	0.79	0.51	1.5	0.83	0.87
3:00 PM	2.17	0.43	0.28	1.14	0.87	0.63
4:00 PM	0.31	0.2	0.2	0.28	0.24	0.08
5:00 PM	0.04	0.16	0.24	0	0	0
6:00 PM	0	0.2	0.2	0	0.04	0
7:00 PM	0.35	0.47	0.43	0.35	0.2	0.28
8:00 PM	0.08	0	0	0.16	0.31	0.28
9:00 PM	0.04	0	0	0.08	0.12	0.2
10:00 PM	0	0	0	0	0.04	0
11:00 PM	0.08	0.04	0.04	0.12	0.12	0.16
12:00 AM	0.12	0.04	0.08	0.08	0.12	0.12

Do the following.

(A) Construct the rainfall hyetographs for each station.

(B) Construct the mass curve for each station and comment on the meteorological nature of the storm event.

(C) Calculate the MAP using the arithmetic mean.

(D) Calculate the MAP using the inverse distance square weighting. Compare and comment on the results obtained in (C) and (D).

(E) Construct the static average temporal pattern of rainfall variation in the watershed.

(F) Construct the dynamic average temporal pattern of rainfall variation in the watershed.

(G) Determine the period and magnitude of maximum intensity of rainfall. Compare this value with the average intensity of the rain event.

Exercise 4.2. Rainfall totals (STP) on June 9, 2001 (last day of Tropical Storm Allision) at the gauges in and around White Oak Bayou watershed in Houston are given in Table 4.27. The Theisen polygons within this watershed are shown in Figure 4.55. The Theisen polygons are constructed from the entire network of rain gauges within Harris County. The areas of the polygons lying within the White Oak Bayou watershed boundary are listed in Table 4.27. Each polygon has a rain gauge, with an identification number, associated with it and the rainfall value assigned to this polygon is the rainfall value recorded at that gauge.

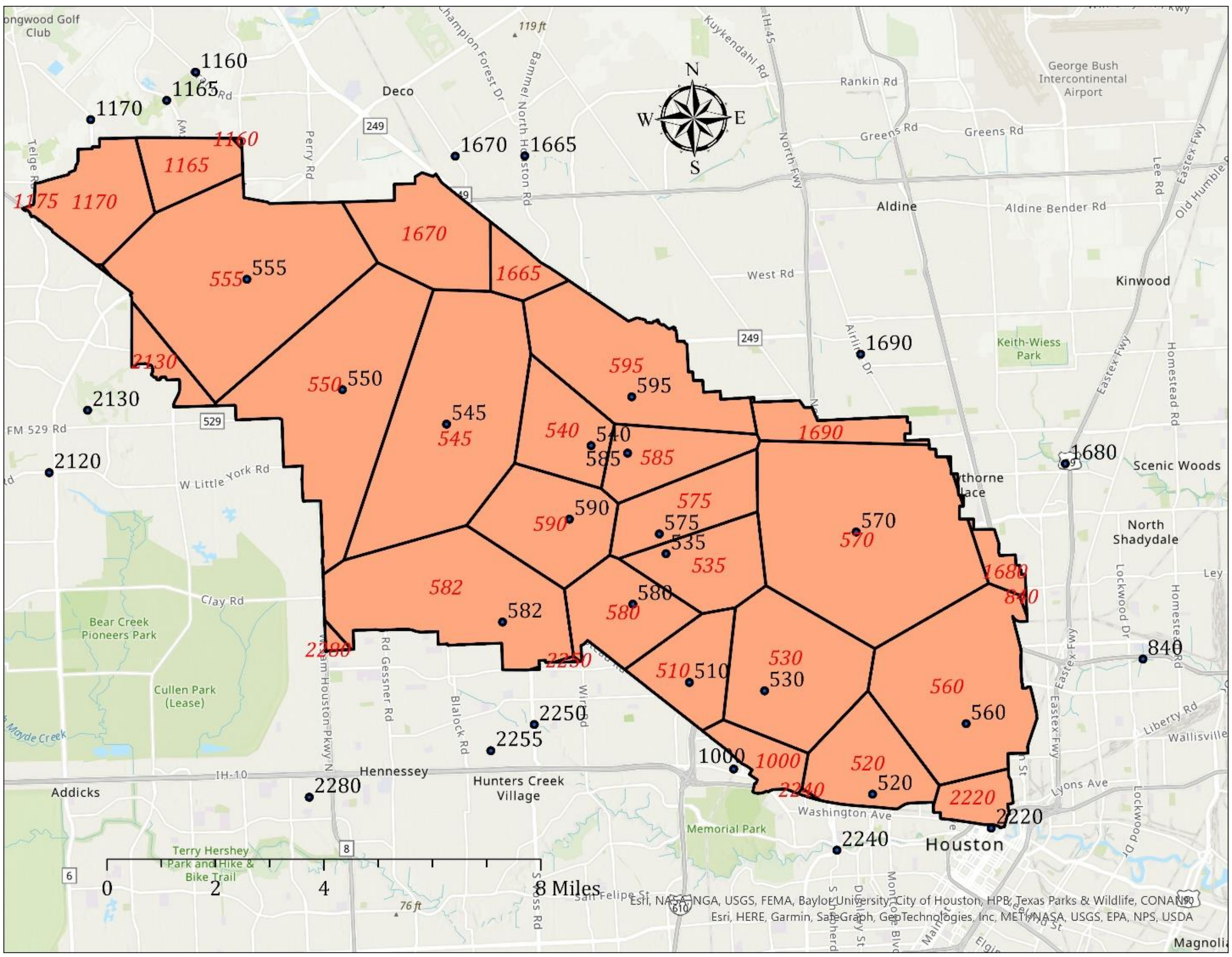

Figure 4.55 Theisen polygons and rain gauges within White Oak Bayou watershed, Houston, Texas, USA.

Do the following.

A) Notice that rainfall records are not available at five gauges. For gauge 510, estimate the rainfall from rainfall records at gauges 530, 1000, 580, and 2250. These gauges are located at 1.40 mi, 1.79 mi, 1.78 mi, and 2.96 mi, respectively from gauge 510. For gauge 582, estimate the rainfall from rainfall records at gauges 580, 2250, and 590. These gauges are located at 2.42 mi, 1.98 mi, and 2.26 mi respectively from gauge 582. Use the inverse distance weighting in the estimation process. Consider rainfall at gauges 2280 and 1165 to be the same as that at gauge 582 and 1160 respectively. For gauge 2130, consider the rainfall as 3.46 inches, recorded at another gauge (2120) located 1.35 mi from it.

B) Compute MAP using the arithmetic mean method.

C) Compute MAP using Theisen polygon method and compare the result with that obtained in (A) and comment on observations.

D) Overlay a transparent paper on the map and construct isohyets.

Table 4.27 *Data for White Oak Bayou watershed, Houston, Texas, USA*

Thiessen Polygon	Area (acres)	Rain Gauge	Location	STP (inches)
1	16.84	2240	Buffalo Bayou @ Shepherd Drive	9.02
2	2109.17	520	White Oak Bayou @ Heights Boulevard	8.5
3	87.91	2280	Rummel Creek @ Brittmoore Road	ND
4	18.86	2250	Spring Branch @ Bingle Road	3.69
5	838.97	1000	Houston Transtar	1.14
6	1594.25	585	Vogel Creek @ Victory Drive	7.54
7	1653.00	510	Harris County Flood Control @ Brookhollow	ND
8	4949.22	582	Brickhouse Gully @ Hollister	ND
9	1856.25	535	White Oak Bayou @ Pinemont Drive	5.01
10	1960.05	580	Brickhouse Gully @ Costa Rica Road	6.45
11	1765.66	540	White Oak Bayou @ Alabonson Road	5.96
12	1843.83	575	White Oak Bayou @ Tidwell Road	6.75
13	1029.15	1690	Halls Bayou @ Airline Drive	8.98
14	2148.88	1170	Cypress Creek @ Huffmeister Road	5.2
15	1200.04	1165	Cypress Creek @ Eldridge Parkway N.	ND
16	654.68	2130	Horsepen Creek @ Trailside Drive	ND
17	10.45	1160	Cypress Creek @ Grant Road	10.42
18	1.35	1175	Cypress Creek @ US 290	4.88
19	7372.89	555	White Oak Bayou @ Jones Road	6.78
20	6090.42	550	White Oak Bayou @ Lakeview Drive	4.74
21	2476.03	1670	Greens Bayou @ Cutten Road	6.84
22	2514.70	590	Cole Creek @ Deihl Road	5.8
23	6562.50	545	White Oak Bayou @ Fairbanks North Houston Road	6.06
24	3995.24	595	Vogel Creek @ Gulf Bank Road	7.79
25	7863.00	570	Little White Oak Bayou @ Tidwell Road	7.65
26	692.04	1665	Greens Bayou @ Bammel N Houston Road	7.73
27	3660.36	530	White Oak Bayou @ Ella Boulevard	8.41
28	722.94	2220	Buffalo Bayou @ Milam Street	6.6

Thiessen Polygon	Area (acres)	Rain Gauge	Location	STP (inches)
29	4960.97	560	Little White Oak Bayou @ Trimble Street	7.33
30	428.85	1680	Halls Bayou @ Jensen Drive	5.91
31	17.26	840	Hunting Bayou @ Lockwood Drive	9.35

Exercise 4.3. Depth-Duration-Frequency for design storms given in the Stormwater Management Guidance Manual (Version 2.1, February 10, 2014) of the City of Philadelphia are given in Table 4.28. Determine the coefficients K, x, b, and n for the Intensity-Duration-Frequency curves represented by the equation: $I = \frac{KF^x}{(T_D+b)^n}$. For design of a city storm drainage system using the rational method (Chapter 10) the return period of the design storm is 10 year and the time of concentration is 10 min. Calculate the intensity for this design purpose.

Table 4.28 *DDF data for design storms for the City of Philadelphia, Pennsylvania, USA*

	Return Period						
	1 yr	**2 yr**	**5 yr**	**10 yr**	**25 yr**	**50 yr**	**100 yr**
Duration	*Rainfall Depth (in.)*						
5 min	0.33	0.38	0.45	0.50	0.56	0.63	0.68
15 min	0.64	0.75	0.90	1.00	1.15	1.35	1.50
1 h	1.10	1.35	1.61	1.85	2.15	2.60	2.98
2 h	1.34	1.66	2.00	2.34	2.70	3.26	3.76
3 h	1.50	1.86	2.28	2.67	3.09	3.69	4.29
6 h	1.86	2.28	2.82	3.36	3.90	4.62	5.40
12 h	2.28	2.76	3.48	4.20	4.92	5.76	6.72
24 h	2.64	3.36	4.32	5.28	6.24	7.20	8.40

Exercise 4.4. The 100-year rainfall depth-duration data for Shoal Creek watershed (Figure 4.56) are given in Table 4.29. The rainfall distribution (percentage mass curve) according to NRCS Type II curve, based on NOAA Atlas 14 based ratios, is tabulated in Table 4.30.

Do the following:

(A) Construct two separate synthetic hyetographs using alternating block method by respectively placing the maximum incremental rainfall at 50% and 67% of the time measured from the beginning of the storm to the total storm duration. Plot the resulting mass curves on the hyetographs.

(B) Construct a synthetic hyetograph according to the NRCS Type II rainfall distribution and plot the mass curve on the hyetograph.

(C) Calculate the maximum intensity for the three cases given above and comment on the results

Table 4.29 *100-year rainfall depth and duration at the centroid of Shoal Creek watershed, Austin, Texas, USA*

Duration (min)	**Rainfall Depth (inches)**
5	1.28
10	2.05
15	2.55
30	3.55
60	4.78
120	6.55
180	7.77
360	9.67
720	11.1
1440	12.4

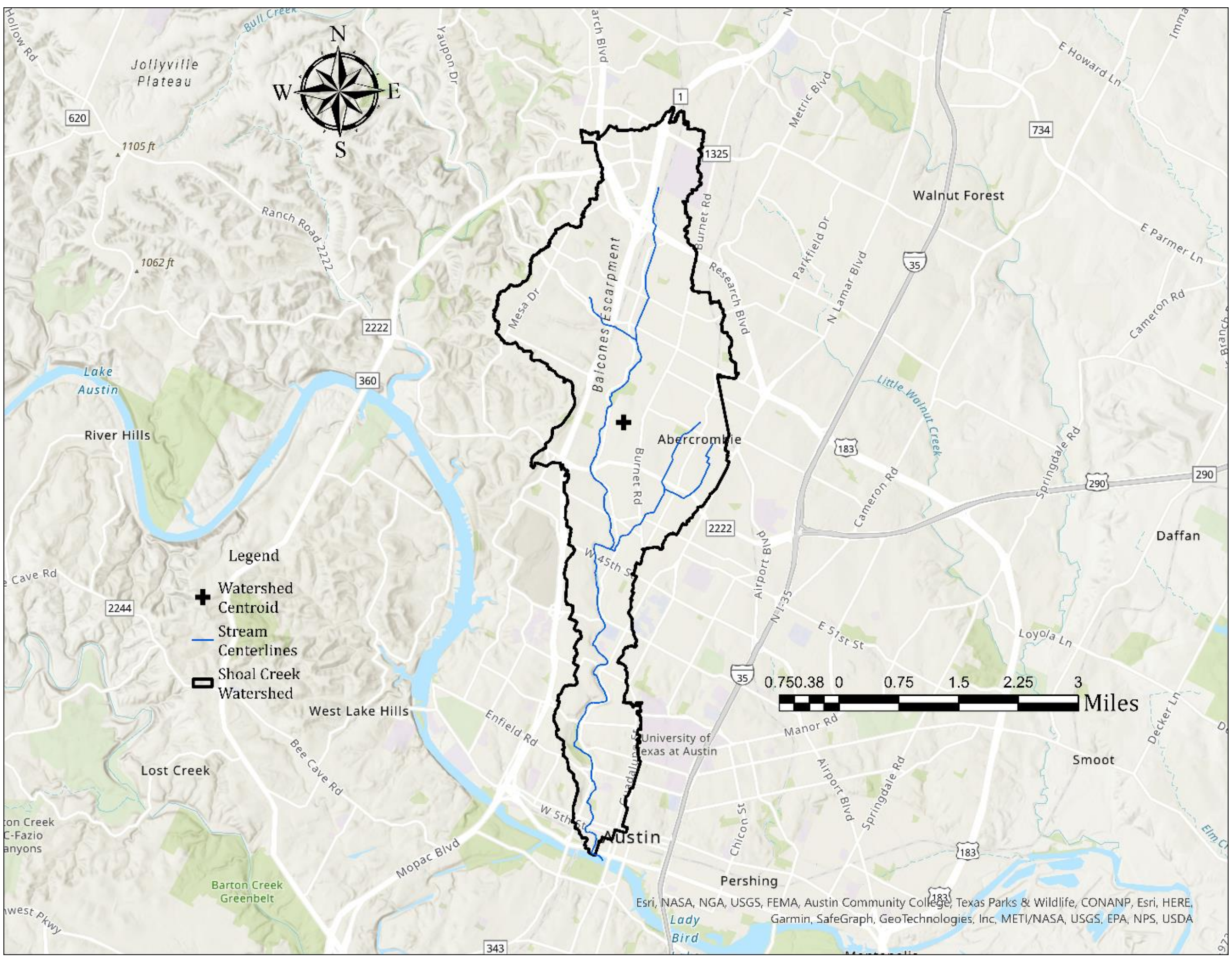

Figure 4.56 Shoal Creek watershed, Austin, Texas, USA.

Table 4.30 Rainfall distribution according to NRCS Type II curve for Exercise 4.4

Time (h)	P/P_{total}	Time (h)	P/P_{total}	Time	P/P_{total}	Time (h)	P/P_{total}
0	0.0000	6.1	0.0540	12.1	0.5907	18.1	0.9491
0.1	0.0002	6.2	0.0556	12.2	0.6270	18.2	0.9507
0.2	0.0004	6.3	0.0572	12.3	0.6561	18.3	0.9522
0.3	0.0006	6.4	0.0589	12.4	0.6781	18.4	0.9537
0.4	0.0009	6.5	0.0606	12.5	0.6927	18.5	0.9552
0.5	0.0012	6.6	0.0623	12.6	0.7088	18.6	0.9566
0.6	0.0015	6.7	0.0640	12.7	0.7240	18.7	0.9580
0.7	0.0018	6.8	0.0657	12.8	0.7382	18.8	0.9594
0.8	0.0021	6.9	0.0675	12.9	0.7516	18.9	0.9608
0.9	0.0025	7	0.0693	13	0.7641	19	0.9621
1	0.0029	7.1	0.0711	13.1	0.7757	19.1	0.9635
1.1	0.0033	7.2	0.0730	13.2	0.7865	19.2	0.9648
1.2	0.0038	7.3	0.0748	13.3	0.7963	19.3	0.9661
1.3	0.0042	7.4	0.0767	13.4	0.8052	19.4	0.9673
1.4	0.0047	7.5	0.0786	13.5	0.8133	19.5	0.9685
1.5	0.0052	7.6	0.0806	13.6	0.8189	19.6	0.9698
1.6	0.0058	7.7	0.0825	13.7	0.8245	19.7	0.9709
1.7	0.0063	7.8	0.0845	13.8	0.8300	19.8	0.9721
1.8	0.0069	7.9	0.0865	13.9	0.8354	19.9	0.9733
1.9	0.0075	8	0.0885	14	0.8407	20	0.9744
2	0.0082	8.1	0.0906	14.1	0.8459	20.1	0.9755
2.1	0.0088	8.2	0.0927	14.2	0.8511	20.2	0.9765
2.2	0.0095	8.3	0.0948	14.3	0.8562	20.3	0.9776
2.3	0.0102	8.4	0.0969	14.4	0.8613	20.4	0.9786
2.4	0.0109	8.5	0.0990	14.5	0.8662	20.5	0.9796
2.5	0.0116	8.6	0.1012	14.6	0.8711	20.6	0.9806
2.6	0.0124	8.7	0.1034	14.7	0.8759	20.7	0.9815
2.7	0.0132	8.8	0.1056	14.8	0.8807	20.8	0.9825
2.8	0.0140	8.9	0.1078	14.9	0.8853	20.9	0.9834
2.9	0.0149	9	0.1101	15	0.8899	21	0.9843
3	0.0157	9.1	0.1147	15.1	0.8922	21.1	0.9851
3.1	0.0166	9.2	0.1193	15.2	0.8944	21.2	0.9860
3.2	0.0175	9.3	0.1241	15.3	0.8966	21.3	0.9868
3.3	0.0185	9.4	0.1289	15.4	0.8988	21.4	0.9876
3.4	0.0194	9.5	0.1338	15.5	0.9010	21.5	0.9884
3.5	0.0204	9.6	0.1387	15.6	0.9031	21.6	0.9891
3.6	0.0214	9.7	0.1438	15.7	0.9052	21.7	0.9898
3.7	0.0224	9.8	0.1489	15.8	0.9073	21.8	0.9905
3.8	0.0235	9.9	0.1541	15.9	0.9094	21.9	0.9912
3.9	0.0245	10	0.1593	16	0.9115	22	0.9918

Time (h)	P/P_{total}	Time (h)	P/P_{total}	Time	P/P_{total}	Time (h)	P/P_{total}
4	0.0256	10.1	0.1646	16.1	0.9135	22.1	0.9925
4.1	0.0267	10.2	0.1700	16.2	0.9155	22.2	0.9931
4.2	0.0279	10.3	0.1755	16.3	0.9175	22.3	0.9937
4.3	0.0291	10.4	0.1811	16.4	0.9194	22.4	0.9942
4.4	0.0302	10.5	0.1867	16.5	0.9214	22.5	0.9948
4.5	0.0315	10.6	0.1948	16.6	0.9233	22.6	0.9953
4.6	0.0327	10.7	0.2037	16.7	0.9252	22.7	0.9958
4.7	0.0339	10.8	0.2135	16.8	0.9270	22.8	0.9962
4.8	0.0352	10.9	0.2243	16.9	0.9289	22.9	0.9967
4.9	0.0365	11	0.2359	17	0.9307	23	0.9971
5	0.0379	11.1	0.2484	17.1	0.9325	23.1	0.9975
5.1	0.0392	11.2	0.2618	17.2	0.9343	23.2	0.9979
5.2	0.0406	11.3	0.2760	17.3	0.9360	23.3	0.9982
5.3	0.0420	11.4	0.2912	17.4	0.9377	23.4	0.9985
5.4	0.0434	11.5	0.3073	17.5	0.9394	23.5	0.9988
5.5	0.0448	11.6	0.3219	17.6	0.9411	23.6	0.9991
5.6	0.0463	11.7	0.3439	17.7	0.9428	23.7	0.9994
5.7	0.0478	11.8	0.3730	17.8	0.9444	23.8	0.9996
5.8	0.0493	11.9	0.4093	17.9	0.9460	23.9	0.9998
5.9	0.0509	12	0.4751	18	0.9476	24	1.0000
6	0.0524						

Exercise 4.5. During the storm event in Las Vegas area, described in Example 4.4, rainfall recorded at another gauge, 3184 (California wash), is given in Table 4.31. In what quartile classification will this record belong to? What was the maximum hourly intensity? Plot the mass curve and hyetograph and compare these plots with the plots given in Example 4.4. Make observations.

Table 4.31 *Rainfall records at Gauge 3184, Las Vegas, Nevada, USA*

Date/Time	Cumulative Rainfall (in.)	Date/Time	Cumulative Rainfall (in.)
9/8/14 12:00 PM	0	9/8/14 3:00 PM	1.74
9/8/14 12:20 PM	0.1	9/8/14 3:01 PM	1.82
9/8/14 12:27 PM	0.16	9/8/14 3:02 PM	1.85
9/8/14 1:06 PM	0.2	9/8/14 3:03 PM	1.89
9/8/14 1:11 PM	0.28	9/8/14 3:05 PM	1.93
9/8/14 1:23 PM	0.32	9/8/14 3:08 PM	2.09
9/8/14 1:29 PM	0.4	9/8/14 3:09 PM	2.13
9/8/14 1:34 PM	0.48	9/8/14 3:10 PM	2.21
9/8/14 1:36 PM	0.56	9/8/14 3:12 PM	2.29
9/8/14 1:48 PM	0.63	9/8/14 3:15 PM	2.37
9/8/14 1:51 PM	0.71	9/8/14 3:19 PM	2.41
9/8/14 2:05 PM	0.83	9/8/14 3:21 PM	2.45

Date/Time	Cumulative Rainfall (in.)	Date/Time	Cumulative Rainfall (in.)
9/8/14 2:07 PM	0.87	9/8/14 3:23 PM	2.52
9/8/14 2:10 PM	0.91	9/8/14 3:24 PM	2.56
9/8/14 2:12 PM	0.95	9/8/14 3:25 PM	2.6
9/8/14 2:46 PM	1.22	9/8/14 3:29 PM	2.72
9/8/14 2:49 PM	1.26	9/8/14 3:30 PM	2.76
9/8/14 2:52 PM	1.34	9/8/14 3:34 PM	2.84
9/8/14 2:53 PM	1.38	9/8/14 3:35 PM	2.88
9/8/14 2:54 PM	1.42	9/8/14 3:36 PM	2.96
9/8/14 2:55 PM	1.46	9/8/14 3:37 PM	3
9/8/14 2:56 PM	1.5	9/8/14 3:38 PM	3.04
9/8/14 2:57 PM	1.58	9/8/14 3:40 PM	3.08
9/8/14 2:58 PM	1.62	9/8/14 3:48 PM	3.15
9/8/14 2:59 PM	1.7	9/8/14 3:57 PM	3.23
		9/8/14 4:22 PM	3.31

Exercise 4.6. Rainfall recorded at Trailwood Drive gauging station during another summer thunderstorm in the same watershed (Walnut Creek, Raleigh, North Carolina), described in Example 4.5, is given in Table 4.32. Determine the maximum 10-minute, 15-minute, and 30-minute intensities and comment on the nature of the storm from plots of mass curve and hyetograph. Determine the quartile distribution of the storm and compare it with the comparable Huff curves of this region.

Table 4.32 *Rainfall records at Trailwood Drive gauge, Raleigh, North Carolina, USA*

Date and Time	Incremental Rainfall (in)	Date and Time	Incremental Rainfall (in)
8/19/2018 23:25	0.02	8/20/2018 1:25	0.01
8/19/2018 23:30	0	8/20/2018 1:30	0.1
8/19/2018 23:35	0.01	8/20/2018 1:35	0.07
8/19/2018 23:40	0	8/20/2018 1:40	0
8/19/2018 23:45	0	8/20/2018 1:45	0.04
8/19/2018 23:50	0.1	8/20/2018 1:50	0.18
8/19/2018 23:55	0.02	8/20/2018 1:55	0.15
8/20/2018 0:00	0.13	8/20/2018 2:00	0.09
8/20/2018 0:05	0.42	8/20/2018 2:05	0
8/20/2018 0:10	0.27	8/20/2018 2:10	0
8/20/2018 0:15	0.33	8/20/2018 2:15	0
8/20/2018 0:20	0.27	8/20/2018 2:20	0
8/20/2018 0:25	0.24	8/20/2018 2:25	0
8/20/2018 0:30	0.11	8/20/2018 2:30	0
8/20/2018 0:35	0.13	8/20/2018 2:35	0
8/20/2018 0:40	0.16	8/20/2018 2:40	0.01
8/20/2018 0:45	0.23	8/20/2018 2:45	0.01
8/20/2018 0:50	0.1	8/20/2018 2:50	0

Date and Time	Incremental Rainfall (in)	Date and Time	Incremental Rainfall (in)
8/20/2018 0:55	0.12	8/20/2018 2:55	0.01
8/20/2018 1:00	0.13	8/20/2018 3:00	0.01
8/20/2018 1:05	0.14	8/20/2018 3:05	0.01
8/20/2018 1:10	0.05	8/20/2018 3:10	0.01
8/20/2018 1:15	0.01	8/20/2018 3:15	0.02
8/20/2018 1:20	0.01	8/20/2018 3:20	0.01
		8/20/2018 3:25	0.01

Exercise 4.7. The annual maxima series for 24 h rainfall at WFAA TV Station located in downtown Dallas is given in Table 4.33. Conduct a frequency analysis to determine the 100 year 24 h rainfall using (1) Gumbel distribution, (2) Weibull distribution, and (3) Generalized Extreme Value distribution. For GEV obtain the parameters of the distribution from the L moments given as: λ_1 = 3.570313; λ_2 = 0.699152; λ_3 = 0.102001; τ_1 = 0.195824; τ_3 = 0.218222; τ_4 = 0.145893. In each case, plot the *pdf, cdf,* and observed versus predicted values.

Table 4.33 *AMS for 24 h rainfall at WFFA TV Station, Dallas, Texas, USA*

Date	Rainfall (in.)	Date	Rainfall (in.)
11/4/1902	3.4	9/14/1934	4.02
7/3/1903	3.45	6/14/1935	4.07
10/26/1904	3.85	9/26/1936	5.55
6/28/1905	3.15	10/16/1937	2.83
5/15/1906	3.88	1/21/1938	3.04
5/24/1907	2.89	4/5/1939	2.11
5/24/1908	2.75	5/29/1946	3.25
6/23/1909	2.12	6/29/1948	3.53
9/6/1910	2.48	5/17/1949	5.97
12/20/1911	1.7	10/26/1991	4.1
6/18/1912	2.93	5/17/1992	2.63
12/3/1913	3.89	9/1/1994	2.77
4/26/1914	2.48	3/12/1995	3.05
8/17/1915	4.71	8/8/1996	2.7
3/31/1916	3.05	4/3/1997	2.31
4/27/1917	2.13	12/3/1998	1.95
11/7/1918	4	6/10/2000	2.05
10/31/1919	3.13	2/15/2001	2.41
3/24/1920	3.95	10/18/2002	4.65
6/22/1921	2.11	8/31/2003	2.38
4/3/1922	5.41	7/28/2004	6.31
6/9/1923	3.86	9/15/2005	1.98
5/25/1924	2.6	3/19/2006	6.95
5/6/1925	3.39	9/9/2007	3.71
4/21/1926	2.75	3/18/2008	4.86

Date	Rainfall (in.)	Date	Rainfall (in.)
10/1/1927	2.77	6/10/2009	7.31
12/16/1928	3.74	9/7/2010	5.77
5/12/1929	3.7	6/21/2011	4.64
5/12/1930	3.23	3/19/2012	6.01
9/10/1931	2.49	5/15/2013	3.88
9/4/1932	3.77	5/8/2014	3.39
4/25/1933	3.08	10/22/2015	5.48

Exercise 4.8. Table 4.34 gives the standard 24 h NRCS rainfall distributions. First determine the distributions at the center of Manhattan, New York, and center of Minneapolis on the west side of Mississippi River, Minnesota based on NOAA Atlas 14 precipitation depth frequency data and the type curve applicable at these two city centers. Then determine the 25 year, 6 h distributions at these two locations using the following equation:

$$\frac{P'(t)}{PD} = \frac{P\left(12+t-D/2\right)-P\left(12-D/2\right)}{P\left(12+D/2\right)-P\left(12-D/2\right)} \tag{4.1}$$

where t is the time with the storm in hours ($0 \leq t \leq D$); D is the storm duration in hours ($D < 24$), PD is the rainfall depth for the duration D and desired frequency, $P(t)$ is the value from the appropriate type curve (Table 4.34), and $P'(t)$ is the accumulated rainfall depth to time t.

Table 4.34 *Standard 24 h NRCS rainfall distribution*

Time (hours)	type I 24-hour	type Ia 24-hour	type II 24-hour	type III 24-hour
0.0	0.00000	0.00000	0.00000	0.00000
0.1	0.00174	0.00224	0.00101	0.00100
0.2	0.00348	0.00432	0.00202	0.00200
0.3	0.00522	0.00628	0.00305	0.00300
0.4	0.00697	0.00816	0.00408	0.00400
0.5	0.00871	0.01000	0.00513	0.00500
0.6	0.01046	0.01184	0.00618	0.00600
0.7	0.01220	0.01372	0.00725	0.00700
0.8	0.01395	0.01568	0.00832	0.00800
0.9	0.01570	0.01776	0.00941	0.00900
1.0	0.01745	0.02000	0.01050	0.01000
1.1	0.01920	0.02276	0.01161	0.01100
1.2	0.02095	0.02568	0.01272	0.01200
1.3	0.02270	0.02872	0.01385	0.01300
1.4	0.02446	0.03184	0.01498	0.01400
1.5	0.02621	0.03500	0.01613	0.01500

Time (hours)	type I 24-hour	type Ia 24-hour	type II 24-hour	type III 24-hour
1.6	0.02797	0.03797	0.01728	0.01600
1.7	0.02972	0.04095	0.01845	0.01700
1.8	0.03148	0.04394	0.01962	0.01800
1.9	0.03324	0.04695	0.02081	0.01900
2.0	0.03500	0.05000	0.02200	0.02000
2.1	0.03677	0.05315	0.02321	0.02101
2.2	0.03858	0.05633	0.02442	0.02203
2.3	0.04041	0.05954	0.02565	0.02307
2.4	0.04227	0.06276	0.02688	0.02412
2.5	0.04416	0.06600	0.02813	0.02519
2.6	0.04608	0.06920	0.02938	0.02627
2.7	0.04803	0.07240	0.03065	0.02737
2.8	0.05001	0.07560	0.03192	0.02848
2.9	0.05201	0.07880	0.03321	0.02961
3.0	0.05405	0.08200	0.03450	0.03075
3.1	0.05611	0.08514	0.03581	0.03191
3.2	0.05821	0.08829	0.03712	0.03308
3.3	0.06033	0.09147	0.03845	0.03427
3.4	0.06248	0.09471	0.03978	0.03547
3.5	0.06466	0.09800	0.04113	0.03669
3.6	0.06687	0.10147	0.04248	0.03792
3.7	0.06911	0.10502	0.04385	0.03917
3.8	0.07138	0.10862	0.04522	0.04043
3.9	0.07367	0.11229	0.04661	0.04171
4.0	0.07600	0.11600	0.04800	0.04300
4.1	0.07835	0.11969	0.04941	0.04431
4.2	0.08070	0.12342	0.05084	0.04563
4.3	0.08307	0.12721	0.05229	0.04697
4.4	0.08545	0.13107	0.05376	0.04832
4.5	0.08784	0.13500	0.05525	0.04969
4.6	0.09024	0.13901	0.05676	0.05107
4.7	0.09265	0.14310	0.05829	0.05247
4.8	0.09507	0.14729	0.05984	0.05388
4.9	0.09751	0.15159	0.06141	0.05531
5.0	0.09995	0.15600	0.06300	0.05675
5.1	0.10241	0.16059	0.06461	0.05821
5.2	0.10487	0.16530	0.06624	0.05968
5.3	0.10735	0.17011	0.06789	0.06117
5.4	0.10984	0.17501	0.06956	0.06267
5.5	0.11234	0.18000	0.07125	0.06419
5.6	0.11485	0.18494	0.07296	0.06572
5.7	0.11737	0.18999	0.07469	0.06727
5.8	0.11990	0.19517	0.07644	0.06883

Time	type I	type Ia	type II	type III
(hours)	24-hour	24-hour	24-hour	24-hour
5.9	0.12245	0.20049	0.07821	0.07041
6.0	0.12500	0.20600	0.08000	0.07200
6.1	0.12761	0.21196	0.08181	0.07363
6.2	0.13034	0.21808	0.08364	0.07530
6.3	0.13317	0.22432	0.08549	0.07703
6.4	0.13610	0.23064	0.08736	0.07880
6.5	0.13915	0.23700	0.08925	0.08063
6.6	0.14230	0.24285	0.09116	0.08250
6.7	0.14557	0.24878	0.09309	0.08443
6.8	0.14894	0.25490	0.09504	0.08640
6.9	0.15241	0.26127	0.09701	0.08843
7.0	0.15600	0.26800	0.09900	0.09050
7.1	0.15966	0.27517	0.10101	0.09263
7.2	0.16334	0.28287	0.10304	0.09480
7.3	0.16706	0.29118	0.10509	0.09703
7.4	0.17082	0.30019	0.10716	0.09930
7.5	0.17460	0.31000	0.10925	0.10163
7.6	0.17842	0.33142	0.11136	0.10400
7.7	0.18226	0.35469	0.11349	0.10643
7.8	0.18614	0.37876	0.11564	0.10890
7.9	0.19006	0.40255	0.11781	0.11143
8.0	0.19400	0.42500	0.12000	0.11400
8.1	0.19817	0.43936	0.12225	0.11666
8.2	0.20275	0.45168	0.12460	0.11943
8.3	0.20775	0.46232	0.12705	0.12232
8.4	0.21317	0.47164	0.12960	0.12532
8.5	0.21900	0.48000	0.13225	0.12844
8.6	0.22523	0.48904	0.13500	0.13167
8.7	0.23185	0.49752	0.13785	0.13502
8.8	0.23885	0.50548	0.14080	0.13848
8.9	0.24623	0.51296	0.14385	0.14206
9.0	0.25400	0.52000	0.14700	0.14575
9.1	0.26233	0.52664	0.15020	0.14956
9.2	0.27139	0.53292	0.15340	0.15348
9.3	0.28119	0.53888	0.15660	0.15752
9.4	0.29173	0.54456	0.15980	0.16167
9.5	0.30300	0.55000	0.16300	0.16594
9.6	0.31942	0.55564	0.16628	0.17032
9.7	0.34542	0.56116	0.16972	0.17482
9.8	0.38784	0.56656	0.17332	0.17943
9.9	0.46316	0.57184	0.17708	0.18416
10.0	0.51500	0.57700	0.18100	0.18900
10.1	0.53220	0.58198	0.18512	0.19402

Time (hours)	type I 24-hour	type Ia 24-hour	type II 24-hour	type III 24-hour
10.2	0.54760	0.58685	0.18948	0.19928
10.3	0.56120	0.59163	0.19408	0.20478
10.4	0.57300	0.59635	0.19892	0.21052
10.5	0.58300	0.60100	0.20400	0.21650
10.6	0.59188	0.60576	0.20940	0.22272
10.7	0.60032	0.61044	0.21520	0.22918
10.8	0.60832	0.61504	0.22140	0.23588
10.9	0.61588	0.61956	0.22800	0.24282
11.0	0.62300	0.62400	0.23500	0.25000
11.1	0.62982	0.62836	0.24268	0.25776
11.2	0.63648	0.63264	0.25132	0.26644
11.3	0.64298	0.63684	0.26092	0.27604
11.4	0.64932	0.64096	0.27148	0.28656
11.5	0.65550	0.64500	0.28300	0.29800
11.6	0.66152	0.64889	0.30684	0.31430
11.7	0.66738	0.65272	0.35436	0.33940
11.8	0.67308	0.65651	0.43079	0.37330
11.9	0.67862	0.66026	0.56786	0.41600
12.0	0.68400	0.66400	0.66300	0.50000
12.1	0.68925	0.66773	0.68196	0.58400
12.2	0.69440	0.67148	0.69864	0.62670
12.3	0.69945	0.67527	0.71304	0.66060
12.4	0.70440	0.67910	0.72516	0.68570
12.5	0.70925	0.68300	0.73500	0.70200
12.6	0.71400	0.68665	0.74344	0.71344
12.7	0.71865	0.69027	0.75136	0.72396
12.8	0.72320	0.69386	0.75876	0.73356
12.9	0.72765	0.69744	0.76564	0.74224
13.0	0.73200	0.70100	0.77200	0.75000
13.1	0.73625	0.70473	0.77796	0.75718
13.2	0.74040	0.70838	0.78364	0.76412
13.3	0.74445	0.71198	0.78904	0.77082
13.4	0.74840	0.71551	0.79416	0.77728
13.5	0.75225	0.71900	0.79900	0.78350
13.6	0.75600	0.72245	0.80360	0.78948
13.7	0.75965	0.72586	0.80800	0.79522
13.8	0.76320	0.72926	0.81220	0.80072
13.9	0.76665	0.73263	0.81620	0.80598
14.0	0.77000	0.73600	0.82000	0.81100
14.1	0.77329	0.73939	0.82367	0.81584
14.2	0.77656	0.74277	0.82726	0.82057
14.3	0.77981	0.74613	0.83079	0.82518
14.4	0.78304	0.74948	0.83424	0.82968

Time (hours)	type I 24-hour	type Ia 24-hour	type II 24-hour	type III 24-hour
14.5	0.78625	0.75281	0.83763	0.83406
14.6	0.78944	0.75613	0.84094	0.83833
14.7	0.79261	0.75943	0.84419	0.84248
14.8	0.79576	0.76271	0.84736	0.84652
14.9	0.79889	0.76598	0.85047	0.85044
15.0	0.80200	0.76924	0.85350	0.85425
15.1	0.80509	0.77248	0.85647	0.85794
15.2	0.80816	0.77571	0.85936	0.86152
15.3	0.81121	0.77892	0.86219	0.86498
15.4	0.81424	0.78211	0.86494	0.86833
15.5	0.81725	0.78529	0.86763	0.87156
15.6	0.82024	0.78845	0.87024	0.87468
15.7	0.82321	0.79160	0.87279	0.87768
15.8	0.82616	0.79474	0.87526	0.88057
15.9	0.82909	0.79786	0.87767	0.88334
16.0	0.83200	0.80096	0.88000	0.88600
16.1	0.83489	0.80405	0.88229	0.88858
16.2	0.83776	0.80712	0.88455	0.89110
16.3	0.84061	0.81018	0.88679	0.89358
16.4	0.84344	0.81322	0.88900	0.89600
16.5	0.84625	0.81625	0.89119	0.89838
16.6	0.84904	0.81926	0.89335	0.90070
16.7	0.85181	0.82226	0.89549	0.90298
16.8	0.85456	0.82524	0.89760	0.90520
16.9	0.85729	0.82821	0.89969	0.90738
17.0	0.86000	0.83116	0.90175	0.90950
17.1	0.86269	0.83410	0.90379	0.91158
17.2	0.86536	0.83702	0.90580	0.91360
17.3	0.86801	0.83992	0.90779	0.91558
17.4	0.87064	0.84281	0.90975	0.91750
17.5	0.87325	0.84569	0.91169	0.91938
17.6	0.87584	0.84855	0.91360	0.92120
17.7	0.87841	0.85140	0.91549	0.92298
17.8	0.88096	0.85423	0.91735	0.92470
17.9	0.88349	0.85704	0.91919	0.92638
18.0	0.88600	0.85984	0.92100	0.92800
18.1	0.88849	0.86262	0.92279	0.92959
18.2	0.89096	0.86539	0.92455	0.93117
18.3	0.89341	0.86815	0.92629	0.93273
18.4	0.89584	0.87089	0.92800	0.93428
18.5	0.89825	0.87361	0.92969	0.93581
18.6	0.90064	0.87632	0.93135	0.93733
18.7	0.90301	0.87901	0.93299	0.93883

Time (hours)	type I 24-hour	type Ia 24-hour	type II 24-hour	type III 24-hour
18.8	0.90536	0.88169	0.93460	0.94032
18.9	0.90769	0.88435	0.93619	0.94179
19.0	0.91000	0.88700	0.93775	0.94325
19.1	0.91229	0.88963	0.93929	0.94469
19.2	0.91456	0.89225	0.94080	0.94612
19.3	0.91681	0.89485	0.94229	0.94753
19.4	0.91904	0.89744	0.94375	0.94893
19.5	0.92125	0.90001	0.94519	0.95031
19.6	0.92344	0.90257	0.94660	0.95168
19.7	0.92561	0.90511	0.94799	0.95303
19.8	0.92776	0.90763	0.94935	0.95437
19.9	0.92989	0.91014	0.95069	0.95569
20.0	0.93200	0.91264	0.95200	0.95700
20.1	0.93409	0.91512	0.95330	0.95829
20.2	0.93616	0.91759	0.95459	0.95958
20.3	0.93821	0.92004	0.95588	0.96085
20.4	0.94024	0.92247	0.95716	0.96211
20.5	0.94225	0.92489	0.95844	0.96336
20.6	0.94424	0.92729	0.95971	0.96460
20.7	0.94621	0.92968	0.96098	0.96582
20.8	0.94816	0.93206	0.96224	0.96704
20.9	0.95009	0.93442	0.96350	0.96824
21.0	0.95200	0.93676	0.96475	0.96944
21.1	0.95389	0.93909	0.96600	0.97062
21.2	0.95576	0.94140	0.96724	0.97179
21.3	0.95761	0.94370	0.96848	0.97295
21.4	0.95944	0.94598	0.96971	0.97410
21.5	0.96125	0.94825	0.97094	0.97523
21.6	0.96304	0.95050	0.97216	0.97636
21.7	0.96481	0.95274	0.97338	0.97747
21.8	0.96656	0.95496	0.97459	0.97858
21.9	0.96829	0.95717	0.97580	0.97967
22.0	0.97000	0.95936	0.97700	0.98075
22.1	0.97169	0.96154	0.97820	0.98182
22.2	0.97336	0.96370	0.97939	0.98288
22.3	0.97501	0.96584	0.98058	0.98392
22.4	0.97664	0.96797	0.98176	0.98496
22.5	0.97825	0.97009	0.98294	0.98598
22.6	0.97984	0.97219	0.98411	0.98700
22.7	0.98141	0.97428	0.98528	0.98800
22.8	0.98296	0.97635	0.98644	0.98899
22.9	0.98449	0.97840	0.98760	0.98997
23.0	0.98600	0.98044	0.98875	0.99094

Time (hours)	type I 24-hour	type Ia 24-hour	type II 24-hour	type III 24-hour
23.1	0.98749	0.98246	0.98990	0.99189
23.2	0.98896	0.98447	0.99104	0.99284
23.3	0.99041	0.98647	0.99218	0.99377
23.4	0.99184	0.98845	0.99331	0.99470
23.5	0.99325	0.99041	0.99444	0.99561
23.6	0.99464	0.99236	0.99556	0.99651
23.7	0.99601	0.99429	0.99668	0.99740
23.8	0.99736	0.99621	0.99779	0.99828
23.9	0.99869	0.99811	0.99890	0.99914
24.0	1.0000	1.0000	1.0000	1.0000

Exercise 4.9. Depth-Area-Duration (DAD) data of the rainfall event of June 23, 1954 with rainfall center located at Victoria Pierce, Texas are given in Table 4.35. Construct the depth-duration and depth-area envelopes.

Table 4.35 *DAD data at Victoria Pierce, Texas, USA*

Duration	6hr	12hr	18hr	24hr	30hr	36hr	48hr	60hr	72hr
Area (km^2)	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)
25.9	406.4	510.54	571.5	678.18	779.78	812.8	878.84	878.84	878.84
259	320.04	419.1	500.38	599.44	701.04	741.68	800.1	800.1	800.1
518	276.86	378.46	472.44	571.5	657.86	698.5	749.3	749.3	749.3
2590	167.64	246.38	370.84	467.36	510.54	546.1	584.2	584.2	584.2
12950	71.12	124.46	187.96	226.06	264.16	302.26	347.98	363.22	363.22
25900	43.18	81.28	119.38	144.78	180.34	203.2	248.92	264.16	266.7
51800	30.48	50.8	71.12	91.44	114.3	132.08	165.1	177.8	182.88

Exercise 4.10. The DAD data developed for Lewis River basin, in Washington state are given in Table 4.36. Construct the depth-duration and depth-area envelopes. How do these curves compare with the corresponding curves obtained in Exercise 4.9?

Table 4.36 *DAD data for Lewis River basin, Washington, USA*

Area (mi^2)	**Duration (hours)**															
	1	2	3	4	5	6	12	18	24	36	48	72	96	120	144	Total
0.33	1.69	3.07	4.27	5.32	6.28	7.06	12.20	16.45	20.36	24.19	26.82	29.61	34.84	38.18	39.42	39.83
1	1.60	2.97	4.18	5.20	6.19	6.92	12.15	16.26	20.16	23.95	26.59	29.40	34.58	37.93	39.17	39.59
10	1.48	2.74	3.82	4.68	5.60	6.34	11.30	15.17	18.88	22.38	25.12	28.03	33.21	36.57	37.80	38.25
25	1.30	2.42	3.38	4.21	4.96	5.74	10.30	14.11	17.33	20.90	23.29	26.33	31.05	34.51	35.81	36.29
50	1.23	2.21	2.90	3.53	4.32	5.05	9.37	12.71	15.69	19.01	21.39	24.46	29.06	32.47	33.66	34.26
100	1.10	1.98	2.59	3.22	3.84	4.41	8.20	11.33	14.22	17.36	19.71	22.42	26.58	30.15	31.67	32.18
121	0.98	1.90	2.52	3.12	3.69	4.25	7.88	10.84	13.81	16.87	19.01	21.81	26.04	29.74	31.13	31.59
135	0.98	1.86	2.45	3.08	3.55	4.22	7.62	10.74	13.50	16.69	18.88	21.31	25.64	29.40	30.84	31.24
150	0.97	1.81	2.40	3.03	3.54	4.16	7.56	10.66	13.22	16.36	18.62	21.24	25.46	29.03	30.51	30.91
200	0.97	1.63	2.24	2.88	3.41	3.97	7.18	10.01	12.74	15.66	17.78	20.25	24.51	27.98	29.46	29.92
300	0.82	1.54	2.11	2.64	3.12	3.75	6.75	9.35	12.01	14.72	17.08	19.55	23.15	26.58	27.81	28.42
475	0.72	1.39	2.05	2.57	3.06	3.50	6.35	8.93	11.17	13.99	15.91	18.43	21.77	24.94	25.98	26.59
500	0.71	1.36	2.03	2.56	3.03	3.48	6.29	8.87	11.03	13.87	15.91	18.18	21.56	24.45	25.92	26.38
1,000	0.66	1.23	1.82	2.24	2.70	3.20	5.66	8.00	10.15	12.61	14.52	16.62	19.54	22.21	23.27	23.62
2,000	0.56	1.06	1.60	2.06	2.44	2.88	4.97	7.19	9.00	11.25	12.95	14.93	17.44	19.48	20.36	20.91
5,000	0.44	0.82	1.23	1.61	1.91	2.30	3.98	5.77	7.12	8.86	10.31	12.03	14.12	15.87	16.59	17.00
9,838	0.32	0.59	0.85	1.11	1.36	1.62	2.79	3.98	4.87	6.05	7.09	8.41	9.90	11.27	11.90	12.10

Exercise 4.11. Determine the number of stations required in Example 4.1 if the station at Leh is included. Mean annual precipitation at Leh, based on a long period of record, is 124.07 mm. Also determine the number of gauges required as per the recommendation of NWS. The total basin area shown in Figure 4.41 is 172,173 km^2.

Exercise 4.12. The 100-year 24 h isopluvial lines of Mandakini catchment, derived from frequency analysis of the gridded rainfall data from IMD, are shown in Figure 4.57. The area of the catchment is 1643 km^2. Determine the minimum number of rain gauges necessary for a network and their suggested locations.

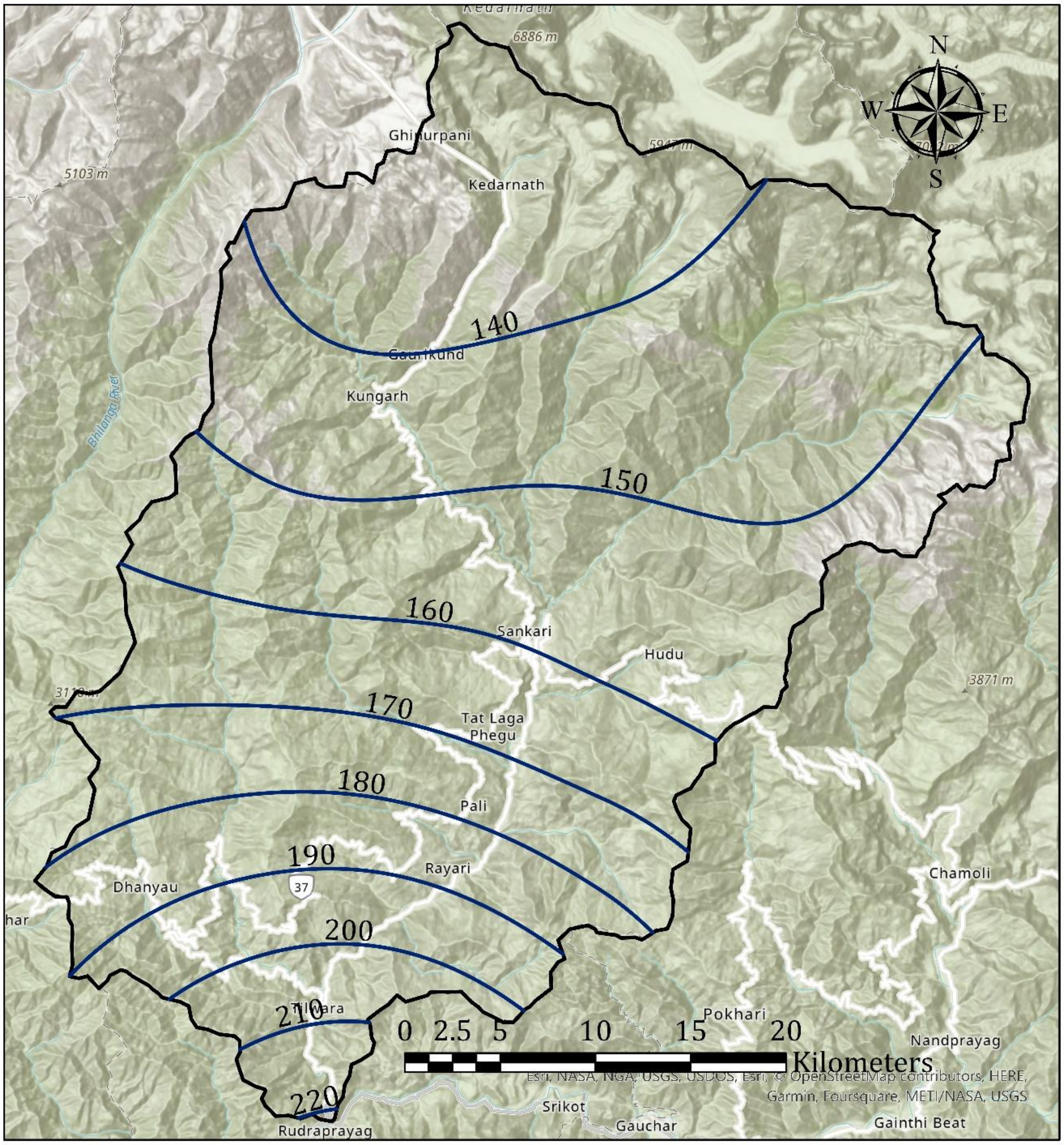

Figure 4.57 100-year 24 h isopluvial lines of Mandakini catchment, Uttarakhand, India.

Chapter 5

Streamflow Measurements and Statistics

Exercise 5.1. A detailed study by the USGS generated velocity profiles at several cross sections of the Lower Fox River, Wisconsin, using ADCP, that are given by S. M. Westenbroek in Scientific Investigations Report 2006-5226 (2006). An example of the velocity profile, generated by averaging all valid velocities for each depth from each ensemble is given in Figure 5.41 which demonstrates how forces other than water flow may influence the resulting velocity profile. The curl at the top of the velocity profile is likely caused by the drag of the wind acting against the direction of water flow.

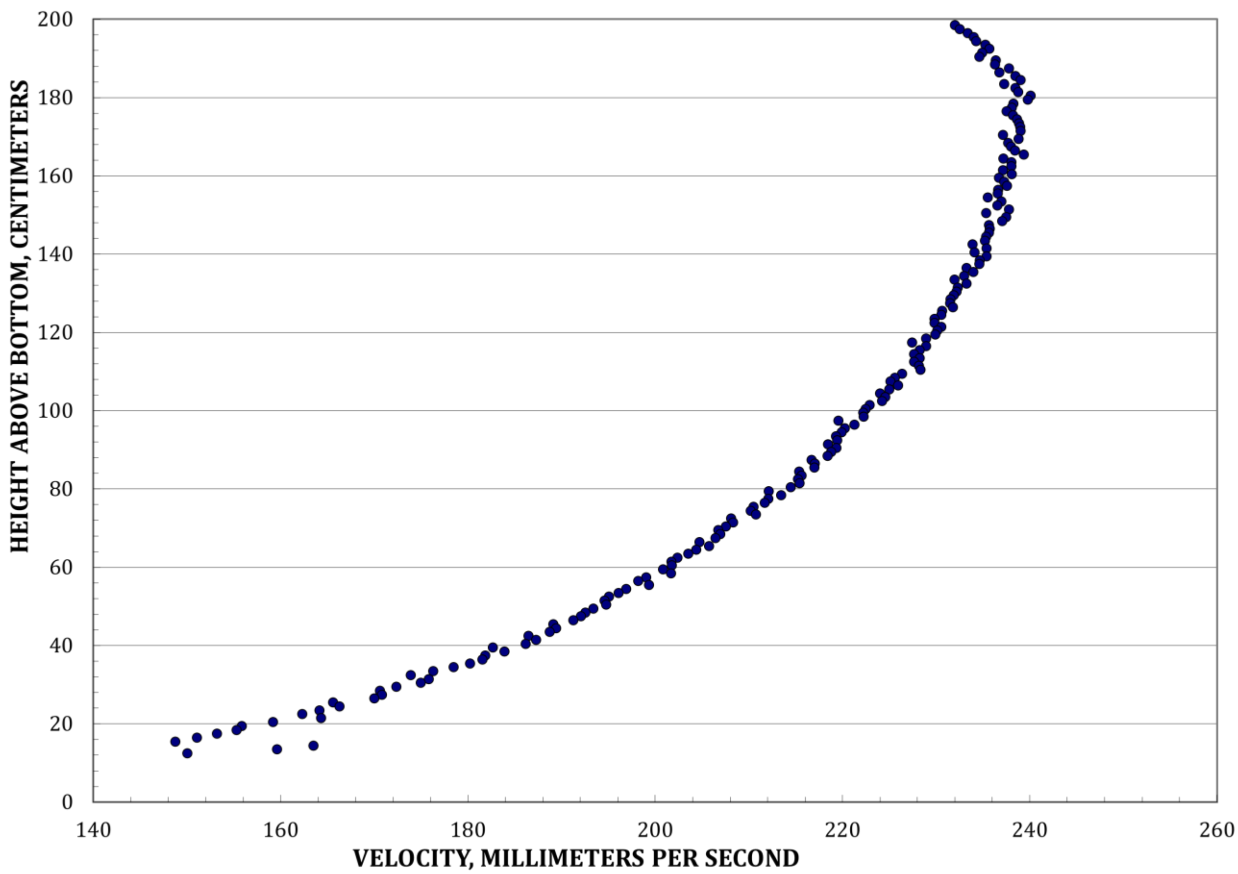

Figure 5.41 Velocity profile at a cross section along Lower Fox River, Wisconsin.

What is the average depth integrated velocity at this cross-section?

Exercise 5.2. Table 5.15 gives the measurements obtained by the USGS at Red Creek near Leesburg, Virginia (Station 01994650) on October 31, 2010. Determine the total discharge, assuming a Price AA Current Meter was used.

Table 5.15 *Measurements of flow velocity for discharge calculation at Red Creek, Virgina, USA*

Distance from Initial Point	Width (ft)	Depth (ft)	Depth of current meter as fraction of total depth from top	Number of revolutions	Time (second)
1	1.5	0			
4	3	0.95	0.6	5	40
7	3	1.4	0.6	7	43
10	3	2	0.6	7	52
13	3	2.1	0.6	7	40
16	3	2.3	0.6	10	55
19	3	2.25	0.6	10	53
22	3	2.21	0.6	10	48
24	2	2.52	0.2	15	50
			0.8	10	50
26	2	2.81	0.2	15	45
			0.8	10	48
28	2	3.01	0.2	15	43
			0.8	10	46
30	2	2.95	0.2	20	52
			0.8	10	40
32	2	3.11	0.2	20	48
			0.8	10	46
34	2	3.21	0.2	20	52
			0.8	15	55
36	2	3.03	0.2	20	48
			0.8	10	46
38	2	3.11	0.2	15	42
			0.8	10	46
40	2	2.82	0.2	15	48
			0.8	10	50
42	2	2.54	0.2	15	52
			0.8	7	40
44	2	2.2	0.6	10	45
47	3	2.05	0.6	10	49
50	3	2.22	0.6	10	50
53	3	2.14	0.6	10	53
56	3	2.23	0.6	10	55
59	3	2.04	0.6	7	40

Distance from Initial Point	Width (ft)	Depth (ft)	Depth of current meter as fraction of total depth from top	Number of revolutions	Time (second)
62	3	1.43	0.6	7	45
65	3	1.07	0.6	10	56
68	3	0.62	0.6	5	40
71	3	0			

Exercise 5.3. A set of older measurements of stage-discharge from Ohio River at Owensboro, Kentucky, is given in Table 5.16. Determine the rating constants for the river at this location. Filter the data, if necessary.

Table 5.16 *Stage-discharge measurements on Ohio River at Owensboro, Kentucky, USA*

Date & Time	Stream flow (ft3/s)	Gage Height (ft)	Meas. Rated	Date & Time	Stream flow (ft3/s)	Gage Height (ft)	Meas. Rated
3/11/1955 9:35	563000	45.36	Good	3/28/1945 10:45	397000	38.48	Good
3/9/1955 9:00	531000	44.85	Good	3/24/1945 9:10	338000	36.75	Good
3/7/1955 8:15	529000	44.29	Good	3/22/1945 11:00	385000	39	Good
3/5/1955 9:15	499000	43.05	Good	3/19/1945 10:15	479000	42.88	Good
3/3/1955 9:40	492000	41.27	Good	3/18/1945 12:10	549000	44.86	Fair
1/4/1955 9:15	296000	28.95	Good	3/17/1945 10:10	623000	46.57	Good
5/6/1954 11:15	157000	19.5	Good	3/16/1945 9:45	676000	47.58	Good
4/21/1954 10:40	188000	22.06	Good	3/15/1945 9:30	702000	48.34	Good
3/10/1954 9:10	2.33	25.15	Good	3/14/1945 9:45	754000	48.98	Good
1/25/1954 10:00	118000		Good	3/13/1945 9:30	806000	49.44	Good
6/9/1953 9:20	133000	17.52	Good	3/12/1945 9:30	813000	49.72	Good
5/22/1953 9:00	222000	26.19	Good	3/11/1945 12:20	859000	49.82	Fair
4/24/1953 9:00	186000	22.38	Good	3/8/1945 10:30	812000	49.16	Fair
3/11/1953 9:05	247000	29.75	Good	3/5/1945 10:45	688000	46.36	Fair
2/12/1953 11:10	89900	14.2	Good	1/12/1945 12:00	215000	26.9	Fair
1/14/1953 9:35	249000	26.96	Good	1/10/1945 13:00	284000	31.93	Good

Date & Time	Stream flow (ft3/s)	Gage Height (ft)	Meas. Rated	Date & Time	Stream flow (ft3/s)	Gage Height (ft)	Meas. Rated
12/16/1952 10:15	119000	18.6	Good	1/6/1945 14:00	400000	38.95	Fair
6/20/1952 10:00	28900	18.79	Good	1/4/1945 11:00	365000	34.84	Good
5/22/1952 10:50	153000	19.42	Good	9/18/1944 11:45	10500	19.2	Good
4/29/1952 8:30	177000	20.89	Good	8/4/1944 9:50	10000	18.5	Poor
3/18/1952 8:50	335000	34.1	Good	7/15/1944 12:00	8600	19	Good
2/4/1952 8:15	519000	43.94	Good	3/26/1944 11:00	420000	38.36	Good
1/11/1952 9:10	424000	40	Good	3/16/1944 10:30	225000	26.68	Good
1/9/1952 10:00	495000	40.54	Good	3/13/1944 10:00	317000	33.52	Fair
11/15/1951 9:55	75900	18.33	Good	2/25/1944 10:30	156000	20.47	Poor
10/26/1951 10:10	8000	18.49	Good	2/3/1944 10:00	80400	13.6	Good
9/12/1951 9:50	11500	18.83	Good	1/8/1944 9:30	114000	15.48	Poor
8/8/1951 13:30	16600	18.86	Good	10/22/1943 12:40	13000	19.6	Fair
7/12/1951 9:00	37300	18.67	Good	8/24/1943 10:40	18900	19.3	Fair
6/21/1951 10:40	179000	21.53	Good	4/5/1943 10:00	141000	21.55	Good
5/11/1951 10:40	186000	22.04	Fair	4/4/1943 9:30	158000	24.48	Good
4/12/1951 11:15	265000	29.89	Poor	4/3/1943 11:05	182000	27.51	Good
3/16/1951 10:30	274000	30.96	Good	3/31/1943 9:50	334000	37.72	Good
2/14/1951 12:00	379000	36.21	Poor	3/30/1943 9:50	433000	40.94	Good
1/19/1951 10:30	469000	40.52	Good	3/29/1943 9:45	501000	43.19	Good
1/17/1951 10:40	429000	38.95	Good	3/25/1943 9:35	662000	46.28	Good
1/16/1951 10:50	406000	37.64	Good	3/23/1943 9:30	661000	45.96	Good
12/13/1950 10:00	510000	43.1	Good	3/21/1943 10:40	615000	44.51	Good
12/11/1950 10:00	519000	42.37	Good	3/20/1943 9:35	549000	43.04	Good
11/30/1950 10:00	165000	20.59	Good	3/12/1943 10:30	244000	25.94	Good
11/1/1950 11:10	26600	19.02	Good	2/8/1943 11:05	251000	28.07	Good

Date & Time	Stream flow (ft3/s)	Gage Height (ft)	Meas. Rated	Date & Time	Stream flow (ft3/s)	Gage Height (ft)	Meas. Rated
9/28/1950 9:15	223000	24.96	Good	2/4/1943 11:05	256000	27.12	Good
9/13/1950 14:00	54900	18.42	Good	1/29/1943 11:30	162000	20.48	Good
8/16/1950 10:55	21100	19.05	Good	1/18/1943 10:05	135000	18.48	Good
7/19/1950 11:20	55100	17.95	Good	1/17/1943 11:00	157000	21.39	Fair
6/12/1950 13:30	162000	20.63	Good	1/16/1943 8:40	190000	25.27	Good
5/23/1950 11:10	149000	20.02	Good	1/14/1943 11:45	265000	33.12	Fair
4/6/1950 12:30	426000	39.03	Good	1/12/1943 9:30	409000	40.58	Poor
4/4/1950 10:40	381000	36.2	Good	1/11/1943 8:30	487000	42.45	Good
3/7/1950 10:20	136000	19.51	Good	1/8/1943 8:15	597000	44.9	Poor
2/9/1950 8:55	548000	45.85	Good	1/6/1943 10:30	599000	44.58	Good
2/7/1950 9:00	535000	45.29	Good	1/5/1943 9:00	567000	43.79	Good
1/18/1950 9:25	507000	45.36	Good	1/4/1943 9:00	542000	42.7	Good
1/16/1950 9:45	513000	45.43	Good	1/3/1943 8:45	506000	40.98	Poor
1/12/1950 12:00	526000	44.05	Good	6/7/1942 10:45	53400	18.55	Fair
12/14/1949 10:00	152000	18.85	Good	5/20/1942 10:15	96800	18.5	Fair
12/1/1949 9:15	72800	18.12	Good	5/18/1942 9:05	84800	18.8	Fair
10/25/1949 9:50	12300	18.88	Good	5/14/1942 12:25	26.9	18.7	Fair
10/13/1949 9:10	17800	19.26	Good	4/17/1942 9:50	317000	33.76	Good
9/22/1949 10:45	12900	18.28	Good	4/15/1942 15:00	319000	35.43	Good
8/17/1949 12:30	63400	18.98	Good	4/14/1942 13:10	308000	32.86	Good
7/12/1949 11:20	49400	18.2	Good	4/12/1942 9:30	305000	31.57	Good
6/7/1949 13:00	36000	19.22	Good	4/7/1942 8:50	108000	15.2	Good
5/3/1949 10:10	152000	19.62	Good	4/6/1942 9:00	109000	15.96	Good
4/6/1949 9:35	173000	22.63	Good	3/27/1942 11:15	259000	30.48	Fair
3/22/1949 9:30	198000	23.18	Good	3/23/1942 10:00	383000	37.72	Poor

Date & Time	Stream flow (ft3/s)	Gage Height (ft)	Meas. Rated	Date & Time	Stream flow (ft3/s)	Gage Height (ft)	Meas. Rated
2/24/1949 9:15	401000	38.86	Good	3/18/1942 9:15	403000	37.69	Poor
2/4/1949 9:45	465000	41.86	Good	3/16/1942 13:20	390000	35.64	Poor
1/14/1949 11:00	286000	31.58	Good	3/6/1942 14:20	48200	18.1	Fair
1/12/1949 12:30	345000	34.51	Good	2/17/1942 9:20	148000	19.58	Good
12/31/1948 9:20	118000	17.6	Good	2/10/1942 10:35	192000	22.51	Good
12/24/1948 9:20	380000	36.68	Fair	1/14/1942 12:40	45600	16.4	Good
11/18/1948 9:00	32800	18.81	Good	12/31/1941 11:45	100000	14.8	Good
10/26/1948 12:05	14100	18.74	Good	12/4/1941 13:45	16000	18.6	Fair
9/16/1948 10:25	7670	18.84	Good	11/8/1941 11:00	48200	18.6	Good
8/3/1948 10:45	42900	18.06	Good	9/24/1941 12:15	12000	9	Poor
6/22/1948 10:20	61300	18.54	Fair	8/15/1941 15:40	8050	9.4	Good
4/26/1948 11:10	475000	41.9	Good	7/23/1941 9:45	99100	14.74	Good
4/23/1948 9:00	664000	46.43	Poor	7/15/1941 10:05	93300	15.08	Good
4/21/1948 9:30	693000	47.08	Good	7/13/1941 6:10	127000	17.74	Good
4/19/1948 9:15	696000	46.6	Good	7/11/1941 8:20	118000	16.54	Good
4/17/1948 8:30	662000	45.35	Good	7/9/1941 17:05	98600	14.57	Good
4/15/1948 11:05	573000	43.25	Good	6/25/1941 11:30	27100	9.6	Fair
4/1/1948 9:05	503000	41.85	Good	6/24/1941 12:00	77100	14.7	Fair
3/10/1948 12:25	207000	25.53	Good	6/24/1941 11:10	73800	14.4	Fair
2/20/1948 10:10	559000	42.47	Good	6/23/1941 10:00	105000	15.21	Good
2/18/1948 9:45	487000	39.81	Good	6/21/1941 9:10	111000	15.79	Good
2/11/1948 9:15	55000		Poor	6/20/1941 9:35	116000	16.2	Fair
2/3/1948 13:00	12500	10	Poor	6/19/1941 12:10	119000	16.2	Poor
1/6/1948 11:45	177000	20.34	Fair	6/17/1941 13:30	104000	15.02	Good
12/4/1947 9:55	24100	10.6	Good	6/14/1941 14:25	175000	22.68	Poor

Date & Time	Stream flow (ft3/s)	Gage Height (ft)	Meas. Rated	Date & Time	Stream flow (ft3/s)	Gage Height (ft)	Meas. Rated
10/24/1947 9:00	13800	9.1	Good	6/13/1941 11:30	230000	26.49	Poor
9/6/1947 12:30	41800	11.1	Good	6/12/1941 14:15	258000	28.06	Fair
8/6/1947 12:00	57900	12.3	Good	6/11/1941 12:05	266000	27.33	Poor
6/24/1947 10:05	114000	15.72	Good	6/10/1941 10:55	227000	24.61	Poor
5/7/1947 11:15	225000	25.95	Good	6/9/1941 11:00	183000	21.28	Poor
3/21/1947 13:25	203000	23.72	Fair	6/8/1941 11:50	136000	17.56	Fair
1/8/1947 9:05	282000	30.08	Good	6/7/1941 9:50	98500	14.49	Poor
10/18/1946 9:45	25600	10.6	Good	6/6/1941 17:00	97300	14.58	Fair
9/24/1946 13:25	22800	9.6	Good	6/5/1941 12:00	109000	15.51	Fair
9/10/1946 12:10	13000	9.5	Good	5/14/1941 10:25	20400	18.95	Poor
8/9/1946 15:30	41800	10.8	Good	4/13/1941 11:20	196000	23.08	Good
7/16/1946 10:55	45400	11.7	Good	4/12/1941 11:50	194000	22.86	Good
6/7/1946 8:35	327000	33.01	Good	3/23/1941 6:10	92400	14.65	Fair
4/26/1946 8:30	47300	19.2	Good	3/22/1941 14:15	107000	15.4	Fair
3/29/1946 9:25	253000	28.46	Good	3/20/1941 11:00	130000	17.72	Fair
3/20/1946 12:45	241000	26.64	Good	3/19/1941 10:00	151000	19.36	Good
2/28/1946 8:30	148000	20.24	Good	3/18/1941 9:30	167000	21.01	Good
2/21/1946 9:20	273000	31.98	Good	3/15/1941 8:30	154000	18.94	Poor
2/19/1946 9:30	322000	34.72	Poor	3/14/1941 8:30	134000	17.43	Fair
2/6/1946 9:55	129000	17.44	Poor	3/6/1941 11:30	55200	18.34	Poor
11/27/1945 10:20	214000	24.29	Poor	1/7/1941 12:15	194000	22.71	Poor
11/7/1945 9:20	67000	19	Fair	12/20/1940 11:30	118000	16.23	Good
10/3/1945 11:00	147000	19.3	Good	12/12/1940 10:50	60000	18.68	Fair
9/12/1945 9:05	26100	19.22	Good	12/7/1940 13:15	52400	17.8	Poor
8/21/1945 10:50	28400	19.08	Good	11/29/1940 13:15	67100	18.49	Fair

Date & Time	Stream flow (ft3/s)	Gage Height (ft)	Meas. Rated	Date & Time	Stream flow (ft3/s)	Gage Height (ft)	Meas. Rated
4/12/1945 12:30	245000	28.08	Fair	11/9/1940 9:50	35500	18.94	Fair
3/30/1945 12:00	397000	38.64	Good	10/29/1940 12:15	7300	18.62	Fair
				10/5/1940 10:00	10000	18.71	Good

Exercise 5.4. The Markland Locks and Dam is located on the Ohio River, 3.5 miles downstream from Warsaw, Kentucky. The navigation locks are located on the Kentucky side of the river. Table 5.17 gives the stage-discharge data at the dam (USGS Gauge 03277200). Determine the rating curve for this site.

Table 5.17 *Stage-discharge data of Ohio River at Markland dam, Kentucky, USA*

Date and Time	Stream flow (ft^3/s)	Gage Height (ft)	Meas. Rated	Date and Time	Stream flow (ft^3/s)	Gage Height (ft)	Meas. Rated
2021-09-09 12:44:20	46600	15.38	Poor	1971-07-15 13:20	35300		Good
2021-08-18 11:18:35	54300	15.84	Poor	1971-06-11 12:40	54000		Good
2021-08-04 11:21	24500	13.59	Fair	1971-05-07 14:10	159000	25.25	Fair
2021-06-16 11:18:52	135000	23.66	Good	1971-05-06 16:25	82800	17.86	Good
2020-11-09 10:18:12	30700	13.68	Fair	1971-05-06 11:00	62200	16.73	Fair
2020-10-22 11:10:15	27500	13.59	Poor	1971-03-31 11:15	96600	19.84	Poor
2020-10-15 11:43:45	32400	14.21	Fair	1971-02-18 11:05	222000	32.16	Good
2020-09-23 11:49:16	22400	13.44	Poor	1971-01-14 11:20	124000		Fair
2020-09-10 12:54:04	49600	15.63	Fair	1970-11-13 11:00	104000	20.32	Good
2020-08-26 11:37:17	34300	14.11	Poor	1970-11-12 15:00	95900		Good
2020-08-05 14:35:37	37700	14.52	Poor	1970-10-08 10:10	30700	13.6	Fair
2020-07-22 10:36:23	34700	14.45	Poor	1970-10-07 14:00	27500	12.91	Poor
2020-03-10 13:03:57	158000	25.69	Good	1970-10-07 10:55	21200	12.4	Fair
2019-12-04 13:30	151000	27.12	Good	1970-10-06 16:00	12400	10.37	Fair
2019-08-01 11:53:29	49300	15.42	Fair	1970-10-06 12:00	15300	12.19	Fair
2018-08-15 12:55:32	33000	13.96	Fair	1970-09-10 21:50	25200	13.11	Poor

Date and Time	Stream flow (ft³/s)	Gage Height (ft)	Meas. Rated	Date and Time	Stream flow (ft³/s)	Gage Height (ft)	Meas. Rated
2018-02-26 11:18:39	621000	56.7	Fair	1970-09-10 00:55	39900	12	Poor
2018-02-21 17:24:12	530000	49.37	Fair	1970-09-09 12:30	21800	12.22	Fair
2017-10-23 15:53:51	22000	13.72	Good	1970-09-01 14:00	17400	12.21	Good
2016-03-16 13:25:15	254000	32.5	Fair	1970-07-30 11:20	25100	13.12	Good
2015-03-09 14:17:13	476000	48.33	Good	1970-07-08 11:30	33000	13.74	Good
2011-04-28 12:12	501000	51.01	Good	1970-06-03 11:00	34300	13.68	Fair
2011-03-02 13:29	421000	43.43	Good	1970-05-06 10:50	116000	22.9	Fair
2010-10-21 14:15	16500	13.32	Fair	1970-03-20 10:10	123000	24.05	Poor
2010-03-17 16:23	460000	44.24	Good	1970-02-18 12:20	285000	38.85	Fair
2007-09-26 14:27	14300	13.18	Fair	1970-01-12 13:45	30000	13.55	Good
2006-08-30 12:45	39400	14.64	Fair	1969-11-25 13:40	58000	16.72	Fair
2005-10-06 12:19	14400	12.68	Fair	1969-10-24 10:50	14500	12.3	Good
2005-01-10 13:51	513000	50.81	Good	1969-08-28 10:30	28800		Good
2004-09-22 14:55	446000	43.98	Good	1969-07-25 10:35	77300		Fair
2004-06-04 12:26	251000	37.01	Excellent	1969-06-30 10:50	42700	15.03	Fair
2003-02-27 13:45	450000	44.9	Fair	1969-05-15 11:45	153000	25.5	Good
2002-03-25 14:03	305000	40.32	Good	1969-04-16 10:40	124000	23.18	Fair
2000-06-16 12:25	50900	15.2	Good	1969-03-13 11:15	51300	16.08	Poor
1997-03-06 12:00	580000	60.67	Fair	1969-02-13 10:40	184000	28.83	Good
1991-09-19 11:20	19900	12.91	Good	1969-01-10 12:20	66200	16.84	Poor
1988-01-29 12:00	55000	16.16	Fair	1968-11-15 11:30	38800	13.92	Good
1985-08-06 -- --	3460	12.19	Poor	1968-10-17 11:50	15200	12.51	Fair
1984-10-17 -- --	14800		Fair	1968-09-11 12:40	12200	12.32	Good
1984-10-16 -- --	24700		Poor	1968-08-01 14:20	35000	12.55	Fair
1984-06-28 -- --	62700	16.85	Fair	1968-06-27 12:30	57000	15.67	Poor

Date and Time	Stream flow (ft³/s)	Gage Height (ft)	Meas. Rated	Date and Time	Stream flow (ft³/s)	Gage Height (ft)	Meas. Rated
1981-07-27 17:10	33500	13.66	Fair	1968-05-14 11:35	130000	22.66	Good
1980-08-19 14:45	203000	26.41	Good	1968-03-29 09:25	245000	33.46	Fair
1980-04-17 11:40	347000	38.57	Good	1968-02-07 12:45	272000	35.38	Poor
1979-07-31 11:40	153000	22.57	Fair	1968-01-05 12:25	68800	17.43	Good
1979-05-10 12:30	95100	20.37	Good	1967-11-28 11:30	103000	21.06	Poor
1978-12-14 10:25	477000	53.85	Good	1967-11-01 12:15	57200	12.5	Fair
1978-12-13 15:35	518000	55.23	Fair	1967-10-11 08:10	34100	12.4	Fair
1978-12-13 11:00	535000	55.29	Fair	1967-09-06 12:20	22800	12.54	Good
1978-12-07 13:55	306000	38.4	Fair	1967-07-27 15:00	33500	13.5	Fair
1978-11-07 11:05	27700	13.13	Fair	1967-06-14 12:15	19600	12.53	Good
1978-11-06 17:45	28700	13.48	Poor	1967-04-20 11:15	124000	22.71	Good
1978-06-27 13:15	63100	15.68	Fair	1967-02-08 11:05	145000	12.25	Good
1978-03-19 13:45	505000	49.36	Good	1967-01-06 11:30	63400	17.01	Fair
1977-09-07 20:00	53200	14.95	Fair	1966-12-02 10:00	96000	12.45	Good
1977-05-11 11:20	127000	23.23	Fair	1966-10-20 12:30	13000	12.45	Fair
1977-04-11 13:20	360000	40.21	Good	1966-08-30 13:10	12400	12.25	Fair
1977-03-24 10:50	180000	28.77	Fair	1966-08-04 13:05	12600	12.3	Good
1977-03-10 11:25	125000	28.45	Fair	1966-07-13 13:10	30600	12.72	Fair
1976-12-14 12:40	106000	20.52	Fair	1966-06-16 13:35	19400	12.3	Fair
1976-05-11 11:10	35000	13.52	Poor	1966-05-17 11:30	145000	24.34	Good
1976-03-23 11:00	294000	34.33	Fair	1966-04-15 10:40	212000	11.97	Good
1976-02-22 11:10	448000	45.4	Fair	1966-03-29 11:00	78200	12.34	Fair
1975-07-31 00:55	12800	12.08	Fair	1966-03-03 10:45	147000	12.1	Good
1975-07-30 21:05	13200	11.96	Fair	1966-02-24 11:20	191000	11.67	Good
1975-06-10 12:45	129000	23.17	Good	1965-12-15 11:35	48100	12.7	Fair

Date and Time	Stream flow (ft^3/s)	Gage Height (ft)	Meas. Rated	Date and Time	Stream flow (ft^3/s)	Gage Height (ft)	Meas. Rated
1975-04-15 11:00	69500	17.56	Fair	1965-12-07 11:15	38400	12.3	Fair
1975-02-27 10:35	459000	44.48	Good	1965-10-26 12:50	49500	12.47	Fair
1974-12-20 11:05	197000	28.48	Good	1965-09-23 14:30	18300	12.31	Unspecified
1974-10-31 10:15	32100	13.68	Fair	1965-09-23 14:30	17900	12.31	Unspecified
1974-09-10 10:50	76400	18.17	Poor	1965-08-25 14:50	9730	12.5	Poor
1974-06-20 08:50	60900	16.06	Fair	1965-08-10 14:10	11600	12.5	Good
1974-03-17 09:15	293000	38.04	Poor	1965-08-10 14:10	11200	12.5	Fair
1973-12-14 12:40	71700	17.32	Fair	1965-06-17 13:30	17800	12.64	Fair
1973-08-29 20:30	16600	12.22	Good	1965-06-17 13:30	17100	12.64	Fair
1973-08-29 19:15	17000	12.12	Good	1965-05-11 12:30	71300	12.18	Poor
1973-07-19 21:25	35900	13.72	Fair	1965-03-08 12:00	237000	11.68	Fair
1973-05-03 10:10	395000	43.08	Fair	1965-01-15 11:05	232000	12.18	Fair
1973-05-02 13:30	427000	45.14	Fair	1964-12-15 10:30	18000	12.5	Fair
1973-03-23 08:40	341000	41.08	Poor	1964-12-09 10:15	85100	19.7	Fair
1973-03-22 14:30	358000	42.7	Fair	1964-11-10 12:10	12700	12.22	Poor
1973-03-22 10:15	373000	43.08	Fair	1964-10-18 12:30	9500	12	Fair
1973-02-27 10:35	80400	18.05	Fair	1964-09-17 -- --	5560		Fair
1972-12-15 10:25	444000	48.79	Fair	1964-08-18 12:55	8500	11.86	Poor
1972-11-29 12:35	166000	26.84	Poor	1964-07-23 12:10	22900	12.6	Good
1972-10-25 14:10	35300	13.73	Fair	1964-06-11 12:50	39300	13.91	Fair
1972-09-13 14:15	16000	12.38	Fair	1964-05-07 12:25	143000		Fair
1972-09-13 09:10	15700	12.31	Fair	1964-02-27 10:50	55000		Good
1972-09-08 13:45	16300	12.25	Fair	1964-01-07 11:50	42600		Good
1972-09-08 09:45	15400	12.18	Fair	1963-11-20 11:10	16400		Poor
1972-09-06 14:00	19200	12.3	Fair	1963-10-28 11:10	5860		Poor

Date and Time	Stream flow (ft³/s)	Gage Height (ft)	Meas. Rated	Date and Time	Stream flow (ft³/s)	Gage Height (ft)	Meas. Rated
1972-08-11 11:00	34700	13.5	Poor	1963-10-24 -- --	8150		Poor
1972-07-07 11:20	194000	27.37	Fair	1963-10-15 11:55	5500		Good
1972-05-18 10:45	161000	27.29	Poor	1963-09-27 11:00	7790		Good
1972-04-18 12:50	448000	49.61	Fair	1963-09-13 11:00	27400		Fair
1972-04-12 10:30	267000	36.05	Poor	1963-08-16 12:15	13800	12.56	Poor
1972-03-03 10:00	345000	42.16	Fair	1963-07-17 12:10	16300		Poor
1972-03-02 09:45	348000	45.09	Fair	1963-06-26 12:20	33600		Good
1972-02-17 11:30	227000	34.2	Good	1963-05-29 12:10	34900	13.42	Fair
1972-01-07 14:00	272000	35.41	Fair	1963-05-27 12:45	43100	14.52	Poor
1971-12-14 10:10	128000	24.47	Good	1963-05-14 12:55	88100	18.85	Good
1971-11-23 12:30	24900	13.09	Fair	1963-04-22 12:40	89200		Fair
1971-10-21 11:05	28100		Poor	1963-04-15 11:50	60500		Fair
1971-09-29 13:05	68200		Unspecified	1963-04-10 10:30	119000		Good
1971-08-20 10:50	17100	12.25	Good	1963-02-14 10:35	94300		Poor
1971-08-19 11:45	14500		Unspecified	1963-01-18 13:00	162000	22.71	Poor
				1963-01-18 10:00	160000	22.9	Poor
				1963-01-16 12:05	215000	22.95	Poor

Exercise 5.5. Mekong River is an important transboundary river in Indochina. Table 5.18 lists the daily flow of Mekong River at Ban Chan Noi station in Laos for a four-year period. The data are from GRDC[2].

(*continued the next page*)

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[2] The Global Runoff Data Centre is an international data centre operating under the auspices of the World Meteorological Organization (WMO). The Global Runoff Database (GRDB) is operated by GRDC at the German Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde – BfG) in Koblenz, Germany. Several sets of data used in the book (e.g. those in Chapter 5 are obtained from GRDB.

Do the following.

(a) Construct a seasonal hydrograph after defining a water year that can be deduced from these data.
(b) Calculate MQ, LQ, HQ, MLQ, and MHQ for this POR.
(c) For the four-year period, what was the flow for 90% of the time, 50% of the time, and 10% of the time?
(d) Answer the questions of (c) for the driest year.

Table 5.18 *Daily flow of Mekong River at Ban Chan Noi station in Laos*

Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)
2/11/1960	2380	5/1/1961	1860	7/20/1962	24500	10/10/1963	18300
2/12/1960	2430	5/2/1961	1820	7/21/1962	22700	10/11/1963	17300
2/13/1960	2530	5/3/1961	1800	7/22/1962	22100	10/12/1963	16300
2/14/1960	2450	5/4/1961	1780	7/23/1962	22200	10/13/1963	15400
2/15/1960	2380	5/5/1961	2000	7/24/1962	21700	10/14/1963	14600
2/16/1960	2170	5/6/1961	2020	7/25/1962	22200	10/15/1963	13900
2/17/1960	2070	5/7/1961	2020	7/26/1962	23500	10/16/1963	13400
2/18/1960	1970	5/8/1961	2020	7/27/1962	23100	10/17/1963	12600
2/19/1960	1790	5/9/1961	2000	7/28/1962	21900	10/18/1963	12300
2/20/1960	1860	5/10/1961	1950	7/29/1962	20600	10/19/1963	13800
2/21/1960	1810	5/11/1961	1950	7/30/1962	19700	10/20/1963	11700
2/22/1960	1760	5/12/1961	2000	7/31/1962	21200	10/21/1963	11400
2/23/1960	1760	5/13/1961	2020	8/1/1962	22900	10/22/1963	13600
2/24/1960	1720	5/14/1961	2070	8/2/1962	22900	10/23/1963	11400
2/25/1960	1700	5/15/1961	2090	8/3/1962	22300	10/24/1963	11100
2/26/1960	1680	5/16/1961	2270	8/4/1962	23300	10/25/1963	10700
2/27/1960	1660	5/17/1961	2300	8/5/1962	29500	10/26/1963	10200
2/28/1960	1640	5/18/1961	2270	8/6/1962	34400	10/27/1963	9850
2/29/1960	1640	5/19/1961	2240	8/7/1962	36100	10/28/1963	9530
3/1/1960	1620	5/20/1961	2300	8/8/1962	36100	10/29/1963	9180
3/2/1960	1660	5/21/1961	2480	8/9/1962	35100	10/30/1963	8850
3/3/1960	1660	5/22/1961	2890	8/10/1962	34200	10/31/1963	8730
3/4/1960	1640	5/23/1961	3160	8/11/1962	34100	11/1/1963	8760
3/5/1960	1660	5/24/1961	3720	8/12/1962	33200	11/2/1963	8420
3/6/1960	1680	5/25/1961	3810	8/13/1962	32200	11/3/1963	8530
3/7/1960	1700	5/26/1961	3980	8/14/1962	31300	11/4/1963	9850
3/8/1960	1720	5/27/1961	4300	8/15/1962	30200	11/5/1963	12800
3/9/1960	1700	5/28/1961	4270	8/16/1962	29200	11/6/1963	14300
3/10/1960	1700	5/29/1961	4010	8/17/1962	28200	11/7/1963	14600
3/11/1960	1680	5/30/1961	4070	8/18/1962	27000	11/8/1963	14400
3/12/1960	1660	5/31/1961	4300	8/19/1962	26100	11/9/1963	13800
3/13/1960	1640	6/1/1961	4300	8/20/1962	25900	11/10/1963	13200
3/14/1960	1620	6/2/1961	4450	8/21/1962	25900	11/11/1963	12700
3/15/1960	1600	6/3/1961	4750	8/22/1962	26400	11/12/1963	12200
3/16/1960	1580	6/4/1961	4790	8/23/1962	26100	11/13/1963	13400
3/17/1960	1540	6/5/1961	5340	8/24/1962	26600	11/14/1963	13500
3/18/1960	1510	6/6/1961	7090	8/25/1962	27000	11/15/1963	12500
3/19/1960	1510	6/7/1961	8050	8/26/1962	26400	11/16/1963	13100
3/20/1960	1510	6/8/1961	8700	8/27/1962	26000	11/17/1963	13200
3/21/1960	1490	6/9/1961	11500	8/28/1962	25900	11/18/1963	13000
3/22/1960	1470	6/10/1961	13100	8/29/1962	25900	11/19/1963	12600

Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)
3/23/1960	1440	6/11/1961	13800	8/30/1962	25900	11/20/1963	12200
3/24/1960	1440	6/12/1961	13900	8/31/1962	25100	11/21/1963	11700
3/25/1960	1420	6/13/1961	13800	9/1/1962	24500	11/22/1963	11400
3/26/1960	1400	6/14/1961	13600	9/2/1962	25000	11/23/1963	11100
3/27/1960	1390	6/15/1961	14600	9/3/1962	24500	11/24/1963	10800
3/28/1960	1370	6/16/1961	16500	9/4/1962	23600	11/25/1963	10300
3/29/1960	1370	6/17/1961	17300	9/5/1962	24900	11/26/1963	10000
3/30/1960	1360	6/18/1961	17800	9/6/1962	31300	11/27/1963	9530
3/31/1960	1310	6/19/1961	17000	9/7/1962	33200	11/28/1963	9140
4/1/1960	1280	6/20/1961	15500	9/8/1962	32900	11/29/1963	8820
4/2/1960	1270	6/21/1961	14800	9/9/1962	31500	11/30/1963	8530
4/3/1960	1220	6/22/1961	14400	9/10/1962	30300	12/1/1963	8230
4/4/1960	1210	6/23/1961	14100	9/11/1962	28800	12/2/1963	7990
4/5/1960	1180	6/24/1961	13200	9/12/1962	26100	12/3/1963	7780
4/6/1960	1160	6/25/1961	12200	9/13/1962	23600	12/4/1963	7630
4/7/1960	1140	6/26/1961	15800	9/14/1962	22900	12/5/1963	7410
4/8/1960	1120	6/27/1961	20000	9/15/1962	22700	12/6/1963	7180
4/9/1960	1110	6/28/1961	19200	9/16/1962	21200	12/7/1963	7660
4/10/1960	1100	6/29/1961	18900	9/17/1962	23000	12/8/1963	6930
4/11/1960	1090	6/30/1961	24100	9/18/1962	28200	12/9/1963	6740
4/12/1960	1090	7/1/1961	24700	9/19/1962	30500	12/10/1963	6520
4/13/1960	1080	7/2/1961	25100	9/20/1962	31000	12/11/1963	6300
4/14/1960	1090	7/3/1961	24500	9/21/1962	30300	12/12/1963	6020
4/15/1960	1100	7/4/1961	21800	9/22/1962	28900	12/13/1963	5830
4/16/1960	1100	7/5/1961	20500	9/23/1962	27100	12/14/1963	5400
4/17/1960	1100	7/6/1961	18300	9/24/1962	24900	12/15/1963	5190
4/18/1960	1100	7/7/1961	18800	9/25/1962	23600	12/16/1963	4970
4/19/1960	1090	7/8/1961	18900	9/26/1962	23100	12/17/1963	4880
4/20/1960	1090	7/9/1961	18500	9/27/1962	22100	12/18/1963	4690
4/21/1960	1090	7/10/1961	17800	9/28/1962	24500	12/19/1963	4660
4/22/1960	1090	7/11/1961	16800	9/29/1962	22500	12/20/1963	4570
4/23/1960	1090	7/12/1961	16900	9/30/1962	24500	12/21/1963	4480
4/24/1960	1090	7/13/1961	17000	10/1/1962	26100	12/22/1963	4390
4/25/1960	1090	7/14/1961	16600	10/2/1962	27900	12/23/1963	4270
4/26/1960	1100	7/15/1961	15500	10/3/1962	26400	12/24/1963	4190
4/27/1960	1100	7/16/1961	14200	10/4/1962	24900	12/25/1963	4070
4/28/1960	1150	7/17/1961	13400	10/5/1962	23600	12/26/1963	4010
4/29/1960	1150	7/18/1961	12600	10/6/1962	22300	12/27/1963	3980
4/30/1960	1150	7/19/1961	15000	10/7/1962	25100	12/28/1963	3900
5/1/1960	1120	7/20/1961	18000	10/8/1962	21100	12/29/1963	3870
5/2/1960	1120	7/21/1961	19300	10/9/1962	19900	12/30/1963	3780
5/3/1960	1100	7/22/1961	18600	10/10/1962	19000	12/31/1963	3690

Month/date/year	Discharge (m³/s)	Month/date/year	Discharge (m³/s)	Month/date/year	Discharge (m³/s)	Month/date/year	Discharge (m³/s)
5/4/1960	1090	7/23/1961	17700	10/11/1962	18500	1/1/1964	3610
5/5/1960	1080	7/24/1961	18000	10/12/1962	17900	1/2/1964	3500
5/6/1960	1080	7/25/1961	18300	10/13/1962	17700	1/3/1964	3440
5/7/1960	1080	7/26/1961	18400	10/14/1962	17500	1/4/1964	3410
5/8/1960	1080	7/27/1961	18100	10/15/1962	17300	1/5/1964	3360
5/9/1960	1090	7/28/1961	17600	10/16/1962	17100	1/6/1964	3300
5/10/1960	1150	7/29/1961	16600	10/17/1962	16700	1/7/1964	3250
5/11/1960	1170	7/30/1961	15800	10/18/1962	18700	1/8/1964	3220
5/12/1960	1200	7/31/1961	15400	10/19/1962	15800	1/9/1964	3160
5/13/1960	1210	8/1/1961	15000	10/20/1962	15100	1/10/1964	3140
5/14/1960	1210	8/2/1961	15000	10/21/1962	15100	1/11/1964	3060
5/15/1960	1210	8/3/1961	15000	10/22/1962	15200	1/12/1964	3030
5/16/1960	1180	8/4/1961	15000	10/23/1962	15500	1/13/1964	2970
5/17/1960	1160	8/5/1961	15000	10/24/1962	15600	1/14/1964	2950
5/18/1960	1150	8/6/1961	14800	10/25/1962	15100	1/15/1964	2890
5/19/1960	1150	8/7/1961	14800	10/26/1962	14600	1/16/1964	2890
5/20/1960	1170	8/8/1961	14800	10/27/1962	14000	1/17/1964	2870
5/21/1960	1240	8/9/1961	15500	10/28/1962	13400	1/18/1964	2820
5/22/1960	1440	8/10/1961	16400	10/29/1962	13000	1/19/1964	2760
5/23/1960	1510	8/11/1961	17000	10/30/1962	12600	1/20/1964	2740
5/24/1960	1510	8/12/1961	19700	10/31/1962	12100	1/21/1964	2690
5/25/1960	1510	8/13/1961	19600	11/1/1962	12000	1/22/1964	2660
5/26/1960	1520	8/14/1961	19100	11/2/1962	11700	1/23/1964	2610
5/27/1960	1640	8/15/1961	20700	11/3/1962	11300	1/24/1964	2610
5/28/1960	1700	8/16/1961	25200	11/4/1962	11000	1/25/1964	2580
5/29/1960	1720	8/17/1961	28500	11/5/1962	10600	1/26/1964	2560
5/30/1960	1790	8/18/1961	29900	11/6/1962	10200	1/27/1964	2560
5/31/1960	1880	8/19/1961	30800	11/7/1962	9900	1/28/1964	2530
6/1/1960	2020	8/20/1961	31600	11/8/1962	9630	1/29/1964	2530
6/2/1960	2170	8/21/1961	35300	11/9/1962	9320	1/30/1964	2530
6/3/1960	2430	8/22/1961	37600	11/10/1962	9140	1/31/1964	-999
6/4/1960	2910	8/23/1961	38900	11/11/1962	8970	2/1/1964	2500
6/5/1960	3880	8/24/1961	40200	11/12/1962	8700	2/2/1964	2500
6/6/1960	4180	8/25/1961	41400	11/13/1962	8400	2/3/1964	2480
6/7/1960	4400	8/26/1961	42400	11/14/1962	8350	2/4/1964	2480
6/8/1960	4760	8/27/1961	41700	11/15/1962	8290	2/5/1964	2450
6/9/1960	4870	8/28/1961	40100	11/16/1962	8170	2/6/1964	2450
6/10/1960	4840	8/29/1961	37800	11/17/1962	8020	2/7/1964	2430
6/11/1960	4840	8/30/1961	35400	11/18/1962	7780	2/8/1964	2480
6/12/1960	4510	8/31/1961	33900	11/19/1962	7500	2/9/1964	2480
6/13/1960	4240	9/1/1961	33300	11/20/1962	7150	2/10/1964	2400
6/14/1960	4400	9/2/1961	34200	11/21/1962	6930	2/11/1964	2300

Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)
6/15/1960	4510	9/3/1961	35600	11/22/1962	6770	2/12/1964	2240
6/16/1960	4340	9/4/1961	35900	11/23/1962	6550	2/13/1964	2240
6/17/1960	4480	9/5/1961	35400	11/24/1962	6340	2/14/1964	2220
6/18/1960	4510	9/6/1961	34900	11/25/1962	6120	2/15/1964	2170
6/19/1960	4450	9/7/1961	34900	11/26/1962	5960	2/16/1964	2170
6/20/1960	4920	9/8/1961	34900	11/27/1962	5830	2/17/1964	2170
6/21/1960	5200	9/9/1961	35500	11/28/1962	5670	2/18/1964	2140
6/22/1960	6310	9/10/1961	36600	11/29/1962	5490	2/19/1964	2140
6/23/1960	6570	9/11/1961	37400	11/30/1962	5370	2/20/1964	2090
6/24/1960	6230	9/12/1961	37600	12/1/1962	5000	2/21/1964	2090
6/25/1960	6030	9/13/1961	38100	12/2/1962	4790	2/22/1964	2070
6/26/1960	6250	9/14/1961	40400	12/3/1962	4600	2/23/1964	2020
6/27/1960	6570	9/15/1961	42700	12/4/1962	4510	2/24/1964	2020
6/28/1960	7200	9/16/1961	43200	12/5/1962	4330	2/25/1964	2000
6/29/1960	8150	9/17/1961	42400	12/6/1962	4100	2/26/1964	2000
6/30/1960	7200	9/18/1961	41300	12/7/1962	4010	2/27/1964	1950
7/1/1960	6600	9/19/1961	40900	12/8/1962	3870	2/28/1964	1920
7/2/1960	6570	9/20/1961	40400	12/9/1962	3780	2/29/1964	1920
7/3/1960	6600	9/21/1961	40200	12/10/1962	3640	3/1/1964	1920
7/4/1960	6780	9/22/1961	39300	12/11/1962	3580	3/2/1964	1900
7/5/1960	8780	9/23/1961	38700	12/12/1962	3500	3/3/1964	1900
7/6/1960	10500	9/24/1961	38200	12/13/1962	3440	3/4/1964	1900
7/7/1960	11200	9/25/1961	40800	12/14/1962	3360	3/5/1964	1880
7/8/1960	10800	9/26/1961	44000	12/15/1962	3330	3/6/1964	1880
7/9/1960	10500	9/27/1961	45300	12/16/1962	3220	3/7/1964	1880
7/10/1960	10500	9/28/1961	45600	12/17/1962	3160	3/8/1964	1860
7/11/1960	10700	9/29/1961	44800	12/18/1962	3140	3/9/1964	1860
7/12/1960	10700	9/30/1961	44400	12/19/1962	3060	3/10/1964	1860
7/13/1960	10400	10/1/1961	44500	12/20/1962	3030	3/11/1964	1840
7/14/1960	9900	10/2/1961	44200	12/21/1962	2970	3/12/1964	1840
7/15/1960	9540	10/3/1961	43800	12/22/1962	2890	3/13/1964	1880
7/16/1960	9670	10/4/1961	43700	12/23/1962	2870	3/14/1964	1920
7/17/1960	9800	10/5/1961	43400	12/24/1962	2820	3/15/1964	1920
7/18/1960	9670	10/6/1961	42400	12/25/1962	2790	3/16/1964	1950
7/19/1960	9570	10/7/1961	40800	12/26/1962	2760	3/17/1964	1950
7/20/1960	9870	10/8/1961	38700	12/27/1962	2760	3/18/1964	1920
7/21/1960	10100	10/9/1961	36800	12/28/1962	2710	3/19/1964	1900
7/22/1960	10100	10/10/1961	34800	12/29/1962	2710	3/20/1964	1880
7/23/1960	9840	10/11/1961	32400	12/30/1962	2710	3/21/1964	1860
7/24/1960	9670	10/12/1961	30300	12/31/1962	2690	3/22/1964	1840
7/25/1960	9800	10/13/1961	28400	1/1/1963	2630	3/23/1964	1820
7/26/1960	10100	10/14/1961	27300	1/2/1963	2610	3/24/1964	1800

Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)
7/27/1960	10400	10/15/1961	25900	1/3/1963	2560	3/25/1964	1800
7/28/1960	11000	10/16/1961	24800	1/4/1963	2500	3/26/1964	1800
7/29/1960	12000	10/17/1961	24200	1/5/1963	2450	3/27/1964	1780
7/30/1960	12800	10/18/1961	23600	1/6/1963	2430	3/28/1964	1780
7/31/1960	14700	10/19/1961	22600	1/7/1963	2430	3/29/1964	1780
8/1/1960	17500	10/20/1961	21500	1/8/1963	2370	3/30/1964	1780
8/2/1960	19700	10/21/1961	25200	1/9/1963	2370	3/31/1964	1780
8/3/1960	20000	10/22/1961	24700	1/10/1963	2370	4/1/1964	1740
8/4/1960	19500	10/23/1961	23200	1/11/1963	2350	4/2/1964	1780
8/5/1960	19500	10/24/1961	22200	1/12/1963	2300	4/3/1964	1780
8/6/1960	21100	10/25/1961	21300	1/13/1963	2270	4/4/1964	1800
8/7/1960	21100	10/26/1961	20400	1/14/1963	2240	4/5/1964	1800
8/8/1960	22900	10/27/1961	19600	1/15/1963	2190	4/6/1964	1820
8/9/1960	22500	10/28/1961	18900	1/16/1963	2120	4/7/1964	1820
8/10/1960	23800	10/29/1961	18000	1/17/1963	2120	4/8/1964	1800
8/11/1960	24900	10/30/1961	16800	1/18/1963	2120	4/9/1964	1860
8/12/1960	24900	10/31/1961	15700	1/19/1963	2090	4/10/1964	1860
8/13/1960	24500	11/1/1961	14800	1/20/1963	2040	4/11/1964	1860
8/14/1960	24400	11/2/1961	14200	1/21/1963	2020	4/12/1964	1820
8/15/1960	24900	11/3/1961	13600	1/22/1963	2020	4/13/1964	1780
8/16/1960	25800	11/4/1961	13200	1/23/1963	2000	4/14/1964	1760
8/17/1960	28800	11/5/1961	12800	1/24/1963	2040	4/15/1964	1740
8/18/1960	31300	11/6/1961	12400	1/25/1963	2020	4/16/1964	1700
8/19/1960	33800	11/7/1961	12000	1/26/1963	2000	4/17/1964	1700
8/20/1960	36300	11/8/1961	11400	1/27/1963	1950	4/18/1964	1680
8/21/1960	38100	11/9/1961	11000	1/28/1963	1920	4/19/1964	1880
8/22/1960	39100	11/10/1961	10600	1/29/1963	1920	4/20/1964	1860
8/23/1960	39600	11/11/1961	10200	1/30/1963	1880	4/21/1964	1800
8/24/1960	41300	11/12/1961	9730	1/31/1963	1880	4/22/1964	1800
8/25/1960	41700	11/13/1961	9320	2/1/1963	1880	4/23/1964	1820
8/26/1960	42100	11/14/1961	8940	2/2/1963	1880	4/24/1964	1860
8/27/1960	41300	11/15/1961	8630	2/3/1963	1880	4/25/1964	1880
8/28/1960	40500	11/16/1961	8260	2/4/1963	1880	4/26/1964	1900
8/29/1960	38400	11/17/1961	7690	2/5/1963	1860	4/27/1964	1900
8/30/1960	36700	11/18/1961	7720	2/6/1963	1860	4/28/1964	1900
8/31/1960	35200	11/19/1961	7470	2/7/1963	1800	4/29/1964	1950
9/1/1960	34000	11/20/1961	7310	2/8/1963	1800	4/30/1964	2000
9/2/1960	32900	11/21/1961	7120	2/9/1963	1780	5/1/1964	2020
9/3/1960	32000	11/22/1961	7090	2/10/1963	1780	5/2/1964	2020
9/4/1960	31900	11/23/1961	7020	2/11/1963	1740	5/3/1964	2040
9/5/1960	31300	11/24/1961	6960	2/12/1963	1720	5/4/1964	2040
9/6/1960	30600	11/25/1961	6680	2/13/1963	1720	5/5/1964	2090

Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)
9/7/1960	30900	11/26/1961	6490	2/14/1963	1720	5/6/1964	2170
9/8/1960	30800	11/27/1961	6240	2/15/1963	1680	5/7/1964	2220
9/9/1960	31200	11/28/1961	6050	2/16/1963	1680	5/8/1964	2350
9/10/1960	31600	11/29/1961	5770	2/17/1963	1660	5/9/1964	2480
9/11/1960	32200	11/30/1961	5550	2/18/1963	1660	5/10/1964	2560
9/12/1960	32900	12/1/1961	5430	2/19/1963	1630	5/11/1964	2630
9/13/1960	33100	12/2/1961	5160	2/20/1963	1610	5/12/1964	2630
9/14/1960	32900	12/3/1961	4940	2/21/1963	1610	5/13/1964	2630
9/15/1960	32200	12/4/1961	4850	2/22/1963	1590	5/14/1964	2660
9/16/1960	31300	12/5/1961	4790	2/23/1963	1560	5/15/1964	2790
9/17/1960	31500	12/6/1961	4570	2/24/1963	1540	5/16/1964	2870
9/18/1960	28700	12/7/1961	4540	2/25/1963	1510	5/17/1964	2820
9/19/1960	26200	12/8/1961	4720	2/26/1963	1490	5/18/1964	2870
9/20/1960	25100	12/9/1961	4910	2/27/1963	1490	5/19/1964	3390
9/21/1960	24200	12/10/1961	5100	2/28/1963	1470	5/20/1964	3550
9/22/1960	23500	12/11/1961	5130	3/1/1963	1460	5/21/1964	3810
9/23/1960	22700	12/12/1961	4910	3/2/1963	1460	5/22/1964	3920
9/24/1960	22700	12/13/1961	4850	3/3/1963	1460	5/23/1964	3980
9/25/1960	23300	12/14/1961	4790	3/4/1963	1440	5/24/1964	3980
9/26/1960	23200	12/15/1961	4420	3/5/1963	1440	5/25/1964	4390
9/27/1960	22500	12/16/1961	4240	3/6/1963	1440	5/26/1964	4570
9/28/1960	22000	12/17/1961	4010	3/7/1963	1420	5/27/1964	4780
9/29/1960	21300	12/18/1961	3950	3/8/1963	1420	5/28/1964	5130
9/30/1960	21000	12/19/1961	3870	3/9/1963	1420	5/29/1964	5800
10/1/1960	21000	12/20/1961	3810	3/10/1963	1400	5/30/1964	5860
10/2/1960	20800	12/21/1961	3720	3/11/1963	1400	5/31/1964	5920
10/3/1960	20500	12/22/1961	3670	3/12/1963	1400	6/1/1964	6050
10/4/1960	20600	12/23/1961	3640	3/13/1963	1400	6/2/1964	6120
10/5/1960	21800	12/24/1961	3580	3/14/1963	1400	6/3/1964	6120
10/6/1960	23600	12/25/1961	3530	3/15/1963	1380	6/4/1964	6120
10/7/1960	25500	12/26/1961	3470	3/16/1963	1380	6/5/1964	6180
10/8/1960	26800	12/27/1961	3410	3/17/1963	1380	6/6/1964	6460
10/9/1960	26600	12/28/1961	3360	3/18/1963	1380	6/7/1964	7060
10/10/1960	26400	12/29/1961	3270	3/19/1963	1370	6/8/1964	8050
10/11/1960	25300	12/30/1961	3250	3/20/1963	1380	6/9/1964	8970
10/12/1960	23900	12/31/1961	3190	3/21/1963	1400	6/10/1964	9560
10/13/1960	22300	1/1/1962	3530	3/22/1963	1420	6/11/1964	9880
10/14/1960	21200	1/2/1962	3500	3/23/1963	1460	6/12/1964	10200
10/15/1960	20100	1/3/1962	3500	3/24/1963	1490	6/13/1964	10400
10/16/1960	19200	1/4/1962	3500	3/25/1963	1490	6/14/1964	10000
10/17/1960	18200	1/5/1962	3500	3/26/1963	1470	6/15/1964	10000
10/18/1960	17300	1/6/1962	3500	3/27/1963	1470	6/16/1964	9730

Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)
10/19/1960	16500	1/7/1962	3440	3/28/1963	1440	6/17/1964	9520
10/20/1960	15800	1/8/1962	3390	3/29/1963	1400	6/18/1964	9350
10/21/1960	15500	1/9/1962	3330	3/30/1963	1400	6/19/1964	9070
10/22/1960	15300	1/10/1962	3300	3/31/1963	1400	6/20/1964	8880
10/23/1960	14900	1/11/1962	3220	4/1/1963	1420	6/21/1964	8850
10/24/1960	14200	1/12/1962	3190	4/2/1963	1460	6/22/1964	8970
10/25/1960	13800	1/13/1962	3190	4/3/1963	1460	6/23/1964	9040
10/26/1960	13400	1/14/1962	3190	4/4/1963	1440	6/24/1964	9140
10/27/1960	13100	1/15/1962	3190	4/5/1963	1420	6/25/1964	9180
10/28/1960	12800	1/16/1962	3160	4/6/1963	1400	6/26/1964	9280
10/29/1960	12600	1/17/1962	3140	4/7/1963	1380	6/27/1964	9630
10/30/1960	12200	1/18/1962	3080	4/8/1963	1380	6/28/1964	10500
10/31/1960	12000	1/19/1962	3030	4/9/1963	1370	6/29/1964	11000
11/1/1960	11600	1/20/1962	2920	4/10/1963	1340	6/30/1964	11100
11/2/1960	11600	1/21/1962	2890	4/11/1963	1300	7/1/1964	11500
11/3/1960	11200	1/22/1962	2820	4/12/1963	1270	7/2/1964	11900
11/4/1960	10900	1/23/1962	2790	4/13/1963	1260	7/3/1964	11600
11/5/1960	10600	1/24/1962	2760	4/14/1963	1240	7/4/1964	12300
11/6/1960	10200	1/25/1962	2710	4/15/1963	1260	7/5/1964	13400
11/7/1960	9970	1/26/1962	2690	4/16/1963	1270	7/6/1964	15300
11/8/1960	9610	1/27/1962	2630	4/17/1963	1270	7/7/1964	18200
11/9/1960	9310	1/28/1962	2610	4/18/1963	1270	7/8/1964	19900
11/10/1960	9040	1/29/1962	2610	4/19/1963	1270	7/9/1964	19200
11/11/1960	8810	1/30/1962	2610	4/20/1963	1270	7/10/1964	18500
11/12/1960	8520	1/31/1962	2580	4/21/1963	1270	7/11/1964	19000
11/13/1960	8250	2/1/1962	2530	4/22/1963	1270	7/12/1964	20500
11/14/1960	7740	2/2/1962	2500	4/23/1963	1270	7/13/1964	24000
11/15/1960	7770	2/3/1962	2500	4/24/1963	1260	7/14/1964	24600
11/16/1960	7560	2/4/1962	2450	4/25/1963	1270	7/15/1964	24000
11/17/1960	7440	2/5/1962	2430	4/26/1963	1290	7/16/1964	23400
11/18/1960	7320	2/6/1962	2430	4/27/1963	1290	7/17/1964	22700
11/19/1960	7350	2/7/1962	2370	4/28/1963	1290	7/18/1964	21200
11/20/1960	7350	2/8/1962	2370	4/29/1963	1290	7/19/1964	20600
11/21/1960	7110	2/9/1962	2370	4/30/1963	1300	7/20/1964	19700
11/22/1960	6810	2/10/1962	2370	5/1/1963	1290	7/21/1964	18900
11/23/1960	6510	2/11/1962	2350	5/2/1963	1270	7/22/1964	17700
11/24/1960	6250	2/12/1962	2350	5/3/1963	1260	7/23/1964	16800
11/25/1960	6060	2/13/1962	2350	5/4/1963	1260	7/24/1964	15900
11/26/1960	5810	2/14/1962	2350	5/5/1963	1300	7/25/1964	15000
11/27/1960	5610	2/15/1962	2350	5/6/1963	1340	7/26/1964	14800
11/28/1960	5360	2/16/1962	2320	5/7/1963	1320	7/27/1964	14500
11/29/1960	5250	2/17/1962	2300	5/8/1963	1320	7/28/1964	14300

Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)
11/30/1960	4980	2/18/1962	2270	5/9/1963	1350	7/29/1964	14200
12/1/1960	4840	2/19/1962	2240	5/10/1963	1370	7/30/1964	14500
12/2/1960	4760	2/20/1962	2170	5/11/1963	1370	7/31/1964	13800
12/3/1960	4680	2/21/1962	2140	5/12/1963	1370	8/1/1964	13700
12/4/1960	4650	2/22/1962	2120	5/13/1963	1370	8/2/1964	13300
12/5/1960	4590	2/23/1962	2120	5/14/1963	1370	8/3/1964	13000
12/6/1960	4450	2/24/1962	2120	5/15/1963	1370	8/4/1964	12600
12/7/1960	4340	2/25/1962	2120	5/16/1963	1350	8/5/1964	12500
12/8/1960	4240	2/26/1962	2120	5/17/1963	1340	8/6/1964	14400
12/9/1960	4130	2/27/1962	2090	5/18/1963	1320	8/7/1964	17400
12/10/1960	4040	2/28/1962	2090	5/19/1963	1300	8/8/1964	17400
12/11/1960	3990	3/1/1962	2090	5/20/1963	1340	8/9/1964	17400
12/12/1960	4070	3/2/1962	2120	5/21/1963	1380	8/10/1964	18300
12/13/1960	4320	3/3/1962	2070	5/22/1963	1460	8/11/1964	17300
12/14/1960	4590	3/4/1962	2020	5/23/1963	1540	8/12/1964	16900
12/15/1960	4700	3/5/1962	2000	5/24/1963	1660	8/13/1964	17000
12/16/1960	4650	3/6/1962	1950	5/25/1963	1800	8/14/1964	19000
12/17/1960	4540	3/7/1962	1920	5/26/1963	1860	8/15/1964	22300
12/18/1960	4150	3/8/1962	1880	5/27/1963	1860	8/16/1964	24700
12/19/1960	4150	3/9/1962	1880	5/28/1963	1800	8/17/1964	25800
12/20/1960	3960	3/10/1962	1920	5/29/1963	1780	8/18/1964	25700
12/21/1960	3790	3/11/1962	1920	5/30/1963	1920	8/19/1964	25500
12/22/1960	3690	3/12/1962	1920	5/31/1963	2300	8/20/1964	25300
12/23/1960	3580	3/13/1962	1920	6/1/1963	2300	8/21/1964	24900
12/24/1960	3500	3/14/1962	1880	6/2/1963	2240	8/22/1964	24900
12/25/1960	3500	3/15/1962	1860	6/3/1963	2240	8/23/1964	25000
12/26/1960	3450	3/16/1962	1860	6/4/1963	2240	8/24/1964	25900
12/27/1960	3390	3/17/1962	1860	6/5/1963	2890	8/25/1964	27800
12/28/1960	3290	3/18/1962	1820	6/6/1963	2690	8/26/1964	30300
12/29/1960	3260	3/19/1962	1820	6/7/1963	2890	8/27/1964	31900
12/30/1960	3210	3/20/1962	1820	6/8/1963	3060	8/28/1964	33100
12/31/1960	3160	3/21/1962	1800	6/9/1963	6050	8/29/1964	34200
1/1/1961	2950	3/22/1962	1800	6/10/1963	9320	8/30/1964	33600
1/2/1961	2890	3/23/1962	1780	6/11/1963	10800	8/31/1964	32400
1/3/1961	2840	3/24/1962	1780	6/12/1963	11800	9/1/1964	31500
1/4/1961	2790	3/25/1962	1740	6/13/1963	11800	9/2/1964	30800
1/5/1961	2740	3/26/1962	1680	6/14/1963	11400	9/3/1964	29400
1/6/1961	2710	3/27/1962	1660	6/15/1963	11100	9/4/1964	28000
1/7/1961	2690	3/28/1962	1630	6/16/1963	11500	9/5/1964	26400
1/8/1961	2660	3/29/1962	1630	6/17/1963	11800	9/6/1964	24900
1/9/1961	2610	3/30/1962	1610	6/18/1963	12000	9/7/1964	24000
1/10/1961	2560	3/31/1962	1590	6/19/1963	12800	9/8/1964	22900

Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)
1/11/1961	2560	4/1/1962	1540	6/20/1963	13400	9/9/1964	22300
1/12/1961	2530	4/2/1962	1540	6/21/1963	14400	9/10/1964	22300
1/13/1961	2500	4/3/1962	1520	6/22/1963	14100	9/11/1964	21900
1/14/1961	2480	4/4/1962	1510	6/23/1963	13000	9/12/1964	22100
1/15/1961	2370	4/5/1962	1510	6/24/1963	11900	9/13/1964	22600
1/16/1961	2350	4/6/1962	1490	6/25/1963	11700	9/14/1964	23000
1/17/1961	2320	4/7/1962	1510	6/26/1963	11500	9/15/1964	23300
1/18/1961	2270	4/8/1962	1490	6/27/1963	11700	9/16/1964	28800
1/19/1961	2270	4/9/1962	1510	6/28/1963	11800	9/17/1964	32200
1/20/1961	2300	4/10/1962	1510	6/29/1963	11700	9/18/1964	33500
1/21/1961	2320	4/11/1962	1560	6/30/1963	11400	9/19/1964	32900
1/22/1961	2320	4/12/1962	1590	7/1/1963	11000	9/20/1964	32200
1/23/1961	2300	4/13/1962	1610	7/2/1963	10400	9/21/1964	32200
1/24/1961	2320	4/14/1962	1660	7/3/1963	10400	9/22/1964	32900
1/25/1961	2270	4/15/1962	1630	7/4/1963	10800	9/23/1964	37500
1/26/1961	2240	4/16/1962	1660	7/5/1963	11800	9/24/1964	42400
1/27/1961	2190	4/17/1962	1610	7/6/1963	13000	9/25/1964	43500
1/28/1961	2170	4/18/1962	1590	7/7/1963	14200	9/26/1964	43400
1/29/1961	2090	4/19/1962	1610	7/8/1963	17000	9/27/1964	40900
1/30/1961	2090	4/20/1962	1630	7/9/1963	18600	9/28/1964	38900
1/31/1961	2070	4/21/1962	1630	7/10/1963	18800	9/29/1964	38200
2/1/1961	2070	4/22/1962	1630	7/11/1963	17900	9/30/1964	36900
2/2/1961	2040	4/23/1962	1680	7/12/1963	18300	10/1/1964	35300
2/3/1961	2020	4/24/1962	1720	7/13/1963	21200	10/2/1964	34100
2/4/1961	2000	4/25/1962	1720	7/14/1963	20300	10/3/1964	33700
2/5/1961	1970	4/26/1962	1740	7/15/1963	19500	10/4/1964	35100
2/6/1961	1970	4/27/1962	1740	7/16/1963	19100	10/5/1964	35300
2/7/1961	1950	4/28/1962	1800	7/17/1963	19100	10/6/1964	34800
2/8/1961	1920	4/29/1962	2020	7/18/1963	18500	10/7/1964	33700
2/9/1961	1920	4/30/1962	2270	7/19/1963	17500	10/8/1964	32200
2/10/1961	1900	5/1/1962	2240	7/20/1963	16500	10/9/1964	31200
2/11/1961	1880	5/2/1962	2270	7/21/1963	16100	10/10/1964	29800
2/12/1961	1860	5/3/1962	2140	7/22/1963	16900	10/11/1964	28700
2/13/1961	1860	5/4/1962	2090	7/23/1963	19500	10/12/1964	27800
2/14/1961	1840	5/5/1962	2120	7/24/1963	21800	10/13/1964	27100
2/15/1961	1820	5/6/1962	2140	7/25/1963	22700	10/14/1964	25900
2/16/1961	1800	5/7/1962	2170	7/26/1963	23500	10/15/1964	24900
2/17/1961	1800	5/8/1962	2170	7/27/1963	26700	10/16/1964	24000
2/18/1961	1780	5/9/1962	2170	7/28/1963	32200	10/17/1964	23200
2/19/1961	1780	5/10/1962	2190	7/29/1963	34400	10/18/1964	22500
2/20/1961	1780	5/11/1962	2270	7/30/1963	35600	10/19/1964	21500
2/21/1961	1780	5/12/1962	2400	7/31/1963	36000	10/20/1964	20000

Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)
2/22/1961	1820	5/13/1962	2760	8/1/1963	36000	10/21/1964	18600
2/23/1961	1860	5/14/1962	2530	8/2/1963	36000	10/22/1964	17600
2/24/1961	1880	5/15/1962	2610	8/3/1963	34900	10/23/1964	16600
2/25/1961	1880	5/16/1962	2630	8/4/1963	34500	10/24/1964	15600
2/26/1961	1860	5/17/1962	2870	8/5/1963	33000	10/25/1964	15000
2/27/1961	1840	5/18/1962	2970	8/6/1963	32300	10/26/1964	14600
2/28/1961	1800	5/19/1962	3060	8/7/1963	32000	10/27/1964	14800
3/1/1961	1780	5/20/1962	3060	8/8/1963	32700	10/28/1964	15200
3/2/1961	1780	5/21/1962	3140	8/9/1963	33000	10/29/1964	15000
3/3/1961	1740	5/22/1962	3060	8/10/1963	37500	10/30/1964	14900
3/4/1961	1720	5/23/1962	3140	8/11/1963	39400	10/31/1964	14800
3/5/1961	1700	5/24/1962	4070	8/12/1963	41700	11/1/1964	14200
3/6/1961	1680	5/25/1962	4270	8/13/1963	40500	11/2/1964	13400
3/7/1961	1660	5/26/1962	4190	8/14/1963	40200	11/3/1964	12800
3/8/1961	1630	5/27/1962	4160	8/15/1963	40700	11/4/1964	12400
3/9/1961	1610	5/28/1962	3810	8/16/1963	40200	11/5/1964	11900
3/10/1961	1610	5/29/1962	3780	8/17/1963	39100	11/6/1964	11800
3/11/1961	1610	5/30/1962	3900	8/18/1963	37600	11/7/1964	11600
3/12/1961	1590	5/31/1962	3870	8/19/1963	36000	11/8/1964	11500
3/13/1961	1590	6/1/1962	4330	8/20/1963	33400	11/9/1964	11800
3/14/1961	1590	6/2/1962	6020	8/21/1963	33600	11/10/1964	12000
3/15/1961	1590	6/3/1962	6520	8/22/1963	32200	11/11/1964	12100
3/16/1961	1590	6/4/1962	6300	8/23/1963	31200	11/12/1964	12000
3/17/1961	1610	6/5/1962	5710	8/24/1963	30300	11/13/1964	11800
3/18/1961	1610	6/6/1962	5860	8/25/1963	28800	11/14/1964	11400
3/19/1961	1610	6/7/1962	6150	8/26/1963	30800	11/15/1964	10800
3/20/1961	1590	6/8/1962	6460	8/27/1963	29300	11/16/1964	10200
3/21/1961	1570	6/9/1962	7120	8/28/1963	25900	11/17/1964	9660
3/22/1961	1540	6/10/1962	8290	8/29/1963	29300	11/18/1964	9210
3/23/1961	1510	6/11/1962	9180	8/30/1963	32100	11/19/1964	8880
3/24/1961	1510	6/12/1962	8760	8/31/1963	26100	11/20/1964	8560
3/25/1961	1490	6/13/1962	9180	9/1/1963	24900	11/21/1964	8320
3/26/1961	1470	6/14/1962	9320	9/2/1963	21700	11/22/1964	8110
3/27/1961	1460	6/15/1962	9140	9/3/1963	25200	11/23/1964	8020
3/28/1961	1460	6/16/1962	9350	9/4/1963	24800	11/24/1964	7900
3/29/1961	1440	6/17/1962	13400	9/5/1963	24000	11/25/1964	7470
3/30/1961	1430	6/18/1962	15400	9/6/1963	23600	11/26/1964	7280
3/31/1961	1420	6/19/1962	17000	9/7/1963	22900	11/27/1964	7090
4/1/1961	1390	6/20/1962	20100	9/8/1963	21900	11/28/1964	6960
4/2/1961	1380	6/21/1962	20700	9/9/1963	21500	11/29/1964	6770
4/3/1961	1370	6/22/1962	20800	9/10/1963	21100	11/30/1964	6550
4/4/1961	1360	6/23/1962	19600	9/11/1963	19300	12/1/1964	6430

Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)	Month/date/year	Discharge (m^3/s)
4/5/1961	1370	6/24/1962	18100	9/12/1963	19500	12/2/1964	6430
4/6/1961	1370	6/25/1962	16600	9/13/1963	29600	12/3/1964	6520
4/7/1961	1380	6/26/1962	15100	9/14/1963	32400	12/4/1964	6770
4/8/1961	1420	6/27/1962	13900	9/15/1963	33900	12/5/1964	6860
4/9/1961	1470	6/28/1962	13000	9/16/1963	33100	12/6/1964	6860
4/10/1961	1520	6/29/1962	12700	9/17/1963	34400	12/7/1964	6640
4/11/1961	1630	6/30/1962	12600	9/18/1963	33500	12/8/1964	6370
4/12/1961	1590	7/1/1962	12400	9/19/1963	32400	12/9/1964	6210
4/13/1961	1590	7/2/1962	12200	9/20/1963	31300	12/10/1964	5990
4/14/1961	1610	7/3/1962	12400	9/21/1963	31000	12/11/1964	5830
4/15/1961	1660	7/4/1962	13000	9/22/1963	30100	12/12/1964	5610
4/16/1961	1780	7/5/1962	13100	9/23/1963	28900	12/13/1964	5430
4/17/1961	1800	7/6/1962	13000	9/24/1963	32700	12/14/1964	5220
4/18/1961	1780	7/7/1962	13200	9/25/1963	32700	12/15/1964	5190
4/19/1961	1780	7/8/1962	12600	9/26/1963	32400	12/16/1964	5060
4/20/1961	1950	7/9/1962	12600	9/27/1963	26800	12/17/1964	4910
4/21/1961	2020	7/10/1962	12600	9/28/1963	25500	12/18/1964	4780
4/22/1961	2020	7/11/1962	13200	9/29/1963	24500	12/19/1964	4690
4/23/1961	1950	7/12/1962	14400	9/30/1963	23500	12/20/1964	4600
4/24/1961	1860	7/13/1962	18100	10/1/1963	22500	12/21/1964	4510
4/25/1961	1820	7/14/1962	20800	10/2/1963	22100	12/22/1964	4390
4/26/1961	1800	7/15/1962	21200	10/3/1963	22400	12/23/1964	4300
4/27/1961	1820	7/16/1962	20700	10/4/1963	21200	12/24/1964	4210
4/28/1961	1820	7/17/1962	20600	10/5/1963	20500	12/25/1964	4100
4/29/1961	1820	7/18/1962	21500	10/6/1963	20200	12/26/1964	4010
4/30/1961	1860	7/19/1962	25300	10/7/1963	20000	12/27/1964	3980
				10/8/1963	19500	12/28/1964	3900
				10/9/1963	18900	12/29/1964	3810
						12/30/1964	3720
						12/31/1964	3580

Exercise 5.6. The AMS at Greenville gauging station (USGS 08057200) on White Rock Creek in Dallas, (Station 1 shown in Figure 4.54) is given in Table 5.19. Without recourse to any program, conduct an FFA using (1) EV I distribution; (2) GEV distribution and (3) LP IIII distribution. For LP III distribution use a regional skew of -0.2484. Which distribution function fits the data best and why?

Table 5.19 *AMS of White Rock Creek at Greenville Avenue, Dallas, Texas, USA*

Date/Water Year	Streamflow (cfs)	Date/Water Year	Streamflow (cfs)
7/27/1962	20000	5/12/1994	37500
10/8/1962	24500	10/21/1994	28900
9/21/1964	38100	6/14/1996	1370
5/10/1965	13800	5/19/1997	2220
4/28/1966	27000	1/5/1998	22100
5/31/1967	6320	12/3/1998	15200
3/20/1968	10800	6/11/2000	23600
5/7/1969	19600	2/16/2001	22600
4/25/1970	7700	3/19/2002	25700
7/28/1971	4160	10/18/2002	18800
12/9/1971	15800	1/17/2004	22100
4/24/1973	12300	10/4/2004	17400
6/7/1974	8590	2/25/2006	14000
2/1/1975	10100	6/26/2007	11200
7/16/1976	2530	3/18/2008	14700
3/27/1977	19700	11/10/2008	11000
5/28/1978	7860	9/8/2010	14100
5/3/1979	16700	5/25/2011	8200
9/29/1980	4310	1/25/2012	13600
4/27/1985	24100	5/16/2013	8980
5/9/1986	36800	5/8/2014	8230
5/28/1987	16900	5/29/2015	18800
9/2/1988	19700	11/27/2015	23200
5/17/1989	28600	6/2/2017	11000
5/2/1990	39200	9/22/2018	62000
4/12/1991	36800	5/18/2019	31900
12/20/1991	24100	3/18/2020	12800
2/25/1993	17500	5/16/2021	52200

Exercise 5.7. Table 5.20 gives the AMS of Brazos River, the longest river in Texas, at a gauging station at the bridge of Highway (Loop) 340 crossing Brazos River at Waco. The Texas Department of Transportation needed an FFA of the gauge data at this crossing during a highway improvement project. Flows at this gauge became regulated since 1945, when the construction of several dams on upstream tributaries and one on the main stem upstream at Whitney began and completed in 1965. Determine the regulation period from a time series analysis and then determine how the data of the regulation period can be made suitable for conventional FFA. Test the data for stationarity,

independence, and homogeneity. Then, conduct an FFA for the unregulated and regulated periods by choosing an appropriate pdf. Conduct goodness of fit test using both chi-squared and Kolmogorov-Smirnov tests.

Table 5.20 *The AMS of Brazos River at Waco, Texas, USA (USGS Station 08096500)*

Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
6/30/1899	117000	6/29/40	38500	6/16/81	34200
9/28/00	69800	5/5/41	68800	5/26/82	27300
5/19/01	22600	4/25/42	126000	2/21/83	12100
7/26/02	106000	10/18/42	67400	12/7/83	8960
2/27/03	43600	5/2/44	137000	12/18/84	13300
10/1/03	22400	4/22/45	144000	6/11/86	18000
5/14/05	85800	3/13/46	37600	6/13/87	26200
6/6/06	40900	11/4/46	29600	12/26/87	7660
7/15/07	13500	2/26/48	36800	6/17/89	25200
5/25/08	132000	5/18/49	71400	5/12/90	40800
6/18/09	23500	2/13/50	16700	6/8/91	18700
12/2/09	29200	6/13/51	18300	12/21/91	50000
7/18/11	35400	5/25/52	25500	4/25/93	11600
8/7/12	24900	5/12/53	61100	5/13/94	11300
5/7/13	19000	5/17/54	22600	5/11/95	30300
12/3/13	211000	5/19/55	23600	9/18/96	9580
4/26/15	73300	5/2/56	46100	3/10/97	38000
4/2/16	113000	4/20/57	101000	3/19/98	36100
10/19/16	17600	5/3/58	70600	12/10/98	10900
4/15/18	30000	6/25/59	10600	6/5/00	19100
11/9/18	125000	10/5/59	80900	3/14/01	26800
10/23/19	78100	1/8/61	62800	12/17/01	20400
6/11/21	31100	10/10/61	35400	12/31/02	10800
5/10/22	122000	10/10/62	16300	5/1/04	22000
4/27/23	66900	6/16/64	49500	12/1/04	28400
12/13/23	41900	5/16/65	45800	12/4/05	8520
5/9/25	49300	5/3/66	33700	3/30/07	39900
6/22/26	40500	6/12/67	18800	5/14/08	16300
6/14/27	62000	5/10/68	39000	4/29/09	9210
4/4/28	24800	5/11/69	38600	9/8/10	28700
9/13/29	31300	3/3/70	15100	11/1/10	3140
5/18/30	74800	9/14/71	7220	3/20/12	29600
10/7/30	93500	10/20/71	17500	1/9/13	7680
2/19/32	62500	4/25/73	32000	10/16/13	8990
7/30/33	41100	10/16/73	11500	6/27/15	30800
4/6/34	45400	10/31/74	40000	10/24/15	37000
5/19/35	112000	7/5/76	23700	4/11/17	27700

Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
9/27/36	246000	4/20/77	33700	3/8/18	4590
10/26/36	26600	8/11/78	4210	10/20/18	31300
1/24/38	88400	5/11/79	19700	3/22/20	30600
6/20/39	43500	5/15/80	12000	6/11/21	27100

Exercise 5.8. The underlying theory behind regional flood frequency analysis is that the flood frequency curve constructed from the annual flood series records at a gauging station is based on a small sample and therefore can never represent the true nature of the curve of the parent population. But if such curves from multiple gauging stations are averaged by an appropriate method such as the index flood method, then the average curve should better represent the population characteristics and can serve the entire region provided that the gauging stations used in this process truly belong to a single parent population which is called a homogeneous region. Figure 5.42 shows the map of the Snohomish River basin (1536 mi^2), to the slightly northeast of Seattle, Washington. The lower part of the basin is eliminated to reduce the chance of introduction of inhomogeneity resulting from coastal climate.

Table 5.21 gives the magnitudes of flood flows of different AEPs determined from the AMS at the gauging stations shown in Figure 5.42. First, determine dimensionless regional flood frequency curve based on these data by the index flood method where the recurrence interval of **mean annual flood** is 2.33 years.

Table 5.21 *Magnitude of discharge at specified AEP at the gauging stations within Snohomish River basin. The estimates, based on AMS and calculated following Bulletin 17C procedures (EMA), are given by Mastin et al (2017) in USGS Scientific Investigation Report 2016-5118*

	Discharge (ft^3/s) – AEP								
Station	**0.5**	**0.2**	**0.1**	**0.04**	**0.02**	**0.01**	**0.005**	**0.002**	**River**
12130500	6,470	9,950	12,500	16,000	18,700	21,600	24,700	29,000	South Fork Skykomish River
12131000	5,630	8,430	10,500	13,200	15,300	17,600	19,900	23,300	Beckler River
12133000	23,300	35,400	44,100	55,600	64,600	73,900	83,500	96,900	South Fork Skykomish River
12133500	945	1,540	1,990	2,620	3,140	3,690	4,290	5,140	Troublesome Creek
12134000	13,800	20,200	24,600	30,400	34,700	39,200	43,700	49,900	North Fork Skykomish
12134500	40,800	61,700	76,200	95,000	109,000	124,000	139,000	159,000	Skykomish River
12135000	2,010	2,670	3,090	3,630	4,020	4,420	4,810	5,340	Wallace River
12135500	991	1,590	2,070	2,770	3,360	4,030	4,760	5,870	Olney Creek
12137290	2,750	4,690	6,230	8,490	10,400	12,500	14,800	18,200	South Fork Sultan River
12137500	15,600	23,300	28,400	35,000	39,900	44,800	49,800	56,400	Sultan River
12141300	1,290	1,780	2,100	2,490	2,770	3,040	3,320	3,670	Woods Creek
12141300	16,400	23,000	26,900	31,500	34,700	37,800	40,600	44,200	Middle Fork Snoqualmie River
12141500	12,600	19,100	23,700	29,800	34,600	39,500	44,700	51,800	Middle Fork Snoqualmie River
12142000	7,480	10,600	12,600	15,000	16,800	18,600	20,300	22,600	North Fork Snoqualmie River
12142300	441	616	732	879	989	1,100	1,210	1,360	Hancock Creek
12143000	8,860	12,300	14,500	17,200	19,100	21,000	22,900	25,200	North Fork Snoqualmie River
12143400	3,780	5,710	7,000	8,630	9,830	11,000	12,200	13,800	South Fork Snoqualmie River
12143600	5,910	8,950	11,000	13,700	15,700	17,800	19,800	22,600	South Fork Snoqualmie
12143700	77.6	117	143	177	202	228	254	288	Boxley Creek

	Discharge (ft^3/s) – AEP								
Station	**0.5**	**0.2**	**0.1**	**0.04**	**0.02**	**0.01**	**0.005**	**0.002**	**River**
12143900	120	160	187	221	247	274	302	340	Boxley Creek
12144000	5,190	7,880	9,670	11,900	13,500	15,100	16,700	18,700	South Fork Snoqualmie
12144500	30,000	43,500	53,400	63,400	71,500	79,500	87,400	97,800	Snoqualmie River
12145500	1,940	2,860	3,520	4,400	5,090	5,800	6,550	7,590	Raging River
12147500	4,740	6,510	7,670	9,100	10,100	11,200	12,200	13,600	North Fork Tolt River
12147600	1,170	1,680	2,000	2,390	2,670	2,940	3,200	3,530	South Fork Tolt River
12148000	3,410	4,730	5,620	6,770	7,650	8,530	9,440	10,700	South Fork Tolt River
12148500	6,460	9,590	11,700	14,500	16,600	18,700	20,800	23,700	Tolt River
12149000	30,200	45,600	55,800	68,400	77,600	86,500	95,400	107,000	Snoqualmie River
12150800	61,600	83,900	98,900	118,000	133,000	148,000	163,000	183,000	Snohomish River

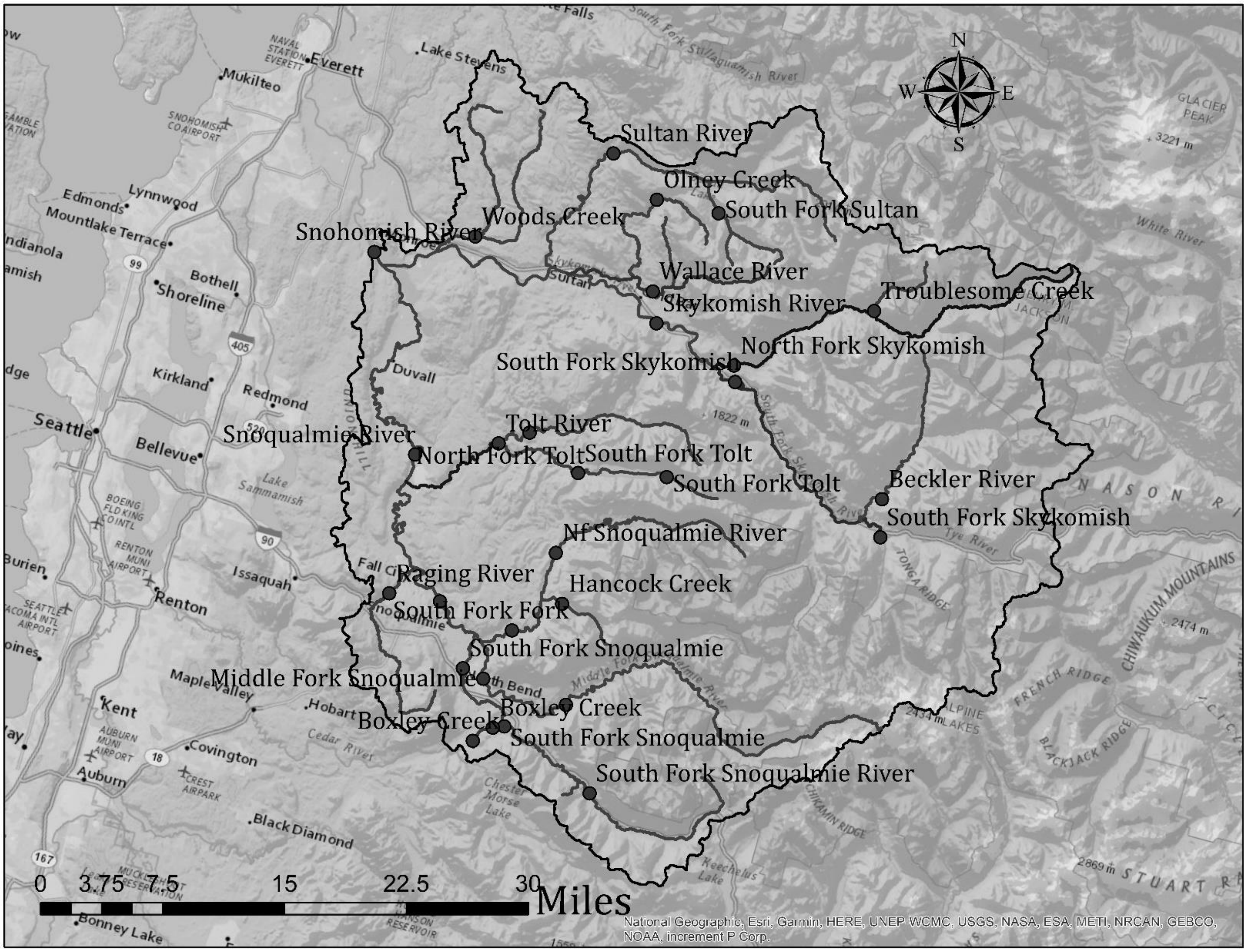

Figure 5.42 Map of Snohomish River Basin to the slightly northeast of Seattle, Washington showing locations of the stream gauging stations.

Several physical and 24 h precipitation intensities (24I) of different ARI of the basin are given in Table 5.22. Conduct multiple regression analysis to determine the parameters that can be used to develop a regional regression equation. From this develop the regional regression equation.

Table 5.22 *Certain physical and precipitation characteristics of the Snohomish River Basin* (*Figure 5.42*)

Station	Drainage area (mi^2)	Relief	Canopy cover (%)	Impervious area	Drainage density	Soil Index	Basin shape	Mean annual precipitation in)	I24H2Y	I24H50Y	I24H100Y	Storm Total (in)
12130500	136.01	6950	64.40	0.5220	1.13	1.94	455.05	97.41	4.39	7.36	8.00	153.24
12131000	96.67	5120	71.91	0.5589	1.22	2.10	378.72	98.33	4.62	7.75	8.43	118.11
12133000	357.3698	7340	67.32	0.5447	1.17	2.05	1262.73	105.50	4.72	7.92	8.61	417.31
12133500	12.96	5890	43.15	0.0000	1.15	no data	46.16	132.03	5.19	8.71	9.47	14.92

Station	Drainage area (mi^2)	Relief	Canopy cover (%)	Impervious area	Drainage density	Soil Index	Basin shape	Mean annual precipitation in)	I24H2Y	I24H50Y	I24H100Y	Storm Total (in)
12134000	145.68	6670	68.38	0.1513	1.19	2.43	545.88	118.47	5.12	8.60	9.35	173.90
12134500	535.1948	7740	66.86	0.4647	1.16	2.08	1883.12	109.28	4.85	8.13	8.84	622.73
12135000	19.21133	5040	72.26	0.7207	0.85	2.86	81.34	126.04	5.39	9.06	9.85	16.36
12135500	7.69	3770	81.57	1.0342	0.87	2.99	72.80	133.40	5.32	8.93	9.71	6.66
12137290	11.7469	3730	60.23	0.0347	0.77	no data	23.88	144.09	5.95	10.01	10.88	9.10
12137500	74.33263	5810	65.52	0.2404	0.89	3.00	154.23	136.11	5.06	8.50	9.24	66.19
12141300	155.0229	6780	65.59	0.0628	1.13	1.90	516.41	122.86	4.95	8.31	9.03	175.36
12141500	168.53	7090	66.36	0.1727	1.13	1.91	561.28	120.30	4.86	8.16	8.87	190.17
12142000	63.95588	4740	69.16	0.6090	1.07	2.13	194.88	132.32	5.64	9.48	10.31	68.44
12142300	7.4	2910	61.69	0.5628	1.05	2.02	30.24	144.46	5.74	9.65	10.49	7.77
12143000	95.8	5420	69.29	0.7288	1.09	2.12	306.59	131.52	5.53	9.30	10.11	104.58
12143400	41.65884	4770	62.08	1.5377	1.03	1.83	115.15	111.80	4.84	8.11	8.82	42.92
12143600	63.70916	5660	65.31	1.5752	1.12	1.91	208.81	110.30	4.74	7.94	8.64	71.53
12143700	1.31	1650	91.70	0.5184	0.30	1.41	2.87	87.92	3.95	6.63	7.21	0.39
12143900	5.418064	2520	79.23	1.6293	1.04	2.03	29.86	80.25	3.61	6.05	6.58	5.65
12144000	81.12189	5800	63.38	2.3665	1.12	1.94	283.91	102.66	4.45	7.46	8.11	91.08
12144500	377.1681	7440	66.45	1.2753	1.14	1.99	1290.23	115.23	4.81	8.08	8.78	430.90
12145500	30.49433	7440	66.45	1.3414	14.13	2.29	15958.11	84.94	3.84	6.43	7.00	430.90
12147500	39.72714	5310	66.19	0.7426	1.12	2.14	150.14	124.12	5.21	8.75	9.51	44.64
12147600	5.454203	3560	71.53	0.2312	0.67	1.85	8.63	153.03	6.48	10.89	11.84	3.67
12148000	20.01	4190	66.87	0.6965	0.80	2.24	35.47	133.23	5.66	9.51	10.34	16.02
12148500	81.15768	5620	63.06	0.7271	1.17	2.12	295.04	114.97	4.88	8.20	8.92	94.97
12149000	602.8619	7510	60.12	1.4317	1.14	2.02	2060.25	103.46	4.39	7.37	8.02	689.21
12150800	1536.139	7940	59.24	1.2537	1.14	2.14	5232.87	100.95	4.32	7.25	7.89	1758.67

Chapter 6

Geomorphologic Concepts and Watershed Characteristics

Exercise 6.1. Two adjacent watersheds have areas of 24 km^2 and 79 km^2, respectively. A rain event affects both watersheds at the same time. Which watershed will exhibit a peaked hydrograph relative to the other showing flatter hydrograph? Justify your answer.

Exercise 6.2. Why has an elongated basin higher bifurcation ratio than a rounder basin? Which basin will show a peaked hydrograph relative to the other showing flatter hydrograph?

Exercise 6.3. How does channel slope affect hydrograph shape? If a basin has a channel slope of 30 percent relative to another basin having a channel slope of 5%, which basin will show more peaked hydrograph?

Exercise 6.4. How does drainage density affect hydrograph shape? Which basin will show a peaked hydrograph relative to the other showing flatter hydrograph one with higher drainage density or lower drainage density? Explain your answer.

Exercise 6.5. Obtain estimates of the bifurcation ratio, the length ratio, and the area ratio for Allegheny River watershed in Pennsylvania, USA., using the data given in Table 6.20 (from Morisawa, 1962 with unit converted to SI). Also determine the drainage density, stream frequency, and average overland flow length. Do the ratios fall in the range commonly cited in the literature? Verify the total area of the basin of order 7 based on the computed R_b, R_l, $\bar{A}_1$, and W.

Table 6.20 *Morphometric parameters of Allegheny River watershed, Pennsylvania, USA*

Order of Stream, w	**Number of Streams, N**	**Average Length, $\bar{L}$ (km)**	**Average Basin Area, $\bar{A}$ (km^2)**
1	5966	0.140	0.129
2	1529	0.488	0.394
3	378	1.284	2.233
4	68	3.983	15.809
5	13	11.338	88.008
6	3	32.106	626.106
7	1	13.021	1424.499

Exercise 6.6. For the headwater watershed of Arkansas River up to Pueblo, shown in Figure 6.8, the longest flow path length is 320.26 km, the mean watershed slope is 19.6 percent, and the curve number (CN) is 67.98, computed by the StreamStats program of the USGS (visit StreamStats (usgs.gov)). StreamStats gives the time of concentration for this watershed as 44.1 h. Confirm this estimate of time of concentration for this watershed.

Exercise 6.7. Mean basin slope and 10-85 channel slope for the eight headwater watersheds of Arkansas River shown in Figure 6.8 are given in Table 6.21. The values of 2-year and 100-year discharge as shown in Figure 6.6, at the watershed outlet, are also given in Table 6.21. Calculate stream power at these locations. What can be predicted about the longitudinal profile of this section of the river (see Table 6.22 for distance).

Table 6.21 *Geomorphologic parameters and frequency flows of eight headwater watersheds of Arkansas River, USA*

Catchment	Mean Basin Slope (%)	S_{10-85} (%)	$Q_{p=0.50}$ (m^3/s)	$Q_{p=0.01}$ (m^3/s)
Leadville	27	92.8	18.44	44.49
Granite	30	53.2	56.46	116.50
Buena Vista	32	49	76.00	117.09
Salida	31	42.1	88.38	196.24
Wellsville	31	41	92.62	191.20
Parkdale	30	34.4	108.85	206.26
Canon City	29	33.7	115.82	212.55
Portland	22.8	82.7	168.17	672.24

Exercise 6.8. With the data given in Table 6.22 for nine headwater watersheds of Arkansas River basin is there any correlation between the time of concentration and the ratio of the longest flow path and square root of 10-85 slope? Using the data given, calculate the time of concentration of each of the watersheds using the applicable equations given in Table 6.9 and evaluate the consistency of the results.

Table 6.22 *Geomorphologic and time parameters of nine headwater watersheds of Arkansas River, USA*

Catchment	Longest Flow Path (km)	10-85 slope	Time of Concentration (h)	Mean Basin Slope (%)
Leadville	33.96	0.928	11.36	27
Granite	65.18	0.532	15.23	30
Buena Vista	94.63	0.49	19.61	32
Salida	141.94	0.421	26.37	31
Wellsville	151.44	0.41	26.67	31
Parkdale	225.31	0.344	27.33	30
Canon City	239.79	0.337	30.2	29
Portland	278.42	0.827	36.64	22.8
Pueblo	320.26	0.707	44.11	19.6

Exercise 6.9. Determine the at-a-station and downstream hydraulic geometry relationships for Ceyhan River in Turkey from the data given in Table 6.23. The station location information is given at the bottom of Table 6.23 (See Figure 7.34). The data are given by Yuce, M. I., Esit, M., and Karata, M. C. (Hydraulic geometry analysis of Ceyhan River, Turkey. SN Applied Sciences, 2019, 1:763).

Table 6.23 *Data for determination of hydraulic geometry relationships of Ceyhan River, Turkey*

Station	Year	Average daily discharge (m^3/s)	Cross sectional area (m^2)	Water surface width (m)	Average depth (m)	Average velocity (m/s)
E20A004	2010	84.900	438.893	69.975	6.272	0.193
	2009	54.700	423.543	70.979	5.967	0.129
	2008	79.800	383.831	67.108	5.720	0.208
	2007	88.700	406.607	70.276	5.786	0.218
	2006	88.700	426.958	70.670	6.042	0.208
	2005	102.000	413.957	70.750	5.851	0.246

Station	Year	Average daily discharge (m^3/s)	Cross sectional area (m^2)	Water surface width (m)	Average depth (m)	Average velocity (m/s)
	2004	92.500	471.600	72.130	6.538	0.196
E20A006	2010	2.130	14.445	14.505	0.996	0.147
	2009	1.670	16.710	16.150	1.035	0.100
	2008	0.980	12.684	14.490	0.875	0.077
	2007	2.700	13.951	16.081	0.868	0.194
	2006	2.140	15.879	18.014	0.881	0.135
	2005	2.560	17.248	17.724	0.973	0.148
	2004	3.410	18.382	17.602	1.044	0.186
	2003	3.230	17.289	17.213	1.004	0.187
E20A007	2010	5.660	15.000	15.874	0.945	0.377
	2009	6.920	20.940	16.000	1.309	0.330
	2008	3.200	20.550	16.000	1.284	0.156
	2007	3.490	12.358	14.555	0.849	0.282
	2006	4.060	12.322	14.742	0.836	0.329
	2005	3.490	15.197	15.791	0.962	0.230
	2004	4.530	20.810	16.000	1.301	0.218
	2003	5.380	16.000	13.989	1.144	0.336
E20A008	2010	0.564	6.384	18.436	0.346	0.088
	2009	1.300	13.402	23.869	0.561	0.097
	2008	1.120	11.227	23.306	0.482	0.100
	2007	1.450	29.894	35.500	0.842	0.049
	2006	1.200	11.520	24.738	0.466	0.104
	2005	0.760	11.717	25.575	0.458	0.065
	2004	2.080	21.750	41.880	0.519	0.096
E20A020	2010	88.500	281.650	93.469	3.013	0.314
	2009	66.900	134.586	72.184	1.864	0.497
	2008	71.000	124.133	73.816	1.682	0.572
	2007	8.680	120.760	70.982	1.701	0.072
	2006	40.600	125.679	73.808	1.703	0.323
	2005	70.500	156.560	75.000	2.087	0.450
	2004	127.000	74.466	138.792	0.537	1.705
	2003	118.000	79.410	173.661	0.457	1.486
E20A022	2010	0.323	3.824	13.146	0.291	0.084
	2009	0.288	14.343	13.183	1.088	0.020
	2008	0.170	4.029	13.015	0.310	0.042
	2007	0.244	4.439	12.321	0.360	0.055
	2006	0.331	4.415	12.705	0.348	0.075
	2005	0.240	14.926	14.092	1.059	0.016
	2004	0.450	5.890	14.690	0.401	0.076
E20A025	2010	4.260	6.142	9.746	0.630	0.694
	2009	2.620	6.390	9.850	0.649	0.410
	2008	3.130	5.478	9.640	0.568	0.571

Station	Year	Average daily discharge (m^3/s)	Cross sectional area (m^2)	Water surface width (m)	Average depth (m)	Average velocity (m/s)
	2007	1.970	5.219	9.223	0.566	0.377
	2006	3.290	6.112	10.272	0.595	0.538
	2005	4.360	6.748	10.765	0.627	0.646
	2004	3.800	6.246	10.287	0.607	0.608

Stations	Drainage area (km^2)	Latitude	Longitude
E20A004	20,466	36°57′28″	35°38′03′′
E20A006	739.2	38°01′55″	36°34′11″
E20A007	623	37°20′29″	35°55′03″
E20A008	480	37°21′43″	36°05′05″
E20A020	14,705	37°16′01″	36°16′32″
E20A022	400	38°15′20″	37°32′01″
E20A025	914.7	38°25′19″	36°55′12″
E20A001	8484	37°37′15″	36°47′54″
E20A012	19,778.8	37°01′57″	35°48′43″
E20A015	915.2	38°25′21″	36°55′14″
D20A005	94	37°05′58″	36°20′12″

From: Hydraulic geometry analysis of Ceyhan River, Turkey

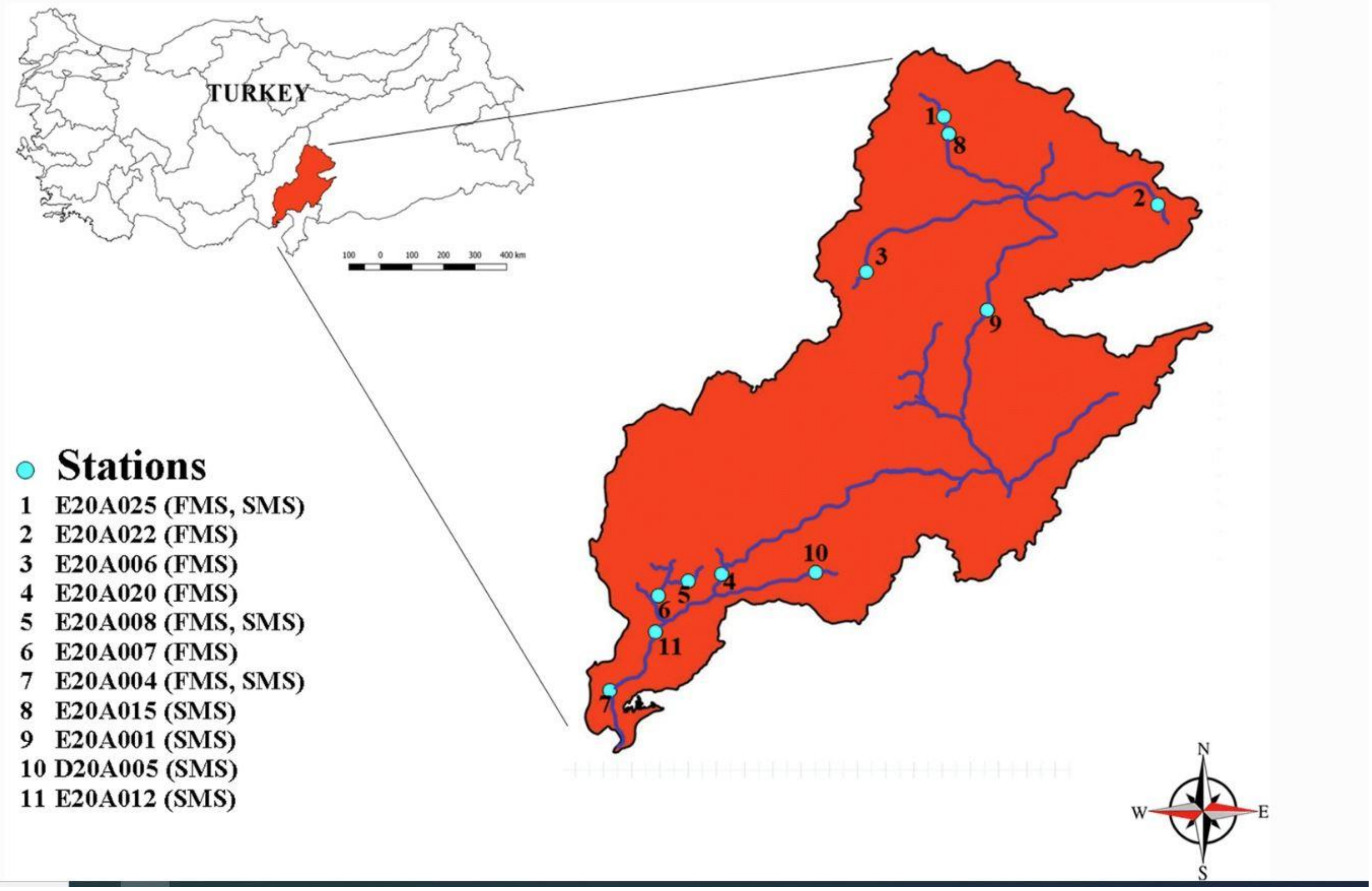

Figure 6.34 Map showing the locations of the stations within Ceyhan River Basin in Turkey at which data (Table 6.23) were collected for the determination of hydraulic geometry relationships (reproduced with permission).

Exercise 6.10. A short segment of an urban stream located to the northeast of Dallas requires erosion control measures. The stream profile is given in Table 6.24. Determine the number of segments that can adequately describe this profile. Determine the equations that best fit each segment. Calculate the equivalent slope of the reach.

Table 6.24 *Data for construction of longitudinal profile of an urban stream to the northeast of Dallas, Texas, USA*

Distance (m)	**Elevation (m)**	**Distance (m)**	**Elevation (m)**	**Distance (m)**	**Elevation (m)**
0.000	194.650	43.526	196.520	87.052	197.820
0.967	194.630	44.493	196.530	88.019	197.810
1.934	194.640	45.461	196.530	88.987	197.810
2.902	194.640	46.428	196.700	89.954	197.830
3.869	194.650	47.395	196.880	90.921	197.850
4.836	194.660	48.362	196.870	91.888	197.970
5.803	194.670	49.329	196.910	92.856	198.290
6.771	194.680	50.297	196.930	93.823	198.370
7.738	194.720	51.264	196.990	94.790	198.370

Distance (m)	Elevation (m)	Distance (m)	Elevation (m)	Distance (m)	Elevation (m)
8.705	194.730	52.231	197.000	95.757	198.600
9.672	194.780	53.198	197.040	96.724	198.720
10.640	194.830	54.166	197.020	97.692	198.750
11.607	194.860	55.133	197.080	98.659	198.750
12.574	194.850	56.100	197.020	99.626	198.750
13.541	194.950	57.067	197.090	100.593	198.750
14.509	194.920	58.035	197.110	101.561	198.760
15.476	195.030	59.002	197.150	102.528	198.760
16.443	195.180	59.969	197.160	103.495	198.770
17.410	195.400	60.936	197.170	104.462	198.750
18.378	195.380	61.904	197.170	105.430	198.750
19.345	195.350	62.871	197.170	106.397	198.760
20.312	195.420	63.838	197.150	107.364	198.800
21.279	195.780	64.805	197.150	108.331	198.830
22.247	196.080	65.773	197.150	109.299	198.840
23.214	196.420	66.740	197.110	110.266	198.880
24.181	196.420	67.707	197.150	111.233	198.940
25.148	196.300	68.674	197.160	112.200	198.900
26.116	196.260	69.642	197.160	113.168	198.900
27.083	196.280	70.609	197.180	114.135	198.880
28.050	196.280	71.576	197.190	115.102	198.880
29.017	196.280	72.543	197.180	116.069	198.920
29.985	196.280	73.511	197.200	117.037	198.930
30.952	196.270	74.478	197.200	118.004	198.920
31.919	196.280	75.445	197.210	118.971	198.900
32.886	196.280	76.412	197.210	119.938	198.930
33.854	196.280	77.380	197.210	120.906	198.930
34.821	196.290	78.347	197.220	121.873	198.970
35.788	196.290	79.314	197.220	122.840	199.060
36.755	196.280	80.281	197.220	123.807	199.100
37.723	196.290	81.249	197.210	124.775	199.150
38.690	196.390	82.216	197.220	125.742	199.190
39.657	196.520	83.183	197.350	126.709	199.250
40.624	196.520	84.150	197.800	127.676	199.160
41.592	196.510	85.118	197.800	128.644	199.120
42.559	196.520	86.085	197.820	129.611	199.120
				130.578	199.150
				131.545	199.170
				132.513	199.170
				133.480	199.310

Exercise 6.11. The hypsometric data for Astore Watershed within the Upper Indus basin (see Figure 18.2 in the color plate section) are given in Table 6.25. The highest elevation within this watershed is the peak of Nanga Parbat (8126 m), the ninth-highest mountain peak on the Earth. This watershed is on the Greater Himalayas. Determine the areas in different elevation zones and plot these as a function of cumulative area and compare this plot with the hypsometric curve.

Table 6.25 *Hypsometric data for Astore Watershed of Upper Indus basin*

Elevation (m)	**Cumulative Area (km^2)**
1213	0.008
1713	8.735
2213	45.881
2713	188.229
3213	537.747
3713	1239.540
4213	2395.673
4713	3575.932
5213	3895.256
5713	3950.995
6213	3972.800
6713	3981.568
7213	3985.771
7713	3987.719
8020	3988.140

Exercise 6.12. A closer examination of the longest flow path of the catchment shown in Figure 6.26 (catchment AVA MCC01 of Graham Branch watershed) reveals that shallow concentrated segment should be subdivided into two parts due to development upstream. The upper part is upland gullies, and the lower part is grassed. Similarly, the channel cross sections show variation from upstream to downstream such that they should be divided into at least three representative sections. Thus, the longest flow path is divided into six segments as shown in Figure 6.35 and the data given in Table 6.26. The upper part of the channel is like floodplain on pasture with short grass (cross section 2 given in Table 6.27), the middle portion is clean winding with some pools and shoals (cross section 1 as given in Table 6.15), and the lower portion is weedy with deep pools (cross section 3 given in Table 6.27). The lengths and elevations of the six segments are given in Table 6.26. Determine the watershed lag time and compare your result with that given in Example 6.3.

Table 6.26. Data for Exercise 6.12.

Flow path segments	**Elevation upstream (ft)**	**Elevation downstream (ft)**	**Length (ft)**
Sheet flow	674	673	100.00
Shallow concentrated flow 1 (upper)	673	657	642.45
Shallow concentrated flow 2 (lower)	657	646	461.80
Channel flow 1 (upper)	646	635	778.00

Flow path segments	Elevation upstream (ft)	Elevation downstream (ft)	Length (ft)
Channel flow 2 (middle)	635	632	813.62
Channel flow 3 (lower)	632	631	598.14

Table 6.27 *Station-elevation data for two cross sections along the stream segment shown in Figure 6.35*

Cross section 2				**Cross section 3**			
Station (ft)	**Elevation (ft)**	**Station (ft)**	**Elevation (ft)**	**Station (ft)**	**Elevation (ft)**	**Station (ft)**	**Elevation (ft)**
0.00	639.98	77.96	638.07	0.00	634.21	58.35	631.63
3.25	639.91	81.21	638.16	3.24	633.11	61.59	631.66
6.50	639.83	84.46	638.24	6.48	632.61	64.83	631.68
9.75	639.67	87.71	638.35	9.72	632.41	68.07	632.07
12.99	639.56	90.96	638.48	12.97	632.25	71.32	632.79
16.24	639.49	94.20	638.57	16.21	631.93	74.56	633.45
19.49	639.33	97.45	638.75	19.45	631.64	77.80	634.13
22.74	639.22	100.70	638.87	22.69	631.58	81.04	634.90
25.99	639.14	103.95	638.94	25.93	631.60	84.28	635.83
29.24	639.02	107.20	639.12	29.17	631.63	87.52	636.64
32.48	638.89	110.45	639.26	32.42	631.63	90.77	637.40
35.73	638.79	113.69	639.34	35.66	631.63	94.01	638.18
38.98	638.70	116.94	639.49	38.90	631.63	97.25	639.64
42.23	638.58	120.19	639.64	42.14	631.63	100.49	640.82
45.48	638.49	123.44	639.73	45.38	631.63	103.73	641.80
48.73	638.36	126.69	639.85	48.62	631.63	106.97	643.02
51.97	638.25	129.94	639.96	51.87	631.63	110.22	644.38
55.22	638.20	133.18	640.07	55.11	631.63	113.46	645.77
58.47	638.06	136.43	640.24			116.70	646.71
61.72	637.95	139.68	640.36				
64.97	637.90	142.93	640.44				
68.22	637.87	146.18	640.62				
71.47	637.92	149.43	640.75				
74.71	637.97	152.68	640.82				
		155.92	640.99				

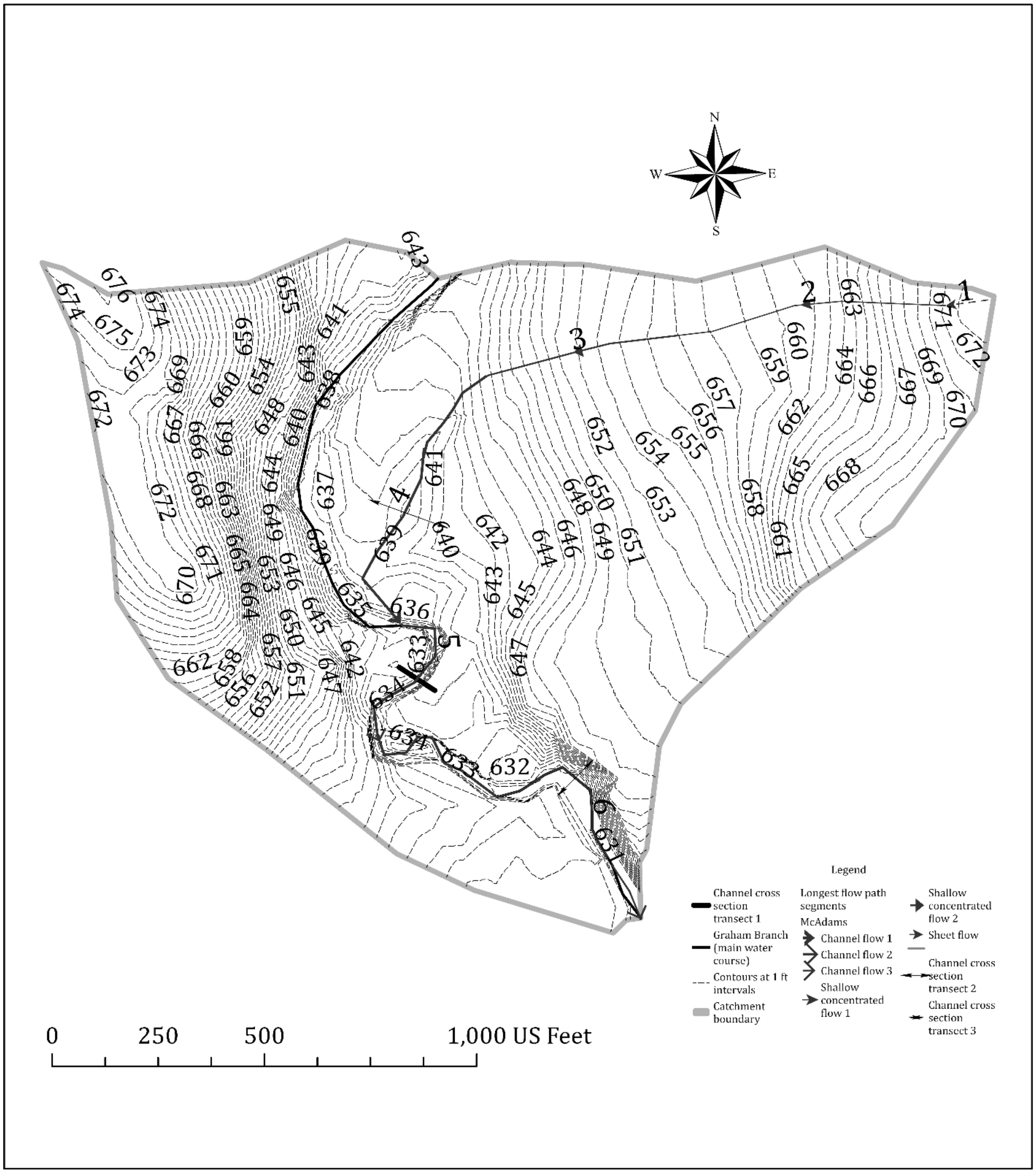

Figure 6.35 Segmental flow paths of a catchment within Graham Branch Watershed.

Chapter 7

Abstractions and Effectve Rainfall

Exercise 7.1. The map of soil texture class within Five Mile Creek watershed in Dallas, Texas, is shown in Figure 7.38 (see the color plate section). The percentages of soil texture classes and the Green-Ampt parameters for these soil texture classes are given in Table 7.21. Estimate the average Green-Ampt parameters for the watershed. Compare the results with those given in Example 7.7.

Table 7.21 *Soil textural classes and corresponding Geen-Ampt parameters of the soil cover of Five Mile Creek Watershed, Dallas, Texas, USA*

Texture class	**%**	**K_s (cm/h)**	**Ψ (cm)**	**η (cm³/cm³)**
Silty clay	43.97	0.05	29.21	0.42
Clay loam	20.50	0.10	20.828	0.31
Fine sandy loam	4.88	0.15	21.844	0.4
Clay	22.50	0.03	31.75	0.39
Loamy fine sand	1.53	3.05	6.096	0.4
Variable	6.45	0.10	26.162	0.35
Loam	0.16	0.25	8.89	0.43

Exercise 7.2. Rainfall records of a rainfall event of August 20, 1977, over Five Mile Creek Watershed are given in Table 7.22. For both the questions posed below, use the Green-Ampt parameters derived for HUC catchment 120301050107 in Example 7.7 and use the Green-Ampt model of infiltration to address the following questions.

(a) Assume that this rainfall occurred at a constant intensity for its entire duration. What would be the cumulative infiltration at the time of ponding? With this assumption, calculate and plot the time distribution of cumulative infiltration and infiltration rate. Compare the plots with one of the curves shown in Figure 7.7 and write what can be observed.

(b) For the actual rainfall time distribution, calculate the cumulative infiltration and infiltration rate as a function of time. Compare the results obtained in this case with the results obtained in the case of (a) above and write what can be observed.

Table 7.22 *Rainfall records of a rainfall event of August 20, 1977, over Five Mile Creek Watershed, Dallas, Texas, USA*

Date/Time	**Hours**	**Cumulative rainfall (in.)**
08/20/1977@02:00:00	0	0.0000
08/20/1977@02:15:00	0.25	0.0200
08/20/1977@02:30:00	0.5	0.1400
08/20/1977@02:45:00	0.75	0.1600
08/20/1977@03:00:00	1	0.1700
08/20/1977@03:15:00	1.25	0.1800

Date/Time	Hours	Cumulative rainfall (in.)
08/20/1977@03:30:00	1.5	0.2200
08/20/1977@03:45:00	1.75	0.2200
08/20/1977@04:00:00	2	0.2400
08/20/1977@04:15:00	2.25	0.2500
08/20/1977@04:30:00	2.5	0.3900
08/20/1977@04:35:00	2.5833	0.5200
08/20/1977@04:40:00	2.6667	0.6300
08/20/1977@04:45:00	2.75	0.7800
08/20/1977@04:50:00	2.8333	0.9900
08/20/1977@04:55:00	2.9167	1.1600
08/20/1977@05:00:00	3	1.3400
08/20/1977@05:05:00	3.0833	1.6400
08/20/1977@05:10:00	3.1667	1.8800
08/20/1977@05:15:00	3.25	2.0800
08/20/1977@05:20:00	3.3333	2.2200
08/20/1977@05:25:00	3.4167	2.3600
08/20/1977@05:30:00	3.5	2.5000
08/20/1977@05:35:00	3.5833	2.5900
08/20/1977@05:40:00	3.6667	2.6900
08/20/1977@05:45:00	3.75	2.7600
08/20/1977@05:50:00	3.8333	2.8200
08/20/1977@05:55:00	3.9167	2.8900
08/20/1977@06:00:00	4	2.9300
08/20/1977@06:05:00	4.0833	3.0200
08/20/1977@06:10:00	4.1667	3.0700
08/20/1977@06:15:00	4.25	3.1200
08/20/1977@06:20:00	4.3333	3.1600
08/20/1977@06:25:00	4.4167	3.1900
08/20/1977@06:30:00	4.5	3.2200
08/20/1977@06:35:00	4.5833	3.2300
08/20/1977@06:40:00	4.6667	3.2500
08/20/1977@06:45:00	4.75	3.2600
08/20/1977@07:00:00	5	3.2900
08/20/1977@07:15:00	5.25	3.2900
08/20/1977@07:20:00	5.3333	3.2900
08/20/1977@07:25:00	5.4167	3.2900
08/20/1977@07:30:00	5.5	3.2900
08/20/1977@07:35:00	5.5833	3.2900
08/20/1977@07:40:00	5.6667	3.2900
08/20/1977@07:45:00	5.75	3.2900
08/20/1977@07:50:00	5.8333	3.2900
08/20/1977@07:55:00	5.9167	3.2900

Date/Time	Hours	Cumulative rainfall (in.)
08/20/1977@08:00:00	6	3.2900
08/20/1977@08:05:00	6.0833	3.2900
08/20/1977@08:10:00	6.1667	3.2900
08/20/1977@08:15:00	6.25	3.2900
08/20/1977@08:30:00	6.5	3.2900
08/20/1977@08:45:00	6.75	3.2900
08/20/1977@09:00:00	7	3.2900
08/20/1977@09:15:00	7.25	3.2900
08/20/1977@09:30:00	7.5	3.2900
08/20/1977@10:00:00	8	3.2900
08/20/1977@11:00:00	9	3.2900
08/20/1977@12:00:00	10	3.2900
08/20/1977@13:00:00	11	3.2900
08/20/1977@14:00:00	12	3.2900
08/20/1977@15:00:00	13	3.2900
08/20/1977@16:00:00	14	3.2900
08/20/1977@17:00:00	15	3.3000

Exercise 7.3. Experimentally observed infiltration data on different types of soils were given by Rawls et al. (1976) in a report of the Agricultural Research Service of the U. S. Department of Agriculture. One dataset on infiltration measurements in Robertsdale loamy sand in the Georgia Coastal Plain is given in Table 6.23. From this dataset (a) estimate the parameters of Smith-Parlange infiltration model and (b) evaluate the approximation given by Eq. 7.46.

Table 7.23 *Experimental data for Robertsdale loamy sand from Georgia Coastal Plain, USA*

Time from Start of Water Application (min)	Infiltration Rate (cm/h)	Accumulated Infiltration (cm)
4	12.21	0.81
5	8.55	0.96
10	5.81	1.60
15	4.89	2.03
20	4.78	2.44
25	4.27	2.82
30	3.86	3.16
35	3.51	3.48
40	3.21	3.75
45	3.23	4.03
50	3.10	4.28
55	3.18	4.56
60	3.21	4.82
65	3.36	5.10
70	3.18	5.34
75	3.31	5.62
80	3.16	5.88

Time from Start of Water Application (min)	Infiltration Rate (cm/h)	Accumulated Infiltration (cm)
85	3.11	6.14
90	2.89	6.38
95	2.51	6.58
100	2.60	6.82
105	2.68	7.04
110	2.31	7.21
115	2.44	7.43
120	2.42	7.61

Exercise 7.4. A set of observed rainfall-runoff data from Turtle Creek Watershed (see Figure 4.42 and Figure 21.20), an urbanized watershed located to the north of downtown Dallas, Texas, are given in Table 7.24. From these data determine the NRCS Curve Number for the watershed.

Table 7.24 *Rainfall-runoff data from Turtle Creek Watershed, Dallas, Texas, USA*

Date mm/dd/yyyy	Rainfall total (cm)	Runoff total (cm)	Date mm/dd/yyyy	Rainfall total (cm)	Runoff total (cm)
11/17/1964	6.81	2.38	10/18/1971	12.50	7.41
5/9/1965	12.85	7.26	4/23/1973	5.61	3.36
2/9/1966	5.66	2.23	5/11/1973	4.65	2.37
4/28/1966	9.04	8.21	6/3/1973	13.69	9.13
6/17/1966	3.43	1.10	10/11/1973	6.32	2.76
4/20/1967	4.65	1.73	10/30/1973	4.85	2.05
5/30/1967	5.72	1.85	5/5/1974	5.89	3.19
3/19/1965	6.83	3.72	9/16/1974	9.30	4.97
4/22/1968	3.02	1.37	10/30/1974	8.59	4.93
5/13/1968	3.66	2.28	1/31/1975	9.14	5.50
8/13/1968	7.29	2.65	4/7/1975	6.17	3.33
10/9/1968	3.89	1.21	4/17/1976	9.93	4.94
1/29/1969	5.79	2.56	5/25/1976	4.34	1.72
5/4/1969	5.97	2.68	3/26/1977	14.48	8.78
5/6/1969	14.25	11.31	6/12/1977	5.21	1.45
10/12/1969	11.13	3.96	3/23/1978	3.23	1.17
8/31/1970	10.77	4.95	3/30/1979	8.31	5.57
8/14/1971	6.40	2.56	5/3/1979	10.74	7.45
10/3/1971	12.27	5.72	5/10/1979	6.05	3.18

Exercise 7.5. A set of observed rainfall-runoff data from Coombs Creek Watershed, an urbanized watershed located in the southern part of downtown Dallas (see Figure 21.20), Texas, are given in Table 7.25. From these data determine the Φ-index.

Table 7.25 *Rainfall-runoff data from Coombs Creek Watershed, Dallas, Texas, USA*

Date (mm/dd/yyy) at time (hh:mm:ss)	Cumulative rainfall (mm)	Date (mm/dd/yyy) at time (hh:mm:ss)	Discharge (m^3/s)
07/07/1973@18:00:00	0.00	07/07/1973@00:00:00	0.03
07/07/1973@18:15:00	8.38	07/07/1973@17:00:00	0.03
07/07/1973@18:30:00	14.48	07/07/1973@18:00:00	0.03
07/07/1973@18:45:00	14.73	07/07/1973@18:15:00	0.03
07/07/1973@19:00:00	14.73	07/07/1973@18:30:00	0.03
07/07/1973@19:10:00	21.84	07/07/1973@18:45:00	0.17
07/07/1973@19:15:00	27.94	07/07/1973@19:00:00	2.10
07/07/1973@19:20:00	33.02	07/07/1973@19:10:00	8.50
07/07/1973@19:30:00	46.99	07/07/1973@19:15:00	16.85
07/07/1973@19:35:00	52.07	07/07/1973@19:20:00	35.11
07/07/1973@19:45:00	62.23	07/07/1973@19:30:00	75.32
07/07/1973@19:55:00	68.58	07/07/1973@19:35:00	81.84
07/07/1973@20:00:00	69.60	07/07/1973@19:45:00	89.76
07/07/1973@20:15:00	72.39	07/07/1973@19:55:00	92.60
07/07/1973@20:30:00	72.64	07/07/1973@20:00:00	94.01
07/07/1973@20:45:00	72.64	07/07/1973@20:15:00	92.60
07/07/1973@21:00:00	72.64	07/07/1973@20:30:00	89.76
07/07/1973@21:15:00	72.64	07/07/1973@20:45:00	81.84
07/07/1973@21:30:00	73.41	07/07/1973@21:00:00	47.86
07/07/1973@22:00:00	74.42	07/07/1973@21:15:00	16.85
		07/07/1973@21:30:00	5.95
		07/07/1973@22:00:00	0.76
		07/07/1973@22:30:00	0.11
		07/08/1973@00:00:00	0.03

Exercise 7.6. Maps of hydrologic soil group and land cover of Five Mile Creek Watershed are shown in Figure 7.38 (see the color plate section). Using GIS, the area is divided into 103 polygonal areas each with a unique combination of land cover and hydrologic soil group. The results of the GIS analysis are presented in Table 7.26. Calculate the CN of the watershed.

Table 7.26 *Hydrologic soil cover complex and corresponding CN in the polygons enclosed by Five Mile Creek Watershed boundary, Dallas, Texas, USA*

Land Use	HSG	Area (m^2)	CN	Land Use	HSG	Area (m^2)	CN
Deciduous Forest	A	10952.43	57	Developed Open Space	A	1396580	52
Developed High Intensity	A	3029.109	88	Emergent Herbaceous Wetlands	A	345572.2	80
Developed Low Intensity	A	3508.201	81	Evergreen Forest	A	27899.88	36

Land Use	HSG	Area (m^2)	CN	Land Use	HSG	Area (m^2)	CN
Developed Medium Intensity	A	12648.13	84	Grassland/Herbaceous	A	1074409	0
Developed Open Space	A	1700.433	52	Mixed Forest	A	106964.2	57
Evergreen Forest	A	76234.43	36	Open Water	A	224834.2	98
Mixed Forest	A	2398.898	57	Pasture/Hay	A	509876.1	40
Shrub/Scrub	A	7753.261	35	Shrub/Scrub	A	131116.1	35
Barren Land	B	3077.523	86	Woody Wetlands	A	749804.1	86
Deciduous Forest	B	376379.5	73	Barren Land	B	27296.57	86
Developed High Intensity	B	160350.5	92	Cultivated Crops	B	91784.4	81
Developed Low Intensity	B	1115722	88	Deciduous Forest	B	2556558	73
Developed Medium Intensity	B	453600.8	89	Developed High Intensity	B	1941110	92
Developed Open Space	B	1418639	68	Developed Low Intensity	B	4391691	88
Evergreen Forest	B	205365.5	60	Developed Medium Intensity	B	2916816	89
Grassland/Herbaceous	B	38556.49	71	Developed Open Space	B	4685368	68
Mixed Forest	B	12444.63	73	Emergent Herbaceous Wetlands	B	93202.33	80
Shrub/Scrub	B	34550.75	56	Evergreen Forest	B	283375.2	60
Barren Land	C	2322.453	91	Grassland/Herbaceous	B	2004662	71
Deciduous Forest	C	2427435	82	Mixed Forest	B	297643.9	73
Developed High Intensity	C	2352922	93	Open Water	B	142488.4	98
Developed Low Intensity	C	8282498	90	Pasture/Hay	B	867429	61
Developed Medium Intensity	C	4603139	93	Shrub/Scrub	B	196182.1	56
Developed Open Space	C	6709729	78	Woody Wetlands	B	480923.8	86
Emergent Herbaceous Wetlands	C	3599.984	80	Barren Land	C	4499.98	91
Evergreen Forest	C	1033992	73	Deciduous Forest	C	3904159	82
Grassland/Herbaceous	C	1044595	81	Developed High Intensity	C	794599.4	93
Mixed Forest	C	167002.2	82	Developed Low Intensity	C	2716700	90
Pasture/Hay	C	279456.6	73	Developed Medium Intensity	C	1681338	93
Shrub/Scrub	C	158748.4	70	Developed Open Space	C	2316523	78
Woody Wetlands	C	23399.9	86	Emergent Herbaceous Wetlands	C	125924.8	80
Barren Land	D	25199.89	94	Evergreen Forest	C	266106.4	73
Cultivated Crops	D	251073.2	91	Grassland/Herbaceous	C	926229	81
Deciduous Forest	D	3553038	86	Mixed Forest	C	466909.8	82
Developed High Intensity	D	11680533	94	Open Water	C	22022.22	98
Developed Low Intensity	D	15972595	93	Pasture/Hay	C	303138.3	73
Developed Medium Intensity	D	14693521	94	Shrub/Scrub	C	153573.7	70
Developed Open Space	D	11376253	84	Woody Wetlands	C	1771657	86
Evergreen Forest	D	3898661	79	Barren Land	D	490952.5	94

Land Use	HSG	Area (m²)	CN	Land Use	HSG	Area (m²)	CN
Grassland/Herbaceous	D	3866004	89	Cultivated Crops	D	2257284	91
Mixed Forest	D	368051.8	86	Deciduous Forest	D	4860853	86
Pasture/Hay	D	325340.8	79	Developed High Intensity	D	8596733	94
Shrub/Scrub	D	395644.9	77	Developed Low Intensity	D	13517824	93
Woody Wetlands	D	1799.992	86	Developed Medium Intensity	D	10610361	94
Barren Land	A	217047.7	77	Developed Open Space	D	10438120	84
Cultivated Crops	A	58685.11	72	Emergent Herbaceous Wetlands	D	3435711	80
Deciduous Forest	A	1155302	57	Evergreen Forest	D	1784053	79
Developed High Intensity	A	435340.6	88	Grassland/Herbaceous	D	8682622	89
Developed Low Intensity	A	801245.3	81	Mixed Forest	D	491976.1	86
Developed Medium Intensity	A	843555.7	84	Open Water	D	1770322	98
				Pasture/Hay	D	1683878	79
				Shrub/Scrub	D	501960	77
				Woody Wetlands	D	8701086	86

Exercise 7.7. For the rainfall data given in Example 7.1, calculate the cumulative abstractions and excess rainfall hyetograph using the CN value calculated in Exercise 7.6. Compare the ERH obtained from the Green-Ampt method and the CN method. Which method seems more reliable and why?

Chapter 8

Groundwater and Baseflow

Exercise 8.1. A confined aquifer is 35 m thick and 8 km wide. A stream cuts through the aquifer. Two observation wells are located 1.5 km apart in the direction of flow. The head in well 1 is 98.5 m and in well 2 it is 90 m. The hydraulic conductivity of the aquifer is 1.3 m/d. What is the total daily baseflow contribution to the stream?

Exercise 8.2. A stream cuts through an unconfined aquifer along 100 m of its length. The hydraulic conductivity of the aquifer is 1.8×10^{-3} cm/s. Two observation wells located 100 m apart and penetrating to the bottom of the aquifer record water heights of 7.5 m and 6 m, respectively. Calculate the baseflow contribution from this aquifer to the stream.

Exercise 8.3. During the period shown in Figure 8.1, the hydrograph data recorded at Short, Oklahoma, resulting from a storm event that occurred on 6/19/2019 over Lee Creek watershed are given in Table 8.4 (in three parts: A, B, and C). Separate the baseflow using (1) master recession curve method and (2) digital filter method and compare the results. Determine the recession constant for an exponential baseflow model. With the exponential recession model, what was the volume of water that remained stored in the watershed?

Table 8.4. *Hydrograph of Lee Creek, Short, Oklahoma, USA for a storm even of June 19 2019.*

Part A							
Date/time	**Flow (ft^3/s)**	**Date/time**	**Flow (ft^3/s)**	**Date/time**	**Flow (ft^3/s)**	**Date/time**	**Flow (ft^3/s)**
6/4/19 10:15	755	6/5/19 0:00	548	6/6/19 0:00	424	6/7/19 0:00	11800
6/4/19 10:30	755	6/5/19 0:15	548	6/6/19 0:15	424	6/7/19 0:15	12300
6/4/19 10:45	755	6/5/19 0:30	543	6/6/19 0:30	424	6/7/19 0:30	13100
6/4/19 11:00	749	6/5/19 0:45	543	6/6/19 0:45	420	6/7/19 0:45	13700
6/4/19 11:15	749	6/5/19 1:00	538	6/6/19 1:00	420	6/7/19 1:00	14400
6/4/19 11:30	736	6/5/19 1:15	538	6/6/19 1:15	420	6/7/19 1:15	15200
6/4/19 11:45	736	6/5/19 1:30	538	6/6/19 1:30	420	6/7/19 1:30	16400
6/4/19 12:00	729	6/5/19 1:45	533	6/6/19 1:45	415	6/7/19 1:45	17300
6/4/19 12:15	723	6/5/19 2:00	533	6/6/19 2:00	415	6/7/19 2:00	18400
6/4/19 12:30	716	6/5/19 2:15	533	6/6/19 2:15	415	6/7/19 2:15	19400
6/4/19 12:45	710	6/5/19 2:30	528	6/6/19 2:30	415	6/7/19 2:30	20300
6/4/19 13:00	710	6/5/19 2:45	528	6/6/19 2:45	415	6/7/19 2:45	21400
6/4/19 13:15	704	6/5/19 3:00	523	6/6/19 3:00	415	6/7/19 3:00	22600
6/4/19 13:30	698	6/5/19 3:15	523	6/6/19 3:15	411	6/7/19 3:15	23500
6/4/19 13:45	691	6/5/19 3:30	523	6/6/19 3:30	411	6/7/19 3:30	24600
6/4/19 14:00	691	6/5/19 3:45	518	6/6/19 3:45	411	6/7/19 3:45	25600
6/4/19 14:15	679	6/5/19 4:00	518	6/6/19 4:00	411	6/7/19 4:00	26400
6/4/19 14:30	679	6/5/19 4:15	518	6/6/19 4:15	411	6/7/19 4:15	27400
6/4/19 14:45	673	6/5/19 4:30	513	6/6/19 4:30	411	6/7/19 4:30	28300
6/4/19 15:00	667	6/5/19 4:45	513	6/6/19 4:45	407	6/7/19 4:45	28600
6/4/19 15:15	667	6/5/19 5:00	508	6/6/19 5:00	407	6/7/19 5:00	28800
6/4/19 15:30	661	6/5/19 5:15	508	6/6/19 5:15	407	6/7/19 5:15	28700

Part A							
Date/time	**Flow (ft^3/s)**	**Date/time**	**Flow (ft^3/s)**	**Date/time**	**Flow (ft^3/s)**	**Date/time**	**Flow (ft^3/s)**
6/4/19 15:45	655	6/5/19 5:30	503	6/6/19 5:30	407	6/7/19 5:30	28300
6/4/19 16:00	649	6/5/19 5:45	503	6/6/19 5:45	407	6/7/19 5:45	27000
6/4/19 16:15	643	6/5/19 6:00	503	6/6/19 6:00	403	6/7/19 6:00	25200
6/4/19 16:30	637	6/5/19 6:15	503	6/6/19 6:15	403	6/7/19 6:15	22900
6/4/19 16:45	637	6/5/19 6:30	498	6/6/19 6:30	403	6/7/19 6:30	20200
6/4/19 17:00	631	6/5/19 6:45	498	6/6/19 6:45	403	6/7/19 6:45	17400
6/4/19 17:15	631	6/5/19 7:00	498	6/6/19 7:00	403	6/7/19 7:00	14500
6/4/19 17:30	625	6/5/19 7:15	493	6/6/19 7:15	403	6/7/19 7:15	12400
6/4/19 17:45	620	6/5/19 7:30	493	6/6/19 7:30	403	6/7/19 7:30	10700
6/4/19 18:00	620	6/5/19 7:45	493	6/6/19 7:45	403	6/7/19 7:45	9550
6/4/19 18:15	614	6/5/19 8:00	488	6/6/19 8:00	403	6/7/19 8:00	8870
6/4/19 18:30	608	6/5/19 8:15	488	6/6/19 8:15	398	6/7/19 8:15	8340
6/4/19 18:45	608	6/5/19 8:30	488	6/6/19 8:30	398	6/7/19 8:30	8040
6/4/19 19:00	608	6/5/19 8:45	488	6/6/19 8:45	398	6/7/19 8:45	7740
6/4/19 19:15	603	6/5/19 9:00	483	6/6/19 9:00	398	6/7/19 9:00	7560
6/4/19 19:30	597	6/5/19 9:15	483	6/6/19 9:15	403	6/7/19 9:15	7370
6/4/19 19:45	597	6/5/19 9:30	478	6/6/19 9:30	403	6/7/19 9:30	7220
6/4/19 20:00	592	6/5/19 9:45	478	6/6/19 9:45	403	6/7/19 9:45	7090
6/4/19 20:15	586	6/5/19 10:00	478	6/6/19 10:00	403	6/7/19 10:00	6960
6/4/19 20:30	586	6/5/19 10:15	478	6/6/19 10:15	403	6/7/19 10:15	6830
6/4/19 20:45	586	6/5/19 10:30	474	6/6/19 10:30	407	6/7/19 10:30	6680
6/4/19 21:00	581	6/5/19 10:45	474	6/6/19 10:45	407	6/7/19 10:45	6570
6/4/19 21:15	581	6/5/19 11:00	474	6/6/19 11:00	407	6/7/19 11:00	6430
6/4/19 21:30	575	6/5/19 11:15	474	6/6/19 11:15	407	6/7/19 11:15	6380
6/4/19 21:45	570	6/5/19 11:30	469	6/6/19 11:30	407	6/7/19 11:30	6240
6/4/19 22:00	570	6/5/19 11:45	469	6/6/19 11:45	407	6/7/19 11:45	6120
6/4/19 22:15	570	6/5/19 12:00	469	6/6/19 12:00	407	6/7/19 12:00	6030
6/4/19 22:30	564	6/5/19 12:15	464	6/6/19 12:15	407	6/7/19 12:15	5890
6/4/19 22:45	564	6/5/19 12:30	464	6/6/19 12:30	411	6/7/19 12:30	5860
6/4/19 23:00	559	6/5/19 12:45	464	6/6/19 12:45	411	6/7/19 12:45	5760
6/4/19 23:15	559	6/5/19 13:00	464	6/6/19 13:00	411	6/7/19 13:00	5730
6/4/19 23:30	554	6/5/19 13:15	464	6/6/19 13:15	411	6/7/19 13:15	5660
6/4/19 23:45	548	6/5/19 13:30	460	6/6/19 13:30	415	6/7/19 13:30	5590
		6/5/19 13:45	460	6/6/19 13:45	415	6/7/19 13:45	5560
		6/5/19 14:00	460	6/6/19 14:00	415	6/7/19 14:00	5460
		6/5/19 14:15	455	6/6/19 14:15	420	6/7/19 14:15	5480
		6/5/19 14:30	455	6/6/19 14:30	420	6/7/19 14:30	5430
		6/5/19 14:45	455	6/6/19 14:45	424	6/7/19 14:45	5350
		6/5/19 15:00	455	6/6/19 15:00	428	6/7/19 15:00	5320
		6/5/19 15:15	455	6/6/19 15:15	428	6/7/19 15:15	5240
		6/5/19 15:30	455	6/6/19 15:30	433	6/7/19 15:30	5180

Part A							
Date/time	**Flow (ft^3/s)**	**Date/time**	**Flow (ft^3/s)**	**Date/time**	**Flow (ft^3/s)**	**Date/time**	**Flow (ft^3/s)**
		6/5/19 15:45	451	6/6/19 15:45	433	6/7/19 15:45	5160
		6/5/19 16:00	451	6/6/19 16:00	433	6/7/19 16:00	5100
		6/5/19 16:15	451	6/6/19 16:15	437	6/7/19 16:15	5080
		6/5/19 16:30	446	6/6/19 16:30	446	6/7/19 16:30	5040
		6/5/19 16:45	446	6/6/19 16:45	451	6/7/19 16:45	5010
		6/5/19 17:00	446	6/6/19 17:00	464	6/7/19 17:00	5010
		6/5/19 17:15	446	6/6/19 17:15	474	6/7/19 17:15	5010
		6/5/19 17:30	442	6/6/19 17:30	474	6/7/19 17:30	4990
		6/5/19 17:45	442	6/6/19 17:45	483	6/7/19 17:45	4980
		6/5/19 18:00	442	6/6/19 18:00	488	6/7/19 18:00	4950
		6/5/19 18:15	442	6/6/19 18:15	592	6/7/19 18:15	4930
		6/5/19 18:30	442	6/6/19 18:30	1260	6/7/19 18:30	4920
		6/5/19 18:45	442	6/6/19 18:45	1880	6/7/19 18:45	4920
		6/5/19 19:00	442	6/6/19 19:00	2160	6/7/19 19:00	4900
		6/5/19 19:15	442	6/6/19 19:15	2140	6/7/19 19:15	4920
		6/5/19 19:30	442	6/6/19 19:30	2030	6/7/19 19:30	4930
		6/5/19 19:45	437	6/6/19 19:45	1860	6/7/19 19:45	4980
		6/5/19 20:00	437	6/6/19 20:00	1750	6/7/19 20:00	5040
		6/5/19 20:15	437	6/6/19 20:15	1730	6/7/19 20:15	5320
		6/5/19 20:30	437	6/6/19 20:30	1990	6/7/19 20:30	5660
		6/5/19 20:45	437	6/6/19 20:45	3230	6/7/19 20:45	5950
		6/5/19 21:00	437	6/6/19 21:00	4130	6/7/19 21:00	6100
		6/5/19 21:15	433	6/6/19 21:15	4630	6/7/19 21:15	6150
		6/5/19 21:30	433	6/6/19 21:30	4900	6/7/19 21:30	6170
		6/5/19 21:45	433	6/6/19 21:45	5210	6/7/19 21:45	6210
		6/5/19 22:00	433	6/6/19 22:00	5740	6/7/19 22:00	6210
		6/5/19 22:15	433	6/6/19 22:15	6520	6/7/19 22:15	6190
		6/5/19 22:30	428	6/6/19 22:30	7400	6/7/19 22:30	6150
		6/5/19 22:45	428	6/6/19 22:45	8200	6/7/19 22:45	6050
		6/5/19 23:00	428	6/6/19 23:00	9070	6/7/19 23:00	6010
		6/5/19 23:15	428	6/6/19 23:15	9690	6/7/19 23:15	5890
		6/5/19 23:30	428	6/6/19 23:30	10400	6/7/19 23:30	5830
		6/5/19 23:45	424	6/6/19 23:45	11100	6/7/19 23:45	5760

Part B

Date/time	Flow (ft^3/s)	Date/time	Flow (ft^3/s)	Date/time	Flow (ft^3/s)	Date/time	Flow (ft^3/s)
6/8/19 0:00	5660	6/9/19 0:00	2660	6/10/19 0:00	1550	6/11/19 0:00	1010
6/8/19 0:15	5610	6/9/19 0:15	2630	6/10/19 0:15	1540	6/11/19 0:15	998
6/8/19 0:30	5530	6/9/19 0:30	2610	6/10/19 0:30	1530	6/11/19 0:30	998
6/8/19 0:45	5460	6/9/19 0:45	2600	6/10/19 0:45	1530	6/11/19 0:45	998
6/8/19 1:00	5400	6/9/19 1:00	2570	6/10/19 1:00	1520	6/11/19 1:00	989
6/8/19 1:15	5380	6/9/19 1:15	2540	6/10/19 1:15	1520	6/11/19 1:15	981
6/8/19 1:30	5320	6/9/19 1:30	2520	6/10/19 1:30	1510	6/11/19 1:30	981
6/8/19 1:45	5300	6/9/19 1:45	2510	6/10/19 1:45	1500	6/11/19 1:45	973
6/8/19 2:00	5300	6/9/19 2:00	2500	6/10/19 2:00	1490	6/11/19 2:00	973
6/8/19 2:15	5340	6/9/19 2:15	2470	6/10/19 2:15	1490	6/11/19 2:15	966
6/8/19 2:30	5320	6/9/19 2:30	2440	6/10/19 2:30	1480	6/11/19 2:30	958
6/8/19 2:45	5380	6/9/19 2:45	2420	6/10/19 2:45	1470	6/11/19 2:45	958
6/8/19 3:00	5420	6/9/19 3:00	2410	6/10/19 3:00	1450	6/11/19 3:00	958
6/8/19 3:15	5450	6/9/19 3:15	2400	6/10/19 3:15	1450	6/11/19 3:15	950
6/8/19 3:30	5430	6/9/19 3:30	2370	6/10/19 3:30	1440	6/11/19 3:30	942
6/8/19 3:45	5420	6/9/19 3:45	2360	6/10/19 3:45	1430	6/11/19 3:45	934
6/8/19 4:00	5400	6/9/19 4:00	2340	6/10/19 4:00	1430	6/11/19 4:00	934
6/8/19 4:15	5340	6/9/19 4:15	2330	6/10/19 4:15	1430	6/11/19 4:15	934
6/8/19 4:30	5290	6/9/19 4:30	2310	6/10/19 4:30	1410	6/11/19 4:30	927
6/8/19 4:45	5210	6/9/19 4:45	2290	6/10/19 4:45	1410	6/11/19 4:45	927
6/8/19 5:00	5160	6/9/19 5:00	2270	6/10/19 5:00	1400	6/11/19 5:00	919
6/8/19 5:15	5080	6/9/19 5:15	2260	6/10/19 5:15	1390	6/11/19 5:15	919
6/8/19 5:30	5010	6/9/19 5:30	2250	6/10/19 5:30	1380	6/11/19 5:30	911
6/8/19 5:45	4950	6/9/19 5:45	2230	6/10/19 5:45	1380	6/11/19 5:45	911
6/8/19 6:00	4870	6/9/19 6:00	2220	6/10/19 6:00	1370	6/11/19 6:00	904
6/8/19 6:15	4800	6/9/19 6:15	2210	6/10/19 6:15	1370	6/11/19 6:15	904
6/8/19 6:30	4720	6/9/19 6:30	2190	6/10/19 6:30	1360	6/11/19 6:30	904
6/8/19 6:45	4680	6/9/19 6:45	2180	6/10/19 6:45	1350	6/11/19 6:45	896
6/8/19 7:00	4620	6/9/19 7:00	2160	6/10/19 7:00	1350	6/11/19 7:00	896
6/8/19 7:15	4580	6/9/19 7:15	2140	6/10/19 7:15	1340	6/11/19 7:15	889
6/8/19 7:30	4550	6/9/19 7:30	2140	6/10/19 7:30	1330	6/11/19 7:30	889
6/8/19 7:45	4500	6/9/19 7:45	2120	6/10/19 7:45	1330	6/11/19 7:45	881
6/8/19 8:00	4450	6/9/19 8:00	2120	6/10/19 8:00	1320	6/11/19 8:00	881
6/8/19 8:15	4390	6/9/19 8:15	2100	6/10/19 8:15	1320	6/11/19 8:15	874
6/8/19 8:30	4350	6/9/19 8:30	2090	6/10/19 8:30	1320	6/11/19 8:30	874
6/8/19 8:45	4310	6/9/19 8:45	2080	6/10/19 8:45	1310	6/11/19 8:45	867
6/8/19 9:00	4270	6/9/19 9:00	2070	6/10/19 9:00	1300	6/11/19 9:00	867
6/8/19 9:15	4220	6/9/19 9:15	2050	6/10/19 9:15	1290	6/11/19 9:15	867
6/8/19 9:30	4180	6/9/19 9:30	2040	6/10/19 9:30	1290	6/11/19 9:30	859
6/8/19 9:45	4160	6/9/19 9:45	2040	6/10/19 9:45	1280	6/11/19 9:45	859
6/8/19 10:00	4100	6/9/19 10:00	2030	6/10/19 10:00	1280	6/11/19 10:00	852

Part B

Date/time	Flow (ft^3/s)	Date/time	Flow (ft^3/s)	Date/time	Flow (ft^3/s)	Date/time	Flow (ft^3/s)
6/8/19 10:15	4080	6/9/19 10:15	2020	6/10/19 10:15	1270	6/11/19 10:15	852
6/8/19 10:30	4050	6/9/19 10:30	2010	6/10/19 10:30	1260	6/11/19 10:30	845
6/8/19 10:45	4010	6/9/19 10:45	1990	6/10/19 10:45	1260	6/11/19 10:45	845
6/8/19 11:00	3980	6/9/19 11:00	1990	6/10/19 11:00	1250	6/11/19 11:00	845
6/8/19 11:15	3960	6/9/19 11:15	1980	6/10/19 11:15	1250	6/11/19 11:15	838
6/8/19 11:30	3930	6/9/19 11:30	1980	6/10/19 11:30	1240	6/11/19 11:30	831
6/8/19 11:45	3900	6/9/19 11:45	1970	6/10/19 11:45	1240	6/11/19 11:45	831
6/8/19 12:00	3860	6/9/19 12:00	1950	6/10/19 12:00	1230	6/11/19 12:00	831
6/8/19 12:15	3840	6/9/19 12:15	1950	6/10/19 12:15	1220	6/11/19 12:15	831
6/8/19 12:30	3810	6/9/19 12:30	1940	6/10/19 12:30	1220	6/11/19 12:30	824
6/8/19 12:45	3770	6/9/19 12:45	1930	6/10/19 12:45	1220	6/11/19 12:45	824
6/8/19 13:00	3750	6/9/19 13:00	1910	6/10/19 13:00	1220	6/11/19 13:00	824
6/8/19 13:15	3720	6/9/19 13:15	1900	6/10/19 13:15	1210	6/11/19 13:15	817
6/8/19 13:30	3700	6/9/19 13:30	1900	6/10/19 13:30	1210	6/11/19 13:30	817
6/8/19 13:45	3690	6/9/19 13:45	1890	6/10/19 13:45	1200	6/11/19 13:45	810
6/8/19 14:00	3660	6/9/19 14:00	1890	6/10/19 14:00	1200	6/11/19 14:00	810
6/8/19 14:15	3620	6/9/19 14:15	1880	6/10/19 14:15	1200	6/11/19 14:15	810
6/8/19 14:30	3590	6/9/19 14:30	1880	6/10/19 14:30	1190	6/11/19 14:30	803
6/8/19 14:45	3570	6/9/19 14:45	1860	6/10/19 14:45	1180	6/11/19 14:45	803
6/8/19 15:00	3560	6/9/19 15:00	1850	6/10/19 15:00	1180	6/11/19 15:00	796
6/8/19 15:15	3540	6/9/19 15:15	1840	6/10/19 15:15	1170	6/11/19 15:15	796
6/8/19 15:30	3500	6/9/19 15:30	1840	6/10/19 15:30	1160	6/11/19 15:30	796
6/8/19 15:45	3490	6/9/19 15:45	1820	6/10/19 15:45	1160	6/11/19 15:45	796
6/8/19 16:00	3460	6/9/19 16:00	1810	6/10/19 16:00	1150	6/11/19 16:00	789
6/8/19 16:15	3440	6/9/19 16:15	1800	6/10/19 16:15	1150	6/11/19 16:15	789
6/8/19 16:30	3420	6/9/19 16:30	1800	6/10/19 16:30	1140	6/11/19 16:30	789
6/8/19 16:45	3390	6/9/19 16:45	1790	6/10/19 16:45	1140	6/11/19 16:45	782
6/8/19 17:00	3370	6/9/19 17:00	1780	6/10/19 17:00	1130	6/11/19 17:00	782
6/8/19 17:15	3360	6/9/19 17:15	1780	6/10/19 17:15	1120	6/11/19 17:15	775
6/8/19 17:30	3320	6/9/19 17:30	1760	6/10/19 17:30	1120	6/11/19 17:30	775
6/8/19 17:45	3310	6/9/19 17:45	1760	6/10/19 17:45	1120	6/11/19 17:45	769
6/8/19 18:00	3290	6/9/19 18:00	1750	6/10/19 18:00	1120	6/11/19 18:00	769
6/8/19 18:15	3260	6/9/19 18:15	1740	6/10/19 18:15	1110	6/11/19 18:15	769
6/8/19 18:30	3230	6/9/19 18:30	1740	6/10/19 18:30	1110	6/11/19 18:30	769
6/8/19 18:45	3220	6/9/19 18:45	1730	6/10/19 18:45	1100	6/11/19 18:45	762
6/8/19 19:00	3190	6/9/19 19:00	1710	6/10/19 19:00	1100	6/11/19 19:00	762
6/8/19 19:15	3160	6/9/19 19:15	1710	6/10/19 19:15	1090	6/11/19 19:15	762
6/8/19 19:30	3130	6/9/19 19:30	1700	6/10/19 19:30	1090	6/11/19 19:30	755
6/8/19 19:45	3100	6/9/19 19:45	1690	6/10/19 19:45	1080	6/11/19 19:45	755
6/8/19 20:00	3060	6/9/19 20:00	1680	6/10/19 20:00	1080	6/11/19 20:00	755
6/8/19 20:15	3050	6/9/19 20:15	1680	6/10/19 20:15	1070	6/11/19 20:15	749

Part B

Date/time	Flow (ft³/s)	Date/time	Flow (ft³/s)	Date/time	Flow (ft³/s)	Date/time	Flow (ft³/s)
6/8/19 20:30	3010	6/9/19 20:30	1670	6/10/19 20:30	1070	6/11/19 20:30	749
6/8/19 20:45	3000	6/9/19 20:45	1660	6/10/19 20:45	1060	6/11/19 20:45	749
6/8/19 21:00	2960	6/9/19 21:00	1660	6/10/19 21:00	1060	6/11/19 21:00	742
6/8/19 21:15	2930	6/9/19 21:15	1640	6/10/19 21:15	1060	6/11/19 21:15	742
6/8/19 21:30	2920	6/9/19 21:30	1630	6/10/19 21:30	1050	6/11/19 21:30	736
6/8/19 21:45	2890	6/9/19 21:45	1630	6/10/19 21:45	1050	6/11/19 21:45	736
6/8/19 22:00	2850	6/9/19 22:00	1620	6/10/19 22:00	1040	6/11/19 22:00	736
6/8/19 22:15	2840	6/9/19 22:15	1610	6/10/19 22:15	1040	6/11/19 22:15	736
6/8/19 22:30	2810	6/9/19 22:30	1610	6/10/19 22:30	1030	6/11/19 22:30	729
6/8/19 22:45	2780	6/9/19 22:45	1600	6/10/19 22:45	1030	6/11/19 22:45	729
6/8/19 23:00	2760	6/9/19 23:00	1590	6/10/19 23:00	1020	6/11/19 23:00	723
6/8/19 23:15	2730	6/9/19 23:15	1580	6/10/19 23:15	1020	6/11/19 23:15	723
6/8/19 23:30	2700	6/9/19 23:30	1560	6/10/19 23:30	1010	6/11/19 23:30	723
6/8/19 23:45	2690	6/9/19 23:45	1550	6/10/19 23:45	1010	6/11/19 23:45	716

Part C

Date/time	Flow (ft³/s)	Date/time	Flow (ft³/s)	Date/time	Flow (ft³/s)
6/12/19 0:00	716	6/13/19 0:00	559	6/14/19 0:00	451
6/12/19 0:15	710	6/13/19 0:15	559	6/14/19 0:15	451
6/12/19 0:30	710	6/13/19 0:30	554	6/14/19 0:30	451
6/12/19 0:45	710	6/13/19 0:45	554	6/14/19 0:45	451
6/12/19 1:00	710	6/13/19 1:00	554	6/14/19 1:00	446
6/12/19 1:15	704	6/13/19 1:15	554	6/14/19 1:15	446
6/12/19 1:30	704	6/13/19 1:30	548	6/14/19 1:30	446
6/12/19 1:45	704	6/13/19 1:45	548	6/14/19 1:45	446
6/12/19 2:00	698	6/13/19 2:00	548	6/14/19 2:00	442
6/12/19 2:15	698	6/13/19 2:15	543	6/14/19 2:15	442
6/12/19 2:30	698	6/13/19 2:30	543	6/14/19 2:30	442
6/12/19 2:45	698	6/13/19 2:45	543	6/14/19 2:45	442
6/12/19 3:00	691	6/13/19 3:00	543	6/14/19 3:00	437
6/12/19 3:15	691	6/13/19 3:15	543	6/14/19 3:15	437
6/12/19 3:30	685	6/13/19 3:30	538	6/14/19 3:30	437
6/12/19 3:45	685	6/13/19 3:45	538	6/14/19 3:45	437
6/12/19 4:00	679	6/13/19 4:00	538	6/14/19 4:00	433
6/12/19 4:15	679	6/13/19 4:15	538	6/14/19 4:15	437
6/12/19 4:30	679	6/13/19 4:30	538	6/14/19 4:30	433
6/12/19 4:45	679	6/13/19 4:45	533	6/14/19 4:45	433
6/12/19 5:00	673	6/13/19 5:00	533	6/14/19 5:00	433
6/12/19 5:15	673	6/13/19 5:15	533	6/14/19 5:15	428

Part C

Date/time	Flow (ft^3/s)	Date/time	Flow (ft^3/s)	Date/time	Flow (ft^3/s)
6/12/19 5:30	673	6/13/19 5:30	528	6/14/19 5:30	428
6/12/19 5:45	673	6/13/19 5:45	528	6/14/19 5:45	428
6/12/19 6:00	667	6/13/19 6:00	528	6/14/19 6:00	428
6/12/19 6:15	667	6/13/19 6:15	528	6/14/19 6:15	428
6/12/19 6:30	667	6/13/19 6:30	528	6/14/19 6:30	428
6/12/19 6:45	667	6/13/19 6:45	523	6/14/19 6:45	424
6/12/19 7:00	661	6/13/19 7:00	523		
6/12/19 7:15	661	6/13/19 7:15	523		
6/12/19 7:30	661	6/13/19 7:30	523		
6/12/19 7:45	655	6/13/19 7:45	518		
6/12/19 8:00	655	6/13/19 8:00	518		
6/12/19 8:15	655	6/13/19 8:15	518		
6/12/19 8:30	649	6/13/19 8:30	518		
6/12/19 8:45	649	6/13/19 8:45	518		
6/12/19 9:00	649	6/13/19 9:00	513		
6/12/19 9:15	643	6/13/19 9:15	513		
6/12/19 9:30	643	6/13/19 9:30	513		
6/12/19 9:45	643	6/13/19 9:45	513		
6/12/19 10:00	637	6/13/19 10:00	508		
6/12/19 10:15	637	6/13/19 10:15	508		
6/12/19 10:30	637	6/13/19 10:30	508		
6/12/19 10:45	637	6/13/19 10:45	508		
6/12/19 11:00	631	6/13/19 11:00	503		
6/12/19 11:15	631	6/13/19 11:15	503		
6/12/19 11:30	631	6/13/19 11:30	503		
6/12/19 11:45	625	6/13/19 11:45	503		
6/12/19 12:00	625	6/13/19 12:00	498		
6/12/19 12:15	625	6/13/19 12:15	498		
6/12/19 12:30	620	6/13/19 12:30	498		
6/12/19 12:45	620	6/13/19 12:45	498		
6/12/19 13:00	620	6/13/19 13:00	498		
6/12/19 13:15	620	6/13/19 13:15	493		
6/12/19 13:30	614	6/13/19 13:30	493		
6/12/19 13:45	614	6/13/19 13:45	493		
6/12/19 14:00	614	6/13/19 14:00	493		
6/12/19 14:15	614	6/13/19 14:15	493		
6/12/19 14:30	608	6/13/19 14:30	493		
6/12/19 14:45	608	6/13/19 14:45	488		
6/12/19 15:00	603	6/13/19 15:00	488		
6/12/19 15:15	608	6/13/19 15:15	488		

Part C

Date/time	Flow (ft^3/s)	Date/time	Flow (ft^3/s)	Date/time	Flow (ft^3/s)
6/12/19 15:30	608	6/13/19 15:30	488		
6/12/19 15:45	603	6/13/19 15:45	488		
6/12/19 16:00	603	6/13/19 16:00	488		
6/12/19 16:15	603	6/13/19 16:15	488		
6/12/19 16:30	603	6/13/19 16:30	483		
6/12/19 16:45	603	6/13/19 16:45	483		
6/12/19 17:00	597	6/13/19 17:00	483		
6/12/19 17:15	597	6/13/19 17:15	478		
6/12/19 17:30	597	6/13/19 17:30	478		
6/12/19 17:45	592	6/13/19 17:45	478		
6/12/19 18:00	592	6/13/19 18:00	478		
6/12/19 18:15	592	6/13/19 18:15	474		
6/12/19 18:30	592	6/13/19 18:30	478		
6/12/19 18:45	586	6/13/19 18:45	474		
6/12/19 19:00	586	6/13/19 19:00	474		
6/12/19 19:15	586	6/13/19 19:15	474		
6/12/19 19:30	581	6/13/19 19:30	469		
6/12/19 19:45	581	6/13/19 19:45	469		
6/12/19 20:00	581	6/13/19 20:00	469		
6/12/19 20:15	581	6/13/19 20:15	469		
6/12/19 20:30	575	6/13/19 20:30	469		
6/12/19 20:45	575	6/13/19 20:45	464		
6/12/19 21:00	575	6/13/19 21:00	464		
6/12/19 21:15	575	6/13/19 21:15	464		
6/12/19 21:30	570	6/13/19 21:30	464		
6/12/19 21:45	570	6/13/19 21:45	464		
6/12/19 22:00	570	6/13/19 22:00	460		
6/12/19 22:15	570	6/13/19 22:15	460		
6/12/19 22:30	564	6/13/19 22:30	460		
6/12/19 22:45	564	6/13/19 22:45	455		
6/12/19 23:00	564	6/13/19 23:00	455		
6/12/19 23:15	564	6/13/19 23:15	455		
6/12/19 23:30	559	6/13/19 23:30	455		
6/12/19 23:45	559	6/13/19 23:45	455		

Chapter 9

Unit Hydrograph Models

Exercise 9.1. The values of C_t and C_p computed in Example 9.5 is applicable to another nearby watershed of the same Saluda River basin. This watershed has a drainage area of 970 square miles. From the map, the length of the main channel and the length from the centroid of the channel to the outlet were found to be 66 miles and 32 miles, respectively. Calculate the lag time and peak discharge for this watershed's derived unit hydrograph. Construct the unit hydrograph.

Exercise 9.2. If the required duration of the unit hydrograph in Example 9.5 is changed to 12 h, estimate C_t and C_p that should be used for this unit hydrograph.

Exercise 9.3. Confirm that the unit hydrograph derived in Example 9.6 (Figure 9.44) indeed has unit volume of effective rainfall (Table 9.18 gives the UH data). Derive a 6 h unit hydrograph from the 3 h unit hydrograph data given in Table 9.18.

Exercise 9.4. A watershed has a drainage area of 11.92 km^2, with a time of concentration of 2.3 h. Another watershed has the same drainage area but a time of concentration of 6 h due to the elongated shape of the watershed. Determine the NRCS unit hydrographs for these two watersheds and compare the characteristics of the hydrographs. Discuss the causes of the differences in the hydrograph parameters.

Exercise 9.5. Rainfall-runoff data for a rain event that occurred on 9/6/1986 over Shoal Creek watershed with a drainage area of 12.3 square miles, in Austin, Texas are given in Table 9.31. See Figure 4.56 for the map of the watershed. Determine the duration and ordinates of the unit hydrograph from the observed rainfall-runoff data. Determine the shape factor for a dimensionless unit hydrograph (1) using the equation given by Haan (Eq. 9.30) and (2) from the *PRF* of an NRCS dimensionless unit hydrograph (Eq. 9.67). Compute the unit hydrographs using the gamma distribution (either Eq. 9.29 or 9.53) with two shape factors. Which shape factor fits the observed data better?

Table 9.31 *Rainfall-runoff data from Shoal Creek watershed, Austin, Texas, USA*

Rainfall data			*Runoff data*		
Date/Time	**Hour lapsed**	**Cumulative rainfall (in.)**	**Date/Time**	**Hour lapsed**	**Observed discharge (ft^3/s)**
09/06/1986@01:30:00	0	0.00	09/06/1986@00:00:00	0	0.3
09/06/1986@02:00:00	0.5	0.08	09/06/1986@01:30:00	1.5	11
09/06/1986@03:15:00	1.75	0.50	09/06/1986@02:00:00	2	37
09/06/1986@03:30:00	2	0.54	09/06/1986@03:15:00	3.25	94
09/06/1986@03:45:00	2.25	0.60	09/06/1986@03:30:00	3.5	106
09/06/1986@04:00:00	2.5	0.76	09/06/1986@03:45:00	3.75	174
09/06/1986@04:15:00	2.75	0.89	09/06/1986@04:00:00	4	204

Rainfall data			*Runoff data*		
Date/Time	**Hour lapsed**	**Cumulative rainfall (in.)**	**Date/Time**	**Hour lapsed**	**Observed discharge (ft³/s)**
09/06/1986@04:30:00	3	0.93	09/06/1986@04:15:00	4.25	273
09/06/1986@04:45:00	3.25	0.99	09/06/1986@04:30:00	4.5	263
09/06/1986@05:30:00	4	1.10	09/06/1986@04:45:00	4.75	277
09/06/1986@06:00:00	4.5	1.18	09/06/1986@05:30:00	5.5	344
09/06/1986@07:15:00	5.75	1.40	09/06/1986@06:00:00	6	380
09/06/1986@07:30:00	6	1.45	09/06/1986@07:15:00	7.25	258
09/06/1986@07:45:00	6.25	1.60	09/06/1986@07:30:00	7.5	254
09/06/1986@08:00:00	6.5	1.89	09/06/1986@07:45:00	7.75	303
09/06/1986@08:15:00	6.75	2.21	09/06/1986@08:00:00	8	454
09/06/1986@08:30:00	7	2.65	09/06/1986@08:15:00	8.25	621
09/06/1986@08:45:00	7.25	2.73	09/06/1986@08:30:00	8.5	778
09/06/1986@09:00:00	7.5	2.80	09/06/1986@08:45:00	8.75	894
09/06/1986@09:15:00	7.75	2.87	09/06/1986@09:00:00	9	1380
09/06/1986@09:30:00	8	2.92	09/06/1986@09:15:00	9.25	1840
09/06/1986@09:45:00	8.25	2.97	09/06/1986@09:30:00	9.5	1790
09/06/1986@10:00:00	8.5	3.00	09/06/1986@09:45:00	9.75	1410
09/06/1986@10:15:00	8.75	3.01	09/06/1986@10:00:00	10	1000
09/06/1986@10:30:00	9	3.01	09/06/1986@10:15:00	10.25	747
09/06/1986@11:30:00	10	3.02	09/06/1986@10:30:00	10.5	611
09/06/1986@12:30:00	11	3.03	09/06/1986@11:30:00	11.5	318
09/06/1986@13:30:00	12	3.03	09/06/1986@12:30:00	12.5	156
09/06/1986@17:30:00	16	3.04	09/06/1986@13:30:00	13.5	84
09/07/1986@00:00:00	22.5	3.05	09/06/1986@17:30:00	17.5	30
			09/07/1986@00:00:00	24	24

Exercise 9.6. Rainfall-runoff data for an event in Seolmacheon basin (8.32 km²) in South Korea are given in Table 9.32. From the observed data, the Clark Unit Hydrograph parameters for the basin has been determined as t_c = 1.42 h and R = 3.75 h. Develop the unit hydrograph for this basin and compare the direct runoff hydrograph calculated from the observed rainfall and calculated unit hydrograph with the observed streamflow given in Table 9.32.

Table 9.32 *Rainfall-runoff data from Seolmacheon basin, South Korea*

yyyy-mm-dd hh:mm	rainfall (mm)	runoff (m³/s)	yyyy-mm-dd hh:mm	rainfall (mm)	runoff (m³/s)
2016/10/02 22:40	0.0	0.000	2016/10/03 17:10	0.0	1.899
2016/10/02 22:50	0.0	0.022	2016/10/03 17:20	0.0	1.854
2016/10/02 23:00	1.0	0.039	2016/10/03 17:30	0.0	1.787
2016/10/02 23:10	0.0	0.050	2016/10/03 17:40	0.0	1.743
2016/10/02 23:20	2.4	0.092	2016/10/03 17:50	0.0	1.678

yyyy-mm-dd hh:mm	rainfall (mm)	runoff (m^3/s)	yyyy-mm-dd hh:mm	rainfall (mm)	runoff (m^3/s)
2016/10/02 23:30	3.2	0.192	2016/10/03 18:00	0.0	1.657
2016/10/02 23:40	3.6	0.330	2016/10/03 18:10	0.0	1.594
2016/10/02 23:50	3.6	0.397	2016/10/03 18:20	0.0	1.512
2016/10/03 00:00	6.8	0.527	2016/10/03 18:30	0.0	1.472
2016/10/03 00:10	3.3	0.817	2016/10/03 18:40	0.0	1.453
2016/10/03 00:20	7.8	1.610	2016/10/03 18:50	0.0	1.375
2016/10/03 00:30	1.2	2.575	2016/10/03 19:00	0.0	1.356
2016/10/03 00:40	0.8	3.501	2016/10/03 19:10	0.0	1.318
2016/10/03 00:50	1.0	12.557	2016/10/03 19:20	0.0	1.300
2016/10/03 01:00	0.2	14.250	2016/10/03 19:30	0.0	1.245
2016/10/03 01:10	1.2	12.826	2016/10/03 19:40	0.0	1.209
2016/10/03 01:20	2.2	12.557	2016/10/03 19:50	0.0	1.173
2016/10/03 01:30	5.1	14.250	2016/10/03 20:00	0.0	1.139
2016/10/03 01:40	11.3	16.469	2016/10/03 20:10	0.0	1.121
2016/10/03 01:50	7.0	19.031	2016/10/03 20:20	0.0	1.087
2016/10/03 02:00	5.7	23.741	2016/10/03 20:30	0.0	1.054
2016/10/03 02:10	1.7	27.160	2016/10/03 20:40	0.0	1.021
2016/10/03 02:20	1.2	28.550	2016/10/03 20:50	0.0	1.004
2016/10/03 02:30	0.2	30.580	2016/10/03 21:00	0.0	0.972
2016/10/03 02:40	1.3	29.484	2016/10/03 21:10	0.0	0.956
2016/10/03 02:50	3.3	27.853	2016/10/03 21:20	0.0	0.909
2016/10/03 03:00	0.5	26.776	2016/10/03 21:30	0.0	0.894
2016/10/03 03:10	0.6	25.478	2016/10/03 21:40	0.0	0.863
2016/10/03 03:20	0.1	24.343	2016/10/03 21:50	0.0	0.848
2016/10/03 03:30	1.0	23.516	2016/10/03 22:00	0.0	0.833
2016/10/03 03:40	3.9	23.816	2016/10/03 22:10	0.0	0.804
2016/10/03 03:50	6.7	24.871	2016/10/03 22:20	0.0	0.775
2016/10/03 04:00	0.9	26.087	2016/10/03 22:30	0.0	0.761
2016/10/03 04:10	1.0	27.468	2016/10/03 22:40	0.0	0.732
2016/10/03 04:20	0.7	27.545	2016/10/03 22:50	0.0	0.718
2016/10/03 04:30	0.5	27.391	2016/10/03 23:00	0.0	0.718
2016/10/03 04:40	1.3	27.468	2016/10/03 23:10	0.0	0.705
2016/10/03 04:50	7.2	27.853	2016/10/03 23:20	0.0	0.677
2016/10/03 05:00	2.8	28.395	2016/10/03 23:30	0.0	0.650
2016/10/03 05:10	3.4	29.874	2016/10/03 23:40	0.0	0.637
2016/10/03 05:20	1.1	31.446	2016/10/03 23:50	0.0	0.624
2016/10/03 05:30	0.9	32.396	2016/10/04 00:00	0.0	0.611
2016/10/03 05:40	0.1	33.032	2016/10/04 00:10	0.0	0.598
2016/10/03 05:50	0.0	32.317	2016/10/04 00:20	0.0	0.585
2016/10/03 06:00	0.0	31.131	2016/10/04 00:30	0.0	0.560
2016/10/03 06:10	0.0	29.406	2016/10/04 00:40	0.0	0.548

yyyy-mm-dd hh:mm	rainfall (mm)	runoff (m^3/s)	yyyy-mm-dd hh:mm	rainfall (mm)	runoff (m^3/s)
2016/10/03 06:20	0.0	27.776	2016/10/04 00:50	0.0	0.535
2016/10/03 06:30	0.0	26.469	2016/10/04 01:00	0.0	0.511
2016/10/03 06:40	0.0	25.099	2016/10/04 01:10	0.0	0.499
2016/10/03 06:50	0.0	23.967	2016/10/04 01:20	0.0	0.487
2016/10/03 07:00	0.0	22.770	2016/10/04 01:30	0.0	0.475
2016/10/03 07:10	0.0	21.658	2016/10/04 01:40	0.0	0.475
2016/10/03 07:20	0.0	20.849	2016/10/04 01:50	0.0	0.452
2016/10/03 07:30	0.0	19.900	2016/10/04 02:00	0.0	0.452
2016/10/03 07:40	0.0	19.031	2016/10/04 02:10	0.0	0.429
2016/10/03 07:50	0.0	18.384	2016/10/04 02:20	0.0	0.418
2016/10/03 08:00	0.0	17.671	2016/10/04 02:30	0.0	0.407
2016/10/03 08:10	0.0	16.962	2016/10/04 02:40	0.0	0.385
2016/10/03 08:20	0.0	16.118	2016/10/04 02:50	0.0	0.385
2016/10/03 08:30	0.0	15.560	2016/10/04 03:00	0.0	0.374
2016/10/03 08:40	0.0	14.937	2016/10/04 03:10	0.0	0.363
2016/10/03 08:50	0.0	14.524	2016/10/04 03:20	0.0	0.353
2016/10/03 09:00	0.0	13.908	2016/10/04 03:30	0.0	0.342
2016/10/03 09:10	0.0	13.297	2016/10/04 03:40	0.0	0.332
2016/10/03 09:20	0.0	12.758	2016/10/04 03:50	0.0	0.321
2016/10/03 09:30	0.0	12.157	2016/10/04 04:00	0.0	0.311
2016/10/03 09:40	0.0	11.627	2016/10/04 04:10	0.0	0.291
2016/10/03 09:50	0.0	11.101	2016/10/04 04:20	0.0	0.291
2016/10/03 10:00	0.0	9.959	2016/10/04 04:30	0.0	0.281
2016/10/03 10:10	0.0	9.633	2016/10/04 04:40	0.0	0.281
2016/10/03 10:20	0.0	9.128	2016/10/04 04:50	0.0	0.271
2016/10/03 10:30	0.0	8.640	2016/10/04 05:00	0.0	0.271
2016/10/03 10:40	0.0	8.228	2016/10/04 05:10	0.0	0.252
2016/10/03 10:50	0.0	7.942	2016/10/04 05:20	0.0	0.242
2016/10/03 11:00	0.0	7.553	2016/10/04 05:30	0.0	0.242
2016/10/03 11:10	0.0	7.229	2016/10/04 05:40	0.0	0.233
2016/10/03 11:20	0.0	6.916	2016/10/04 05:50	0.0	0.214
2016/10/03 11:30	0.0	6.611	2016/10/04 06:00	0.0	0.205
2016/10/03 11:40	0.0	6.364	2016/10/04 06:10	0.0	0.205
2016/10/03 11:50	0.0	6.123	2016/10/04 06:20	0.0	0.196
2016/10/03 12:00	0.0	5.889	2016/10/04 06:30	0.0	0.196
2016/10/03 12:10	0.0	5.615	2016/10/04 06:40	0.0	0.187
2016/10/03 12:20	0.0	5.350	2016/10/04 06:50	0.0	0.187
2016/10/03 12:30	0.0	5.135	2016/10/04 07:00	0.0	0.178
2016/10/03 12:40	0.0	4.926	2016/10/04 07:10	0.0	0.169
2016/10/03 12:50	0.0	4.763	2016/10/04 07:20	0.0	0.160
2016/10/03 13:00	0.0	4.564	2016/10/04 07:30	0.0	0.152

yyyy-mm-dd hh:mm	rainfall (mm)	runoff (m^3/s)	yyyy-mm-dd hh:mm	rainfall (mm)	runoff (m^3/s)
2016/10/03 13:10	0.0	4.409	2016/10/04 07:40	0.0	0.143
2016/10/03 13:20	0.0	4.220	2016/10/04 07:50	0.0	0.135
2016/10/03 13:30	0.0	4.072	2016/10/04 08:00	0.0	0.126
2016/10/03 13:40	0.0	3.892	2016/10/04 08:10	0.0	0.118
2016/10/03 13:50	0.0	3.752	2016/10/04 08:20	0.0	0.118
2016/10/03 14:00	0.0	3.616	2016/10/04 08:30	0.0	0.118
2016/10/03 14:10	0.0	3.482	2016/10/04 08:40	0.0	0.118
2016/10/03 14:20	0.0	3.319	2016/10/04 08:50	0.0	0.118
2016/10/03 14:30	0.0	3.256	2016/10/04 09:00	0.0	0.110
2016/10/03 14:40	0.0	3.131	2016/10/04 09:10	0.0	0.110
2016/10/03 14:50	0.0	3.009	2016/10/04 09:20	0.0	0.094
2016/10/03 15:00	0.0	2.949	2016/10/04 09:30	0.0	0.094
2016/10/03 15:10	0.0	2.773	2016/10/04 09:40	0.0	0.086
2016/10/03 15:20	0.0	2.745	2016/10/04 09:50	0.0	0.086
2016/10/03 15:30	0.0	2.660	2016/10/04 10:00	0.0	0.078
2016/10/03 15:40	0.0	2.523	2016/10/04 10:10	0.0	0.070
2016/10/03 15:50	0.0	2.469	2016/10/04 10:20	0.0	0.062
2016/10/03 16:00	0.0	2.390	2016/10/04 10:30	0.0	0.055
2016/10/03 16:10	0.0	2.312	2016/10/04 10:40	0.0	0.047
2016/10/03 16:20	0.0	2.235	2016/10/04 10:50	0.0	0.047
2016/10/03 16:30	0.0	2.161	2016/10/04 11:00	0.0	0.047
2016/10/03 16:40	0.0	2.087	2016/10/04 11:10	0.0	0.040
2016/10/03 16:50	0.0	2.063	2016/10/04 11:20	0.0	0.025
2016/10/03 17:00	0.0	1.969	2016/10/04 11:30	0.0	0.025
			2016/10/04 11:40	0.0	0.018
			2016/10/04 11:50	0.0	0.018
			2016/10/04 12:00	0.0	0.018

Exercise 9.7. Rainfall-runoff data from Soofi Chai Watershed located in northwestern Iran, are given in Table 9.33. Compute the unit hydrograph using the least square method. The rainfall given is effective rainfall. If necessary, use ridge regression using a set of values of regularization factor (e.g., 0.0, 0.01, 0.1, 1, 3, 5). Compare the unit hydrograph obtained by this process with the one that would be obtained from observed runoff data.

Table 9.33 *Rainfall-runoff data from Soofi Chai Watershed, Iran*

	Storm Date	**05/01/2004**
Time (h)	P (mm)	Q (m^3/s)
1	4.83	1.50
2	1.65	5.50
3	0.74	13.40
4	0.21	25.10

	Storm Date	05/01/2004
Time (h)	*P* (mm)	*Q* (m³/s)
5		36.00
6		52.40
7		65.40
8		64.30
9		58.10
10		45.00
11		34.00
12		24.10
13		19.30
14		14.50
15		12.40
16		15.00
17		17.70
18		15.50
19		9.20
20		6.10
21		4.32
22		3.00
23		2.00
24		1.50
25		1.00
26		0.50

Exercise 9.8. Rainfall-runoff data from Soofi Chai Watershed, located in northwestern Iran, are given in columns 1, 2, and 3 of Table 9.34. Columns 4 and 5 give the unit hydrographs obtained from gamma and lognormal distributions.

Table 9.34 *Rainfall-runoff data from Soofi Chai Watershed, Iran*

Storm Date	4/7/2002	Observed	Gamma UH	Log normal UH
Time (h)	**P (mm)**	**Q (m³/s)**	**Q (m³/s)**	**Q (m³/s)**
1	2.17	2.416667	0	0
2	0.76	12.11806	0.296869	0.03481471
3		31.11806	5.285765	4.19414754
4		50.22222	14.26561	14.6348438
5		44.72222	17.78318	17.7228437
6		31.11806	14.51821	13.8174419
7		9.020833	9.068803	8.71289554
8		8.020833	4.709253	4.92383824
9		7.520833	2.136128	2.6268297
10		6.020833	0.873874	1.3611973
11		3.416667	0.329526	0.696504
12		2.916667	0.116334	0.35540547

Storm Date	4/7/2002	Observed	Gamma UH	Log normal UH
Time (h)	P (mm)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)
13		2.416667	0.038894	0.18194735
14		2.020833	0.012423	0.09380126
15		1.520833	0.003816	0.04880991
16		0.979167	0.001134	0.02567081
17		0.493056	0.000327	0.01365649
18		0	0	0

A) Compute the direct runoff hydrograph using rainfall and UH derived using the gamma distribution.

B) Compute the direct runoff hydrograph using rainfall and UH derived using the lognormal distribution.

C) Which DRH computed in (A) and (B) above gives a better goodness-of-fit to the observed DRH?

D) Derive the unit hydrograph using deconvolution.

Exercise 9.9. A flood control project at Lambagad in the Alakananda River basin in western Himalaya (Indian subzone 7; Figure 9.12) required computation of a flood hydrograph according to CWC guidelines and procedures. For subzone 7, the coefficients for the unit hydrograph parameters given in Table 9.2 are as follows.

Unit Hydrograph Parameters					***Physiographic parameters***		
a_1	2.498	b_1	0.156		A	301.60	km^2
a_2	1.048	b_2	-0.178		L	35.37	km
a_3	1.954	b_3	0.099		L_c	23.41	km
a_4	0.972	b_4	0.124		S	76.62	m/km
a_5	0.189	b_5	1.769				
a_6	0.419	b_6	1.246				
a_7	7.845	b_7	0.453	$t_p = 1.1t_l$			

The unit for q_p is $m^3/s/km^2$. For all other parameters listed in Table 9.2 the unit is h. Rainfall for 100 y 24 h storm is 24 cm. The t_p of the unit hydrograph (4 h) is the design storm duration and the conversion factor from 24 h storm total to 4 h storm total is 0.65. In addition, an areal reduction factor of 0.819 has to be applied. A constant loss rate of 0.20 cm/h also must be applied to rainfall. The distribution of rainfall total in a 4 h storm is as given below.

h	1	2	3	4
Coefficient	0.62	0.82	0.94	1.00

First develop the unit hydrograph ensuring that the total volume of runoff is 1 cm. Then compute the flood hydrograph.

Exercise 9.10. Rainfall -runoff data from the Myntdu-Leska River basin (536 km^2), located in the Jaintia Hills in Meghalaya, in the north eastern part of India (Indian subzone 2C; Figure 9.12), are given in Table 9.35. See Figure 4.39 in the color plate section for the map of the basin. The unit hydrograph used by the Water Resources Department of Meghalaya is also given in Table 9.35.

Derive the unit hydrograph parameters according to Eqs. 9.31, 9.32, and 9.33. Develop the unit hydrograph using the form of gamma distribution function given by Eq. 9.26. Also develop the unit hydrograph from observed flow. Compare the three unit hydrographs and record your observations.

Table 9.35. *Rainfall -runoff data from the Myntdu-Leska River basin, India*

Event	**8/3/1996**			**Total P**	**7.125 mm**	**3 hr**	**Flow**	**10 h**	**Start**	**18:00**	**h**	
Time (h)	0	1	2	3	4	5	6	7	8	9	10	11
Rainfall (mm)	0	1.3	1.1	4	0.5	0.15	0.05	0	0	0.025	0	
Flow (m^3/s)	0	31.2	30.75	38.6	93	102	109	118	104	82	72	68
UH (m^3/s)	0	0.223	2.39	8.699	9.336	11.829	9.566	6.262	5.163	4.723	3.882	4.117
Time (h)	12	13	14	15	16	17	18	19	20	21	22	23
Rainfall (mm)												
Flow (m^3/s)	62.2	62.8	69.5	62	60	55.6	51	48.5	46.5	45	44	43
UH (m^3/s)	3.962	4.109	3.787	3.131	2.497	2.219	1.959	1.778	1.662	1.373	1.265	1.131
Time (h)	25	26	27	28	29	30	31					
Rainfall (mm)												
Flow (m^3/s)	39	38.5	37.7	31								
UH (m^3/s)	0.957	0.851	0.59	0.465	0.42	0.27	0					

Exercise 9.11. Develop an average unit hydrograph for the subbasin draining to gauging station 8057425 within Five Mile Creek Watershed in Dallas (Figure 9.53) for the three rain events of similar duration. Rainfall-Runoff Data for the event of 07/07/1973 are given in Table 9.36 (A and B). Rainfall-Runoff Data for the event of 07/03/1976 are given in Table 9.37 (A and B). Rainfall-Runoff Data for the event of 08/20/1977 are given in Table 9.38 (A and B).

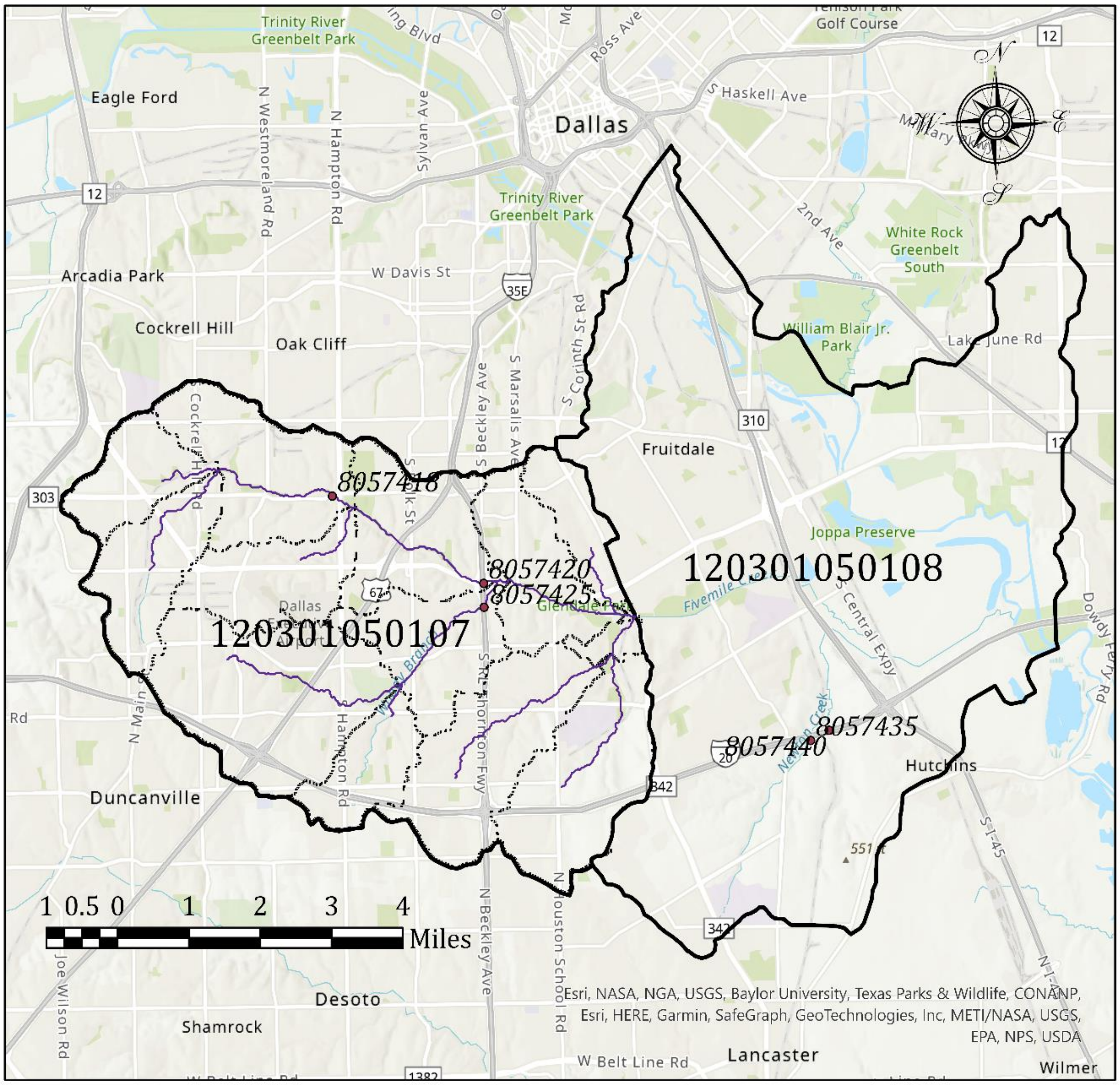

Figure 9.53 Map of Five Mile Creek Watershed in Dallas, Texas, USA.

Table 9.36 A. *Rainfall data*

mm:dd:yyyy@h:min:s	Cumulative Rainfall (in.)
07/07/1973@17:00:00	0
07/07/1973@18:00:00	0.03
07/07/1973@18:15:00	0.45
07/07/1973@18:30:00	0.49
07/07/1973@18:45:00	0.51
07/07/1973@19:00:00	0.53
07/07/1973@19:10:00	0.75
07/07/1973@19:20:00	1.45
07/07/1973@19:30:00	1.93
07/07/1973@19:35:00	2.05
07/07/1973@19:45:00	2.36
07/07/1973@20:00:00	2.47
07/07/1973@20:15:00	2.54
07/07/1973@20:30:00	2.57

Table 9.36B. *Runoff data*

mm:dd:yyyy@h:min:s	Runoff (ft^3/s)
07/07/1973@00:00:00	2
07/07/1973@17:00:00	2
07/07/1973@18:00:00	2
07/07/1973@18:15:00	2
07/07/1973@18:30:00	2
07/07/1973@18:45:00	797
07/07/1973@19:00:00	1330
07/07/1973@19:10:00	1930
07/07/1973@19:20:00	2810
07/07/1973@19:30:00	3740
07/07/1973@19:35:00	3910
07/07/1973@19:45:00	4680
07/07/1973@20:00:00	4870
07/07/1973@20:15:00	4500
07/07/1973@20:30:00	3730
07/07/1973@20:45:00	2320
07/07/1973@21:00:00	1680
07/07/1973@21:10:00	1080
07/07/1973@21:15:00	797
07/07/1973@21:30:00	470
07/07/1973@21:45:00	400
07/07/1973@22:00:00	350
07/07/1973@22:30:00	270
07/07/1973@23:00:00	200
07/08/1973@00:00:00	120

Table 9.37 A. *Rainfall data*

mm:dd:yyyy@h:min:s	Cumulative Rainfall (in.)
07/03/1976@17:30:00	0
07/03/1976@17:45:00	0.02
07/03/1976@18:00:00	0.29
07/03/1976@18:15:00	0.58
07/03/1976@18:30:00	1.39
07/03/1976@18:45:00	1.75
07/03/1976@19:00:00	2.2
07/03/1976@19:15:00	2.37
07/03/1976@19:30:00	2.4
07/03/1976@19:40:00	2.42
07/03/1976@19:45:00	2.45
07/03/1976@20:00:00	2.49
07/03/1976@20:15:00	2.51
07/03/1976@20:30:00	2.53
07/03/1976@20:45:00	2.55

Table 9.37 B. *Runoff data*

mm:dd:yyyy@h:min:s	Runoff (ft^3/s)
07/03/1976@00:00:00	2
07/03/1976@17:30:00	2
07/03/1976@17:45:00	2
07/03/1976@18:00:00	2
07/03/1976@18:15:00	2
07/03/1976@18:30:00	2
07/03/1976@18:45:00	15
07/03/1976@19:00:00	2620
07/03/1976@19:15:00	4350
07/03/1976@19:30:00	5600
07/03/1976@19:40:00	5850
07/03/1976@19:45:00	5700
07/03/1976@20:00:00	4350
07/03/1976@20:15:00	2900
07/03/1976@20:30:00	1650
07/03/1976@20:45:00	1100
07/03/1976@21:00:00	815
07/03/1976@21:15:00	570
07/03/1976@21:30:00	395
07/03/1976@21:45:00	255
07/03/1976@22:00:00	95
07/03/1976@22:15:00	25
07/03/1976@22:30:00	15
07/03/1976@22:45:00	10
07/03/1976@23:00:00	10
07/03/1976@23:15:00	10
07/04/1976@00:00:00	10

Table 9.38A. *Rainfall data*

mm:dd:yyyy@h:min:s	Cumulative Rainfall (in.)
08/20/1977@02:00:00	0
08/20/1977@02:15:00	0.02
08/20/1977@02:30:00	0.16
08/20/1977@03:00:00	0.2
08/20/1977@03:30:00	0.24
08/20/1977@04:00:00	0.27
08/20/1977@04:15:00	0.29
08/20/1977@04:30:00	0.43
08/20/1977@04:45:00	0.82
08/20/1977@05:00:00	1.42
08/20/1977@05:15:00	2.07
08/20/1977@05:30:00	2.48
08/20/1977@05:45:00	2.73
08/20/1977@06:00:00	2.87
08/20/1977@06:15:00	3.08
08/20/1977@06:30:00	3.18
08/20/1977@06:45:00	3.23
08/20/1977@07:00:00	3.26
08/20/1977@07:15:00	3.27

Table 9.38B. *Runoff data*

mm:dd:yyyy@h:min:s	Runoff (ft^3/s)
08/20/1977@04:00:00	1
08/20/1977@04:15:00	10
08/20/1977@04:30:00	70
08/20/1977@04:45:00	584
08/20/1977@05:00:00	759
08/20/1977@05:15:00	1000
08/20/1977@05:30:00	1430
08/20/1977@05:45:00	2280
08/20/1977@06:00:00	2820
08/20/1977@06:15:00	2820
08/20/1977@06:30:00	1970
08/20/1977@06:45:00	1310
08/20/1977@07:00:00	899
08/20/1977@07:15:00	619
08/20/1977@07:30:00	409
08/20/1977@07:45:00	280
08/20/1977@08:00:00	200
08/20/1977@08:15:00	140
08/20/1977@08:30:00	97
08/20/1977@08:45:00	67
08/20/1977@09:00:00	46
08/20/1977@09:30:00	23
08/20/1977@10:00:00	11
08/20/1977@10:30:00	5.4
08/20/1977@11:00:00	2.7
08/20/1977@11:30:00	1.3
08/21/1977@00:00:00	1

Exercise 9.12. Create and run HEC-HMS models for the examples given in Example 9.5, 9.7, and Exercise 9.4. Develop a hypothetical design storm with one unit of rainfall and assume no abstraction so that a DRH computed by HEC-HMS is a unit hydrograph. For each case, compare the UH derived in the examples and the exercise with the ones obtained from HEC-HMS run.

Chapter 10

Kinematic Wave Model of Overland Flow

Exercise 10.1. In the example problem 10.1, there is a proposed development in the upper catchment that will change 20 percent of the area to completely impervious area. The storm drainage system that will serve the area will have 300 feet of triangular gutters with a slope of 0.002 and roughness of 0.003 and 1800 feet of concrete circular pipe of 4 feet diameter, 0.004 slope, and Manning's n of 0.002. Use the kinematic wave runoff and routing options of HEC-HMS to compute the direct runoff hydrographs from both catchments.

Exercise 10.2. Suppose a rainfall with an intensity of 10cm/h is falling on a 200 m long and 50 m wide plane with kinematic wave parameters m_o = 1.5 and α_0 = 50.5/s for an indefinite period. Do the following:

(a) Compute the x-t characteristics and plot the solution domain.
(b) Compute the depth and discharge hydrographs.
(c) Compute and plot the depth and discharge hydrographs as functions of time at 50, 100, 150, and 200 m along the length of the plane.
(d) Compute and plot the depth and discharge hydrographs as functions of space for different times.
(e) Compute the time to equilibrium
(f) Compute the depth and discharge at equilibrium

Exercise 10.3. In the Exercise Problem 10.2, the rainfall duration becomes 200 s leading to partial equilibrium conditions. Do the following:

(a) Compute the maximum time of travel to the outlet.
(b) Compute the depth and discharge at the maximum time of travel.
(c) Compute the x-t characteristics and plot the solution domains.
(d) Compute the depth and discharge hydrographs at the outlet.
(e) Compute the depth and discharge hydrographs as functions of time at x = 50, 10, 150, and 200 m.
(f) Compute the depth and discharge hydrographs as functions of space for t = 100, 150,200, 250, 300, 400, and 500s

Chapter 11

Rational Method

Exercise 11.1. The layout of eight lots of a proposed residential development is shown in Figure 11.9. The system is a curb and gutter drainage with storm drain pipes. The development will be served by the storm drains shown as P1, P2, P3, and P4, each of which is a reinforced concrete pipe with Manning's n of 0.015. The inlets are designated by I_1, I_2, I_3, and I_4. Table 11.7 gives the characteristics of the lots and Table 11.8 gives the length and slope of the pipes. Design the storm drainage system for a 10-year design frequency (F in year). The IDF relationship of the area is given by $I(\text{cm/h}) = \dfrac{305F^{0.175}}{27 + t_d(\text{min})}$.

Table 11.7 *Characteristics of the lots shown in Figure 11.9*

Catchment	**Area (m^2)**	**L_o (m)**	**S_o**	***N***	***C***
Lot A	32000	183	0.010	0.015	0.8
Lot B	16000	91	0.015	0.015	0.8
Lot C	24000	183	0.010	0.015	0.8
Lot D	12000	91	0.015	0.015	0.8
Lot E	16000	61	0.020	0.015	0.8
Lot F	16000	61	0.030	0.015	0.8
Lot G	12000	61	0.020	0.015	0.8
Lot H	12000	61	0.030	0.015	0.8

Table 11.8 *Dimensions of the storm drain pipes*

Pipe	**L_o (m)**	**S_o**
P_1	500	0.020
P_2	500	0.020
P_3	400	0.020
P_4	200	0.020

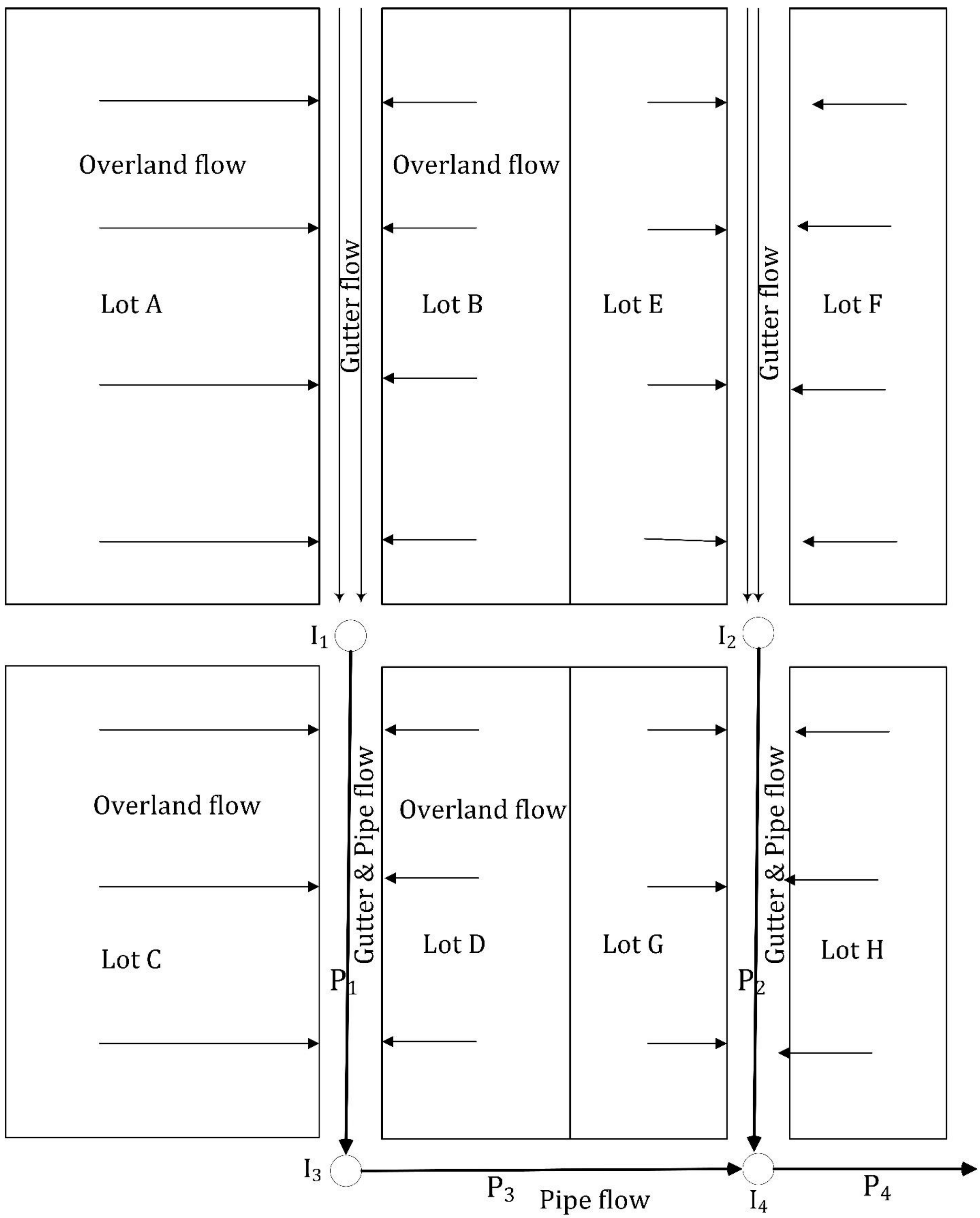

Figure 11.9 Layout of the residential lots.

Exercise 11.2. Two additional catchments are proposed to be developed in the existing layout shown in Figure 11.8. The proposed layout is shown in Figure 11.10. Table 11.9 lists the characteristics of catchments for the existing condition and Table 11.10 lists the same for the proposed conditions. As per the drainage ordinance of the local municipality, any new development will be required to provide detention of stormwater runoff for a 100-year storm. The length and slope of the pipes are the same as given in Table 11.6. The IDF relationship is also the same as given in Example 11.1. Do the following:

1. Determine the pipe sizes that will be required for lines 21-31 and 31-41 to convey 25-year flows.
2. Determine the detention volumes that will be required for the management of stormwater runoff from Catchments VI and VII.
3. The storm drains outfalls to the creek, shown in Figure 11.10. The 25-year flow in the creek is 3000 cfs. A new road is proposed as shown in Figure 11.10. Determine the size that will be required for a circular concrete culvert for a length of 150 feet at a slope of 0.005. The wall roughness of the pipe is 0.012.

Table 11.9 *Existing catchment characteristics for Exercise 11.2*

Catchment	**Area (acres)**	L_o **(ft)**	S_o	N	C
I	3	300	0.010	0.015	0.8
II	2	400	0.008	0.016	0.7
III	4	450	0.012	0.030	0.4
IV	6	650	0.010	0.020	0.6
V	8	700	0.010	0.010	0.5
VI	10	750	0.015	0.035	0.35
VII	8	600	0.013	0.035	0.4

Table 11.10 *Catchment characteristics for the proposed conditions*

Catchment	**Area (acres)**	L_o **(ft)**	S_o	N	C
I	3	300	0.010	0.015	0.8
II	2	400	0.008	0.016	0.7
III	4	450	0.012	0.030	0.4
IV	6	650	0.010	0.020	0.6
V	8	700	0.010	0.021	0.5
VI	10	750	0.015	0.010	0.85
VII	8	600	0.013	0.01	0.75

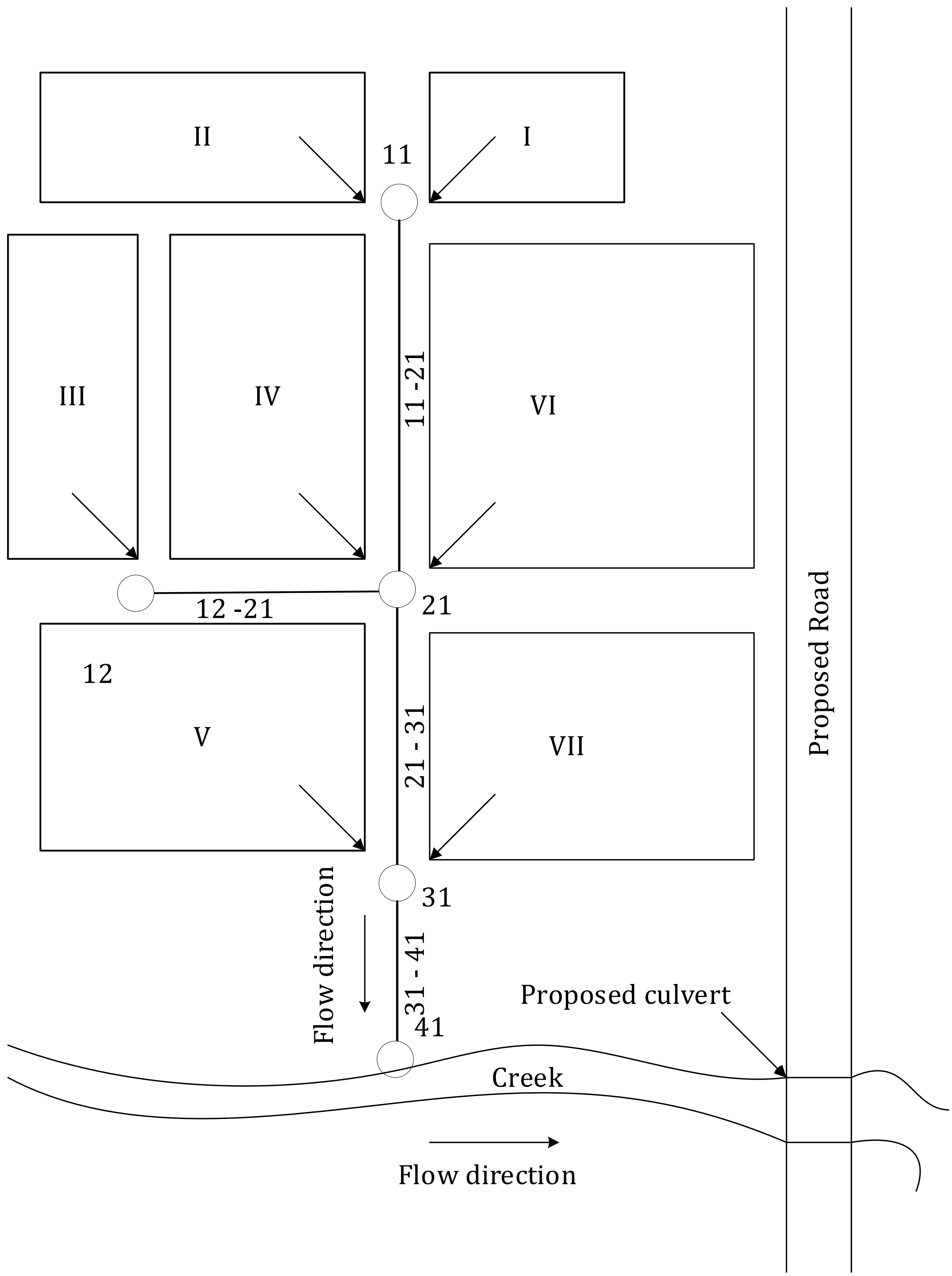

Figure 11.10 Proposed layout of the lots.

Chapter 12

Channel Routing

Exercise 12.1. For the inflow and storage-discharge relationship given in Example 12.2, calculate the outflow using the Modified Puls method with the number of subreaches = 2. First perform the calculations using Excel as shown in Example 12.2 and then do the calculations using HEC-HMS and compare the results. Do you see characteristics of channel flow in the outflow hydrograph when the number of subreaches is increased from one (as given in Example 12.1) to two?

Exercise 12.2. For the channel data given in Example 12.5, calculate the outflows at 6, 12, and 18 km downstream with the following changes: (1) increase celerity to 4 m/s keeping everything else the same; (2) decrease celerity to 1 m/s keeping everything else the same; (3) increase Δx to 6000 m keeping everything else the same; (4) decrease Δx to 1500 m keeping everything else the same; (5) increase Δt to 3000 seconds keeping everything else the same; and (6) decrease Δt to 600 seconds keeping everything else the same. Determine the effects of each of these changes and write your observations about sensitivity of Muskingum-Cunge model to each of these parameters.

Exercise 12.3. For the channel data given in Example 12.5, calculate the storage outflow curves at 6, 12, and 18 km downstream and write your observations.

Exercise 12.4. Configure the channel given in Example 12.6 in a HEC-RAS model and use the HEC-HMS model given in this example to develop storage-discharge relationship that can be used in the Modified Puls method. Determine the number of sub-reaches that should be used in HEC-HMS. Calculate the outflow hydrograph assuming one sub-reach and compare the results with the results obtained from the Muskingum-Cunge model given in Example 12.6. Then, run the HEC-HMS model using the number of sub-reaches obtained in this exercise and compare the results with the results obtained from the Muskingum-Cunge model.

Exercise 12.5. Develop an unsteady state HEC-RAS model from the model developed in Exercise 12.4 and compare the results from (1) dynamic wave model; (2) Muskingum-Cunge model; and (3) Modified Puls method.

Exercise 12.6. As much as 22 inches of rain fell in Oklahoma in May 2019, resulting in historic flooding along the Arkansas River in Oklahoma and Arkansas. The flooding along the Arkansas River and its tributaries that began in May continued into June 2019. Table 12.21 gives the observed hydrographs at USGS gauging stations on Arkansas River at Fort Smith and Van Buren (Figure 12.50). Determine the Muskingum routing parameters for this reach and then use the best estimated parameters to calculate the hydrograph at Van Buren from the hydrograph at Fort Smith. Compare the observed and calculated hydrographs and refine the parameters.

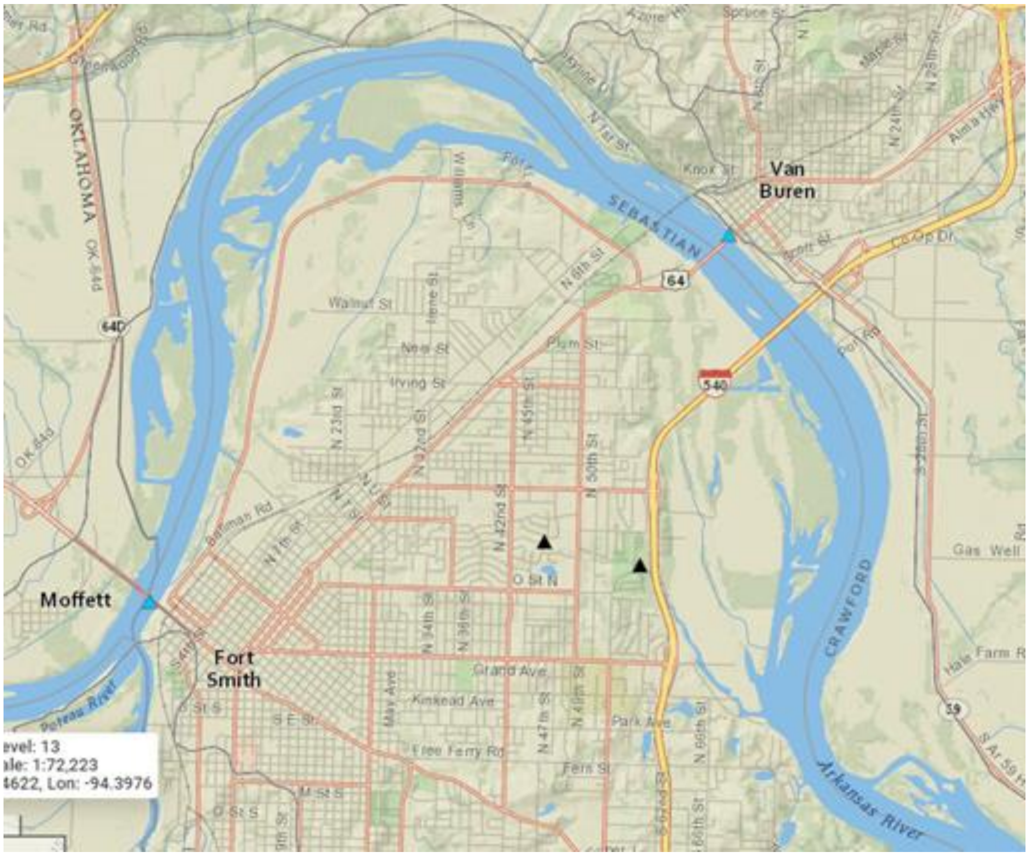

Figure 12.50 Reach of the Arkansas River from Fort Smith to Van Buren.

Table 12.21 *Hydrograph data at Fort Smith and Van Buren during a period of flooding in May-June, 2019, Arkansas River, USA*

Date/Time	Discharge at Fort Smith (ft^3/s)	Discharge at Van Buren (ft^3/s)
5/21/2019 20:00	144000	143000
5/21/2019 21:00	146000	143000
5/21/2019 22:00	147000	144000
5/21/2019 23:00	150000	144000
5/22/2019 0:00	152000	145000
5/22/2019 1:00	155000	148000
5/22/2019 2:00	158000	149000
5/22/2019 3:00	161000	151000
5/22/2019 4:00	164000	153000
5/22/2019 5:00	167000	156000
5/22/2019 6:00	170000	158000
5/22/2019 7:00	174000	160000

Date/Time	Discharge at Fort Smith (ft³/s)	Discharge at Van Buren (ft³/s)
5/22/2019 8:00	177000	163000
5/22/2019 9:00	180000	165000
5/22/2019 10:00	183000	168000
5/22/2019 11:00	186000	170000
5/22/2019 12:00	189000	174000
5/22/2019 13:00	194000	176000
5/22/2019 14:00	197000	179000
5/22/2019 15:00	201000	183000
5/22/2019 16:00	205000	185000
5/22/2019 17:00	209000	189000
5/22/2019 18:00	214000	192000
5/22/2019 19:00	218000	195000
5/22/2019 20:00	224000	199000
5/22/2019 21:00	229000	203000
5/22/2019 22:00	236000	207000
5/22/2019 23:00	241000	211000
5/23/2019 0:00	247000	216000
5/23/2019 1:00	252000	221000
5/23/2019 2:00	254000	225000
5/23/2019 3:00	263000	230000
5/23/2019 4:00	266000	234000
5/23/2019 5:00	271000	239000
5/23/2019 6:00	276000	244000
5/23/2019 7:00	280000	249000
5/23/2019 8:00	283000	254000
5/23/2019 9:00	286000	258000
5/23/2019 10:00	292000	262000
5/23/2019 11:00	294000	266000
5/23/2019 12:00	298000	270000
5/23/2019 13:00	301000	274000
5/23/2019 14:00	304000	279000
5/23/2019 15:00	306000	283000
5/23/2019 16:00	309000	288000
5/23/2019 17:00	311000	292000
5/23/2019 18:00	314000	297000
5/23/2019 19:00	317000	302000
5/23/2019 20:00	320000	307000
5/23/2019 21:00	321000	312000
5/23/2019 22:00	325000	316000

Date/Time	Discharge at Fort Smith (ft^3/s)	Discharge at Van Buren (ft^3/s)
5/23/2019 23:00	326000	320000
5/24/2019 0:00	327000	325000
5/24/2019 1:00	330000	328000
5/24/2019 2:00	331000	332000
5/24/2019 3:00	332000	338000
5/24/2019 4:00	333000	340000
5/24/2019 5:00	336000	344000
5/24/2019 6:00	337000	347000
5/24/2019 7:00	337000	348000
5/24/2019 8:00	339000	351000
5/24/2019 9:00	342000	353000
5/24/2019 10:00	344000	355000
5/24/2019 11:00	345000	357000
5/24/2019 12:00	346000	359000
5/24/2019 13:00	348000	362000
5/24/2019 14:00	348000	362000
5/24/2019 15:00	354000	365000
5/24/2019 16:00	356000	367000
5/24/2019 17:00	359000	368000
5/24/2019 18:00	359000	370000
5/24/2019 19:00	362000	373000
5/24/2019 20:00	364000	375000
5/24/2019 21:00	369000	378000
5/24/2019 22:00	368000	380000
5/24/2019 23:00	373000	382000
5/25/2019 0:00	373000	385000
5/25/2019 1:00	379000	387000
5/25/2019 2:00	377000	389000
5/25/2019 3:00	378000	391000
5/25/2019 4:00	382000	394000
5/25/2019 5:00	382000	395000
5/25/2019 6:00	390000	397000
5/25/2019 7:00	391000	400000
5/25/2019 8:00	393000	403000
5/25/2019 9:00	397000	406000
5/25/2019 10:00	403000	408000
5/25/2019 11:00	407000	413000
5/25/2019 12:00	410000	416000
5/25/2019 13:00	413000	420000

Date/Time	Discharge at Fort Smith (ft³/s)	Discharge at Van Buren (ft³/s)
5/25/2019 14:00	419000	424000
5/25/2019 15:00	420000	427000
5/25/2019 16:00	423000	429000
5/25/2019 17:00	428000	430000
5/25/2019 18:00	429000	433000
5/25/2019 19:00	434000	436000
5/25/2019 20:00	437000	438000
5/25/2019 21:00	438000	439000
5/25/2019 22:00	443000	442000
5/25/2019 23:00	446000	445000
5/26/2019 0:00	449000	446000
5/26/2019 1:00	453000	449000
5/26/2019 2:00	457000	451000
5/26/2019 3:00	459000	454000
5/26/2019 4:00	463000	455000
5/26/2019 5:00	466000	458000
5/26/2019 6:00	472000	461000
5/26/2019 7:00	470000	462000
5/26/2019 8:00	475000	466000
5/26/2019 9:00	479000	467000
5/26/2019 10:00	483000	471000
5/26/2019 11:00	486000	474000
5/26/2019 12:00	485000	478000
5/26/2019 13:00	490000	480000
5/26/2019 14:00	492000	484000
5/26/2019 15:00	499000	486000
5/26/2019 16:00	504000	487000
5/26/2019 17:00	506000	490000
5/26/2019 18:00	508000	493000
5/26/2019 19:00	511000	495000
5/26/2019 20:00	514000	498000
5/26/2019 21:00	518000	500000
5/26/2019 22:00	519000	503000
5/26/2019 23:00	523000	504000
5/27/2019 0:00	523000	507000
5/27/2019 1:00	528000	510000
5/27/2019 2:00	529000	512000
5/27/2019 3:00	533000	514000
5/27/2019 4:00	532000	516000

Date/Time	Discharge at Fort Smith (ft^3/s)	Discharge at Van Buren (ft^3/s)
5/27/2019 5:00	537000	518000
5/27/2019 6:00	537000	520000
5/27/2019 7:00	540000	522000
5/27/2019 8:00	544000	524000
5/27/2019 9:00	545000	526000
5/27/2019 10:00	546000	528000
5/27/2019 11:00	548000	531000
5/27/2019 12:00	546000	533000
5/27/2019 13:00	548000	534000
5/27/2019 14:00	550000	535000
5/27/2019 15:00	554000	536000
5/27/2019 16:00	552000	538000
5/27/2019 17:00	556000	539000
5/27/2019 18:00	557000	541000
5/27/2019 19:00	556000	543000
5/27/2019 20:00	558000	544000
5/27/2019 21:00	559000	546000
5/27/2019 22:00	559000	547000
5/27/2019 23:00	560000	548000
5/28/2019 0:00	560000	550000
5/28/2019 1:00	561000	551000
5/28/2019 2:00	560000	551000
5/28/2019 3:00	563000	551000
5/28/2019 4:00	561000	552000
5/28/2019 5:00	562000	553000
5/28/2019 6:00	563500	554000
5/28/2019 7:00	565000	554000
5/28/2019 8:00	564000	554000
5/28/2019 9:00	566000	555000
5/28/2019 10:00	567000	555000
5/28/2019 11:00	566000	555000
5/28/2019 12:00	567000	556000
5/28/2019 13:00	567000	556000
5/28/2019 14:00	566000	556000
5/28/2019 15:00	566000	556000
5/28/2019 16:00	563000	556000
5/28/2019 17:00	563000	556000
5/28/2019 18:00	564000	556000
5/28/2019 19:00	564000	556000

Date/Time	Discharge at Fort Smith (ft^3/s)	Discharge at Van Buren (ft^3/s)
5/28/2019 20:00	563000	556000
5/28/2019 21:00	566000	556000
5/28/2019 22:00	563000	556000
5/28/2019 23:00	560000	556000
5/29/2019 0:00	560000	556000
5/29/2019 1:00	560000	556000
5/29/2019 2:00	561000	556000
5/29/2019 3:00	558000	556000
5/29/2019 4:00	561000	555000
5/29/2019 5:00	562000	555000
5/29/2019 6:00	562000	555000
5/29/2019 7:00	560000	555000
5/29/2019 8:00	557000	554000
5/29/2019 9:00	554000	554000
5/29/2019 10:00	553000	554000
5/29/2019 11:00	556000	553000
5/29/2019 12:00	555000	552000
5/29/2019 13:00	554000	551000
5/29/2019 14:00	554000	551000
5/29/2019 15:00	552000	550000
5/29/2019 16:00	553000	550000
5/29/2019 17:00	553000	551000
5/29/2019 18:00	552000	551000
5/29/2019 19:00	551000	550000
5/29/2019 20:00	551000	551000
5/29/2019 21:00	551000	550000
5/29/2019 22:00	551000	550000
5/29/2019 23:00	551000	550000
5/30/2019 0:00	551000	549000
5/30/2019 1:00	550000	549000
5/30/2019 2:00	551000	550000
5/30/2019 3:00	550000	551000
5/30/2019 4:00	552000	552000
5/30/2019 5:00	550000	552000
5/30/2019 6:00	550000	551000
5/30/2019 7:00	550000	552000
5/30/2019 8:00	551000	552000
5/30/2019 9:00	552000	552000
5/30/2019 10:00	554000	552000

Date/Time	Discharge at Fort Smith (ft^3/s)	Discharge at Van Buren (ft^3/s)
5/30/2019 11:00	551000	552000
5/30/2019 12:00	552500	552000
5/30/2019 13:00	553000	552000
5/30/2019 14:00	553000	552000
5/30/2019 15:00	556000	552000
5/30/2019 16:00	556000	552000
5/30/2019 17:00	560000	552000
5/30/2019 18:00	559000	552000
5/30/2019 19:00	560000	553000
5/30/2019 20:00	563000	552000
5/30/2019 21:00	563000	553000
5/30/2019 22:00	565000	555000
5/30/2019 23:00	565000	555000
5/31/2019 0:00	567000	557000
5/31/2019 1:00	567000	557000
5/31/2019 2:00	569000	558000
5/31/2019 3:00	569000	558000
5/31/2019 4:00	573000	558000
5/31/2019 5:00	576000	559000
5/31/2019 6:00	576000	561000
5/31/2019 7:00	575000	561000
5/31/2019 8:00	577000	560000
5/31/2019 9:00	579000	562000
5/31/2019 10:00	579000	564000
5/31/2019 11:00	581000	563000
5/31/2019 12:00	579000	565000
5/31/2019 13:00	581000	564000
5/31/2019 14:00	584000	566000
5/31/2019 15:00	583000	566000
5/31/2019 16:00	582000	567000
5/31/2019 17:00	584000	565000
5/31/2019 18:00	583000	566000
5/31/2019 19:00	584000	567000
5/31/2019 20:00	583000	568000
5/31/2019 21:00	586000	567000
5/31/2019 21:30	587000	566500
5/31/2019 22:00	585000	566000
5/31/2019 23:00	583000	569000
6/1/2019 0:00	584000	570000

Date/Time	Discharge at Fort Smith (ft³/s)	Discharge at Van Buren (ft³/s)
6/1/2019 1:00	584000	569000
6/1/2019 2:00	580000	569000
6/1/2019 3:00	583000	567000
6/1/2019 4:00	582000	569000
6/1/2019 5:00	578000	568000
6/1/2019 6:00	578000	567000
6/1/2019 7:00	580000	568000
6/1/2019 8:00	576000	568000
6/1/2019 9:00	577000	568000
6/1/2019 10:00	575000	566000
6/1/2019 11:00	574000	566000
6/1/2019 12:00	570000	565000
6/1/2019 13:00	572000	565000
6/1/2019 14:00	568000	565000
6/1/2019 15:00	568000	564000
6/1/2019 16:00	568000	563000
6/1/2019 17:00	564000	562000
6/1/2019 18:00	563000	560000
6/1/2019 19:00	563000	560000
6/1/2019 20:00	561000	558000
6/1/2019 21:00	559000	558000
6/1/2019 22:00	555000	557000
6/1/2019 23:00	553000	556000
6/2/2019 0:00	550000	554000
6/2/2019 1:00	549000	552000
6/2/2019 2:00	548000	552000
6/2/2019 3:00	545000	550000
6/2/2019 4:00	540000	549000
6/2/2019 5:00	540000	547000
6/2/2019 6:00	537000	546000
6/2/2019 7:00	536000	545000
6/2/2019 8:00	531000	543000
6/2/2019 9:00	529000	542000
6/2/2019 10:00	525000	541000
6/2/2019 11:00	526000	538000
6/2/2019 12:00	517000	537000
6/2/2019 13:00	517000	534000
6/2/2019 14:00	512000	532000
6/2/2019 15:00	508000	530000

Date/Time	Discharge at Fort Smith (ft^3/s)	Discharge at Van Buren (ft^3/s)
6/2/2019 16:00	507000	528000
6/2/2019 17:00	502000	524000
6/2/2019 18:00	496000	523000
6/2/2019 19:00	490000	519000
6/2/2019 20:00	489000	517000
6/2/2019 21:00	484000	514000
6/2/2019 22:00	480000	512000
6/2/2019 23:00	475000	509000
6/3/2019 0:00	471000	507000
6/3/2019 1:00	467000	504000
6/3/2019 2:00	464000	500000
6/3/2019 3:00	456000	497000
6/3/2019 4:00	454000	494000
6/3/2019 5:00	447000	490000
6/3/2019 6:00	445000	489000
6/3/2019 7:00	442000	486000
6/3/2019 8:00	438000	483000
6/3/2019 9:00	433000	480000
6/3/2019 10:00	430000	477000
6/3/2019 11:00	423000	475000
6/3/2019 12:00	419000	471000
6/3/2019 13:00	416000	469000
6/3/2019 14:00	413000	466000
6/3/2019 15:00	408000	462000
6/3/2019 16:00	405000	461000
6/3/2019 17:00	400000	457000
6/3/2019 18:00	395000	455000
6/3/2019 19:00	393000	452000
6/3/2019 20:00	387000	449000
6/3/2019 21:00	383000	445000
6/3/2019 22:00	379000	441000
6/3/2019 23:00	376000	439000
6/4/2019 0:00	372000	435000
6/4/2019 1:00	369000	431000
6/4/2019 2:00	366000	428000
6/4/2019 3:00	360000	423000
6/4/2019 4:00	358000	419000
6/4/2019 5:00	354000	416000
6/4/2019 6:00	351000	411000

Date/Time	Discharge at Fort Smith (ft^3/s)	Discharge at Van Buren (ft^3/s)
6/4/2019 7:00	346000	406000
6/4/2019 8:00	344000	402000
6/4/2019 9:00	340000	397000

Exercise 12.7. Figure 12.51 shows five reaches of Mahoning Creek, a tributary channel of the Alleghany River in Pennsylvania (see Figure 1.5 also). The length and average slope of each of the reaches are given in Table 12.22. Several cross sections within a reach were cut. The representative cross-sectional data are given in Table 12.23. The inflow hydrograph at the upstream end of Reach 4 is given in Table 12.18 (Example 12.8). Calculate the hydrograph at the end of Reach 1 using the Muskingum-Cunge method after determining the appropriate Δx and Δt. The observed hydrograph is given in Table 12.18. Looking at the map, what do you think is a significant shortcoming of this method?

Table 12.22 *Length and slope of the reaches of Mahoning Creek, Pennsylvania, USA*

	Length (mile)	Slope
Reach 5	0.956	0.0035
Reach 4	2.242	0.00193
Reach 3	5.274	0.00108
Reach 2	2.416	0.00135
Reach 1	7.815	0.0006

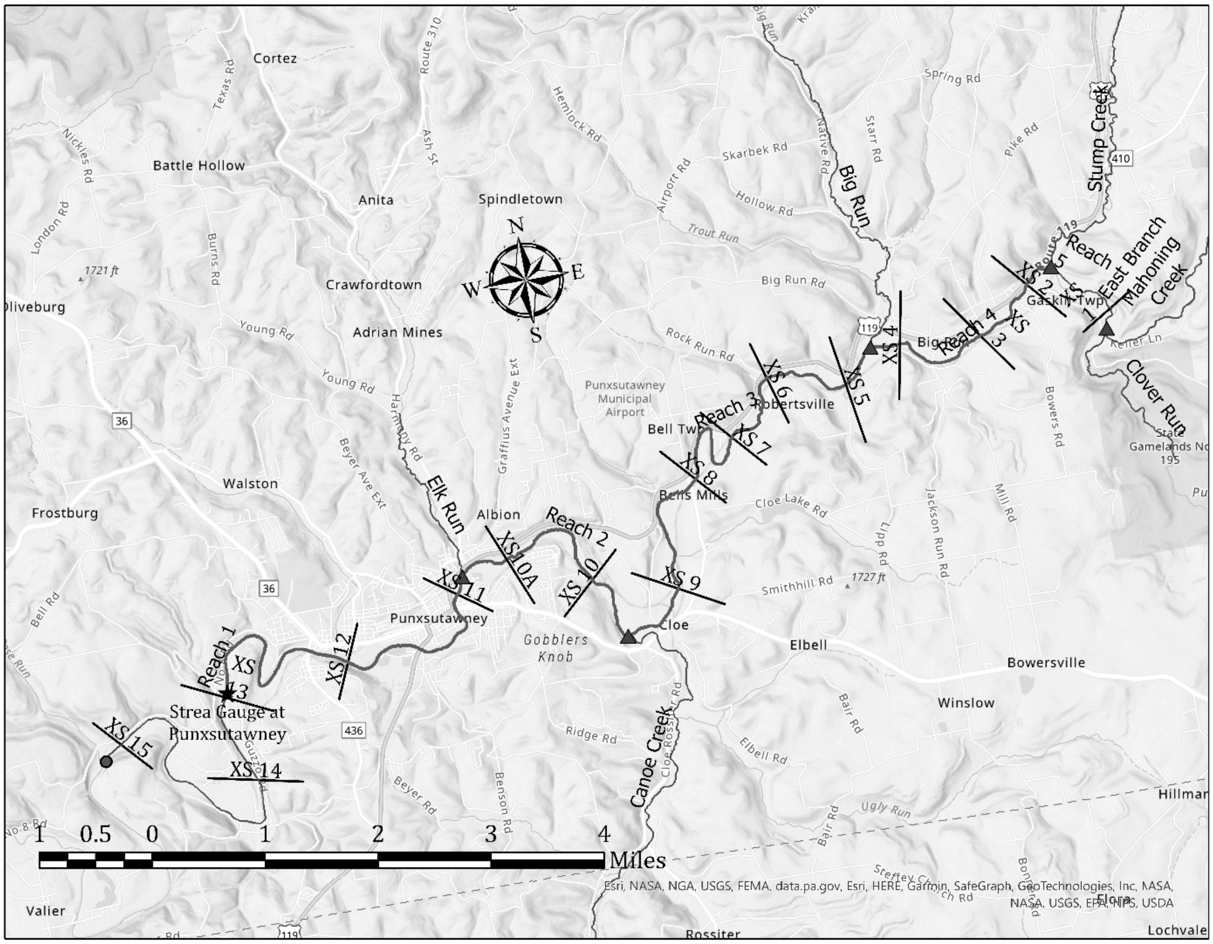

Figure 12.51 Mahoning Creek, Pennsylvania, USA.

Table 12.23 *Cross sectional data of the reaches of Mahoning Creek shown in Figure 12.51*

Reach 4		**Reach 3**		**Reach 2**		**Reach 1**	
XS 3		XS 8		XS 9		XS 14	
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)
0.00	1528.40	0.00	1422.09	0.00	1380.21	0.00	1317.80
204.65	1502.58	102.80	1413.96	34.19	1372.59	308.46	1324.69
409.30	1481.30	308.40	1399.94	68.38	1362.67	514.09	1321.42
613.95	1475.68	514.00	1388.54	102.57	1349.04	616.91	1310.77
818.59	1452.11	719.60	1377.80	136.76	1335.45	719.73	1301.50
955.03	1399.44	890.93	1361.84	170.96	1323.13	856.82	1279.05
1091.46	1365.61	1028.00	1344.90	205.15	1308.63	993.91	1244.87
1227.89	1341.62	1199.33	1323.61	239.34	1290.70	1062.46	1239.73
1432.54	1305.36	1302.13	1310.62	273.53	1274.13	1165.28	1233.92
1603.08	1295.85	1507.73	1289.75	376.10	1258.29	1268.10	1233.75
1807.73	1287.65	1713.33	1280.07	547.06	1248.45	1370.92	1233.52

Reach 4		Reach 3		Reach 2		Reach 1	
XS 3		XS 8		XS 9		XS 14	
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)
2012.38	1281.42	1918.93	1265.55	649.63	1247.56	1508.01	1230.52
2217.03	1282.17	2090.27	1248.34	752.20	1247.91	1610.83	1230.13
2421.67	1274.21	2227.33	1271.56	854.78	1248.57	1713.65	1219.75
2626.32	1310.84	2432.93	1268.07	957.35	1249.55	1747.92	1217.44
2830.97	1357.62	2604.27	1260.29	1059.92	1248.06	1885.01	1227.09
3001.51	1380.76	2809.87	1278.27	1196.69	1248.38	1953.56	1228.39
3206.16	1405.54	3015.47	1375.21	1299.26	1247.77	2056.37	1229.59
3410.81	1424.31	3221.07	1427.34	1367.64	1256.93	2159.19	1230.08
3615.46	1441.99	3426.67	1434.57	1470.22	1247.82	2262.01	1230.38
3820.11	1452.74	3632.27	1416.35	1572.79	1246.10	2364.83	1230.54
4024.75	1468.13	3803.60	1397.05	1675.36	1249.00	2501.92	1230.33
4263.51	1487.90			1812.13	1266.78	2604.74	1231.16
4434.05	1514.30			1914.70	1268.98	2707.56	1230.53
4638.70	1549.39			2051.47	1277.58	2913.20	1232.97
				2256.61	1290.26	3153.11	1245.55
				2393.38	1302.88	3564.38	1267.54
				2564.33	1326.99		
				2701.10	1358.24		
				2872.05	1402.85		
				3043.01	1438.86		
				3179.77	1462.64		
				3350.73	1473.88		

Exercise 12.8. Do the problem in Exercise 12.7 by modeling the system in HEC-HMS.

Chapter 13

Reservoir Routing

Exercise 13.1. Figure 13.25 shows a small detention basin. Develop the storage-area and storage-discharge curves for this detention facility. The side slopes on both sides are 1V:4H; the weir coefficient is 1.48 and the discharge coefficient is 0.6.

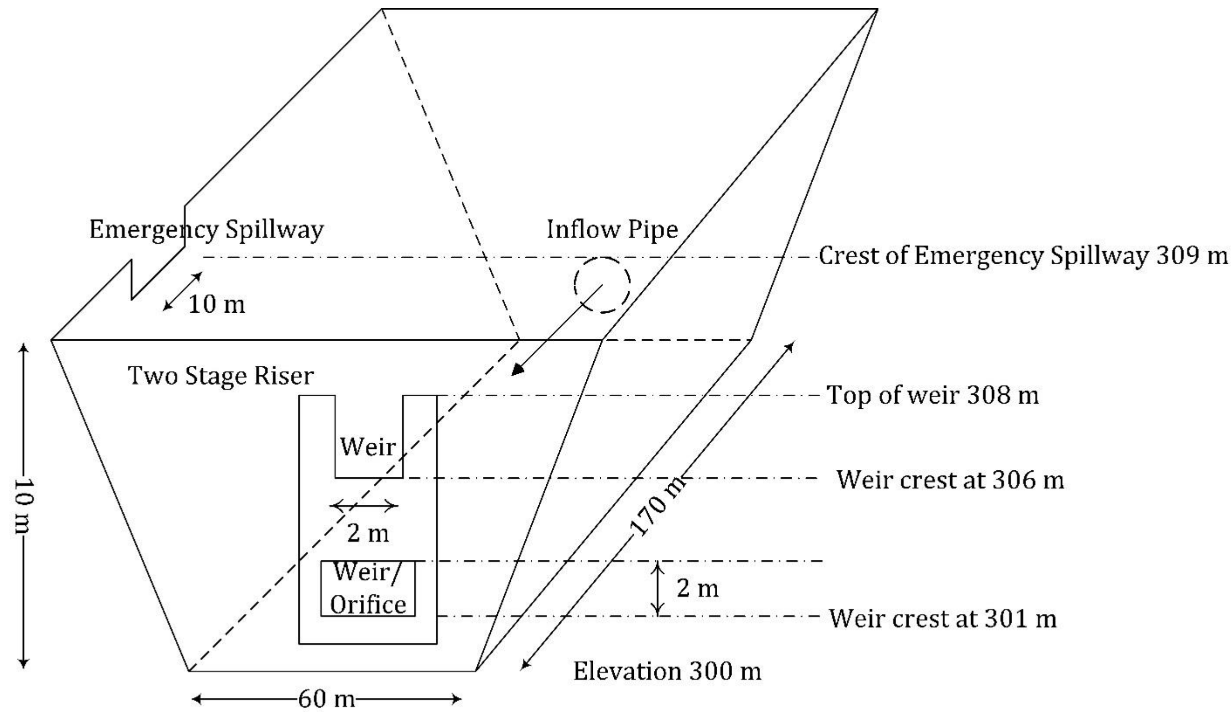

Figure 13.25 Line drawing of the detention basin in Exercise 13.1.

Exercise 13.2. Lake Crabtree is a 520-acre (2.1 km^2) reservoir in Cary, North Carolina. In order to alleviate the possibility of flooding, it was constructed in 1989 by the Natural Resources Conservation Service by damming the Crabtree Creek. Table 13.14 gives the bathymetric data for this reservoir. Develop a power function to represent storage as a function of elevation and using this relationship develop a stage-storage graph.

Table 13.14 *Area-elevation relationship for Crabtree Lake reservoir, North Carolina, USA*

Contour (feet)	Stage (feet)	Contour area (acre)
276.00	0.00	508.08
277.03	1.03	581.24
278.05	2.05	654.40
279.08	3.08	727.56
280.11	4.11	799.52
280.71	4.71	835.51
281.31	5.31	871.51

Contour (feet)	Stage (feet)	Contour area (acre)
281.91	5.91	907.51
282.50	6.50	943.50
283.10	7.10	979.50
283.70	7.70	1,015.50
284.30	8.30	1,051.50
284.90	8.90	1,087.50
285.65	9.65	1,132.90
286.41	10.41	1,178.30
287.77	11.77	1,259.90
289.43	13.43	1,359.80
292.45	16.45	1,595.20
296.22	20.22	1,905.20
300.00	24.00	2,215.20

Exercise 13.3. From the data given in Table 13.9 and 13.11 for Sartik Dam, determine the outflow hydrograph using the Modified Puls method and compare the results with those given in Example 13.3. How do you increase the numerical accuracy to get the outflow hydrograph that is theoretically correct?

Exercise 13.4. For the Sirikit Dam discussed in Example 13.2, the discharge values for various gate openings are given in Table 13.15. These are for a single gate but assume both gates are open (see Figure 13.19 C in the color plate section). The RWL for PMF given in the dam construction design manual is given in Table 13.16. Use both S formulation and H formulation of the fourth-order Runge-Kutta method to determine the outflow and RWL. Compare the calculated RWL with those given in Table 13.16. Route the 100-year hydrograph given in Table 13.9 using the Modified Puls Method and Runge-Kutta method and compare the results.

Table 13.15 *Elevation-discharge relationship for various gate openings at Sirikit Dam, Thailand*

Discharge (m^3/s)

RWL from spillway crest (m)	Gate Open 0.4 m	Gate Open 1.2 m	Gate Open 2 m	Gate Open 2.8 m	Gate Open 3.2 m	Gate Open 4 m	Gate Open 4.8 m	Gate Open 5.6 m	Gate Open 6.4 m	Gate Open 7.2 m	Gate Open 8 m	Gate Open 8.8 m	Gate Open 9.6 m
150.5	0	0	0	0	0	0	0	0	0	0	0	0	0
157.5	46	133	209	276	307	365	428	478.5	507.5	508	508	508	507.5
158	49	140	217	288	321	383	448.5	503	561	574	574	574	574
158.5	52.5	145	225	300	335	401	469	527.5	588	644	644	644	644
159	55.5	151	234	312	349	419	489.5	552.5	615.5	681	714	715	714.5
159.5	57	156	242	324	362	437	510	577	642.5	711	786	786	785.5
160	58.5	161	250	336	376	455	530	601.5	670	741	820	860	860
160.5	60	166	259	347	389	473	550	625	697	771	850	927	935

Discharge (m^3/s)

RWL from spillway crest (m)	Gate Open 0.4 m	Gate Open 1.2 m	Gate Open 2 m	Gate Open 2.8 m	Gate Open 3.2 m	Gate Open 4 m	Gate Open 4.8 m	Gate Open 5.6 m	Gate Open 6.4 m	Gate Open 7.2 m	Gate Open 8 m	Gate Open 8.8 m	Gate Open 9.6 m
161	61.5	171	267	358.5	402	490	570	648	723.5	801	880	959	1010
161.5	62	175	275	369.5	415	505	590	671	749.5	830	910	991	1091
162	62.5	180	284	381	428	520	610	694.5	775.5	859	940	1023	1177
162.5	63	184	292	392	441	535	629.5	717.5	801	888	970	1054	1261
163	63.5	188	300	403	454	550	649	741	827	916	1000	1086	1345
163.5	64	191	305	414.5	467	565	668	762	852.5	943	1030	1118	1428
164	64.5	193	310	425.5	480	580	687	783.5	878	970	1060	1149	1512
164.5	65	196	315	437	493	595	704.5	805	901.5	994	1088	1181	1601
165	65.5	199	320	448	505	609	722	826	925	1019	1115	1213	1690
165.5	66	201	325	459.5	518	624	739.5	845	948.5	1042	1143	1245	1779
166	66.5	204	330	470.5	531	639	757	864	971.5	1066	1170	1276	1870
166.5	66.5	204	330	470.5	531	639	757	864	971.5	1066	1170	1276	1927

Table 13.16 *RWL for PMF in Sirikit Dam according to design construction manual of the dam*

Time(h)	RWL (m)
0	158
6	158.04
12	158.03
18	158.04
24	158.1
30	158.3
36	158.65
42	159.08
48	159.56
54	160.05
60	160.5
66	160.99
72	161.5
78	162.06
84	162.7
90	163.32
96	163.86

Time(h)	RWL (m)
102	164.29
108	164.85
114	164.85
120	165.02
126	165.15
132	165.25
138	165.31
144	165.36
150	165.4
156	165.44
162	165.48
168	165.54
174	165.61
180	165.7
186	165.82
192	165.91
198	165.95
204	165.93
210	165.88
216	165.79
222	165.67
228	165.52
234	165.35
240	165.17
246	164.99
252	164.8
258	164.61
264	164.43

Exercise 13.5. A private land development company is pursuing a large commercial development in a presently undeveloped area within a catchment near Fort Worth, Texas. The local drainage ordinance requires that the post-development DRH must match the pre-development DRH from the drainage outfall at the creek flowing along the downstream of the development. Table 13.17 gives the ordinates of the DRH of the post-development and pre-development conditions that are shown in Figure 13.26. The enterprise asked its consulting engineer to provide a preliminary estimate of the area they need to dedicate for a detention basin and after getting that estimate, they asked the consulting engineer to proceed with the more accurate estimation and a concept plan. Calculate the detention volume that is needed to meet the regulatory requirement. How does this estimate compare with the preliminary estimate used for planning and decision making? Plot the storage-time graph and time derivative of storage to evaluate the detention time and pond performance. Now

design a detention basin for which the desirable depth should be no more than 10 ft, minimum surface area to preserve land value for which only for a couple of feet from the bottom the side slopes can be as steep as 3:1 (H:V) but the upper part will have 4:1 side slopes for mowing. The detention basin should remain dry during no rain event to utilize its full capacity during a rain event. Design an outlet system that will produce the required outflow hydrograph.

Table 13.17 *Pre-development and post-development hydrographs for Exercise 13.5.*

Time (minutes)	Post-development (ft^3/s)	Pre-development (ft^3/s)	Time (minutes)	Post-development (ft^3/s)	Pre-development (ft^3/s)
0	0	0	705	205.3	65.5
15	0	0	720	320.2	88.6
30	0	0	735	694.4	143.6
45	0	0	750	895.3	231.4
60	0	0	765	623	324.6
75	0	0	780	408.5	362.3
90	0	0	795	288.6	347.3
105	0	0	810	217.9	299.4
120	0	0	825	171.7	235.9
135	0	0	840	137.8	188.1
150	0	0	855	115.8	151.9
165	0	0	870	102.4	123.3
180	0	0	885	93.1	102
195	0.1	0	900	86	85.7
210	0.4	0	915	77.2	73.4
225	1.1	0	930	66.9	63.9
240	1.9	0.1	945	60.1	56.1
255	2.8	0.2	960	55.7	49.7
270	3.7	0.4	975	52.4	44.7
285	4.6	0.8	990	49.7	40.6
300	5.6	1.2	1005	47.4	37.2
315	6.6	1.6	1020	45.4	34.4
330	7.6	2.1	1035	43.6	32
345	8.6	2.7	1050	41.9	30.3
360	9.7	3.3	1065	40.4	28.8
375	11.3	3.9	1080	39	27.5
390	13.3	4.6	1095	36.8	26.3
405	15.1	5.4	1110	33.8	25.2
420	16.8	6.2	1125	31.8	24
435	18.5	7.1	1140	30.4	22.8
450	20.3	8.1	1155	29.4	21.7
465	22.2	9.1	1170	28.5	20.8
480	24.2	10.1	1185	27.7	20
495	26.4	11.2	1200	27	19.3

Time (minutes)	Post-development (ft^3/s)	Pre-development (ft^3/s)	Time (minutes)	Post-development (ft^3/s)	Pre-development (ft^3/s)
510	28.7	12.3	1215	26.3	18.7
525	31.3	13.5	1230	25.7	18.1
540	34.1	14.9	1245	25.1	17.6
555	39.4	16.4	1260	24.5	17.1
570	47	18.2	1275	24	16.7
585	53.7	20.4	1290	23.4	16.3
600	60.1	22.9	1305	22.9	15.9
615	67	25.8	1320	22.5	15.5
630	74.9	29	1335	22	15.2
645	88.5	32.7	1350	21.6	14.9
660	108.1	37.5	1365	21.2	14.6
675	131.9	43.9	1380	20.8	14.3
690	163.5	52.7	1395	20.4	14
			1410	20.1	13.7
			1425	19.7	13.5
			1440	19.4	13.3

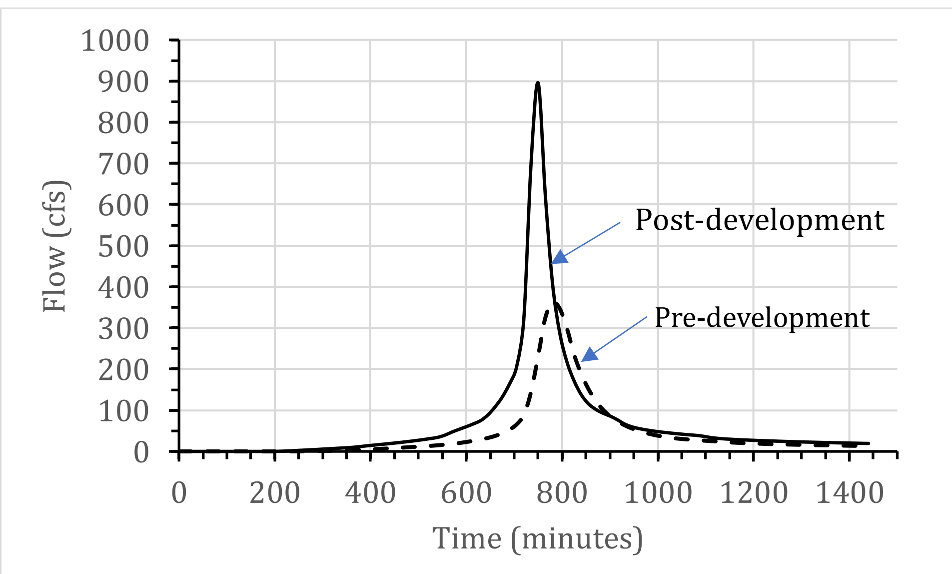

Figure 13.26 Hydrographs for pre- and post-development conditions.

Exercise 13.6. A water supply reservoir along a reach of a river is being planned after a water quality study has indicted that the river water meets the standard acceptable for a treatment plant. However, from a dam safety standard, the design calls for an outlet structure where the emergency spillway should not be engaged during 100-year flow. The synthetic hydrograph used for the design standard is given by the following equation where the design peak flow (Q_P) and time of peak flow (t_P) *have* been determined from a detailed hydrologic study of the watershed.

$$\frac{Q}{Q_p} = \left(\frac{t}{t_p}\right)^4 \exp\left[4 - 4\left(\frac{t}{t_p}\right)\right]$$

For 100-year, Q_P = 750 m³/s and t_P = 5 h. The river reach under consideration is 900 m long and 600 m wide and can be approximated as a prismatic channel. The designer has pulled an out of the shelf design for a similar project he did in the past and just adjusted the elevations based on the restriction present in this case. His concept is shown in Figure 13.27. Your task is to verify the design and adjust it so that the design criteria can be met. Use the Modified Puls, S- and H- formulations of the fourth-order Runge-Kutta method to route the inflow hydrograph through the impoundment. Select a Δt that gives reasonably accurate results. Remember to account for flow when the orifice in the primary spillway is partially full and effective storage is in the flood pool, as shown in Figure 13.27.

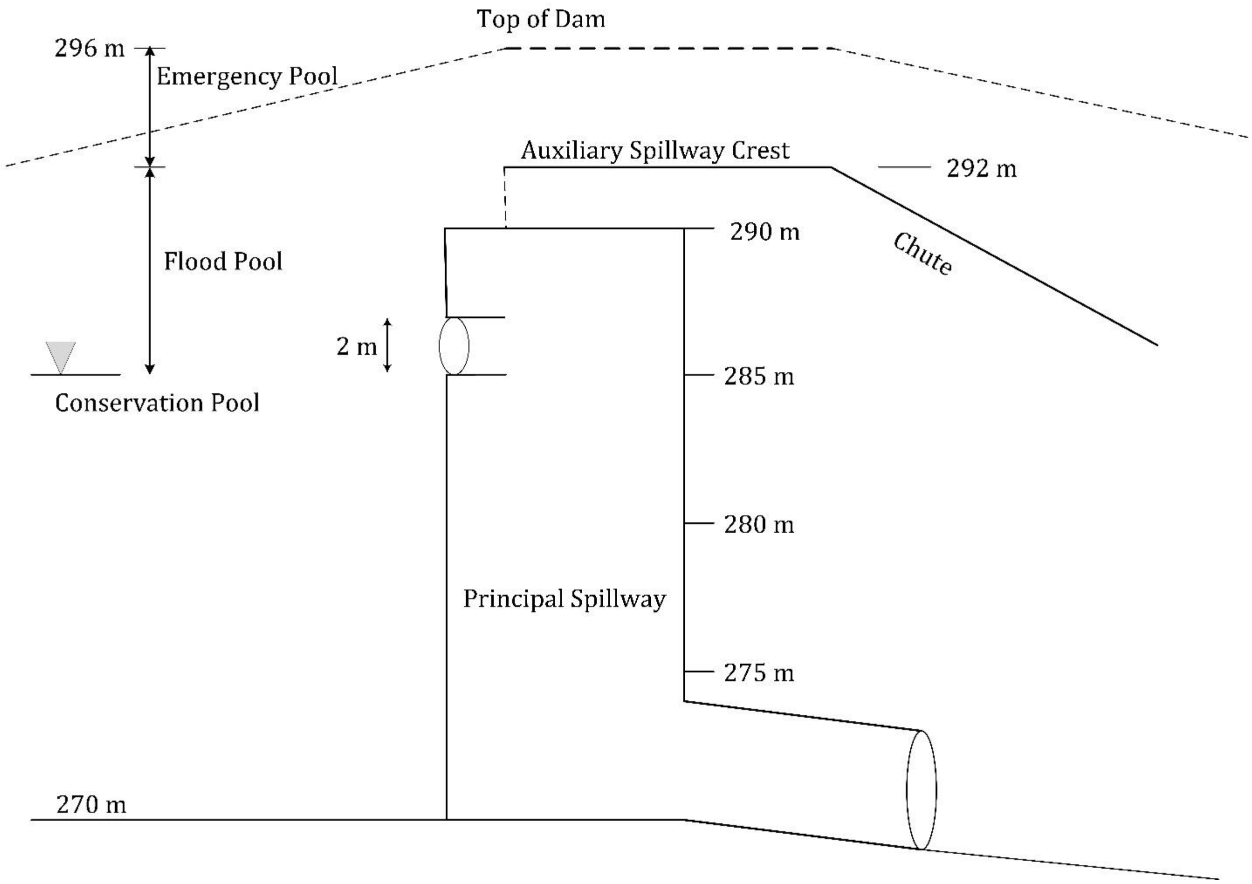

Figure 13.27 Elevation diagram for the reservoir in Exercise 13.6.

Exercise 13.7. The Glenmore Reservoir is a large reservoir on the Elbow River that flows through the City of Calgary in Alberta, Canada (Figure 13.28). It is controlled by the Glenmore Dam, a concrete gravity dam on the Elbow River. The Glenmore Reservoir is a primary source of drinking water to the city of Calgary. Although the dam usually provides effective flood protection, a major flood in June 2005 caused the reservoir to exceed its capacity. In June 2013, heavy rainfall west of the city also caused the reservoir to exceed its capacity. Table 13.18 gives the results of a recent bathymetric survey of the reservoir. From this information, provide an approximate estimate of the capacity of Glenmore Reservoir.

Table 13.18 *Bathymetric data of Glenmore Reservoir, Alberta, Canada*

Contour Elevation (m)	**Depth (m)**	**Contour Length (m)**
1071.36	1.52	1581.64
1071.36	1.52	4856.38
1071.36	1.52	11249.91
1068.31	4.57	390.18
1066.78	6.1	469.84
1065.26	7.62	881.01
1063.74	9.14	1067.14
1062.21	10.67	3749.78
1062.21	10.67	267.15
1062.21	10.67	261.16
1059.16	13.72	903.38
1057.64	15.24	927.79
1059.16	13.72	644.29
1057.64	15.24	354.52
1065.26	7.62	258.31
1065.26	7.62	2346.86
1065.26	7.62	290.49
1068.31	4.57	9434.96
1060.69	12.19	865.54
1063.74	9.14	9763.71
1065.26	7.62	8233.00
1066.78	6.1	9609.74
1069.83	3.05	15711.11
1056.12	16.76	526.86
1062.21	10.67	1520.09
1066.78	6.1	1527.59
1057.64	15.24	134.22
1059.16	13.72	1542.04
1057.64	15.24	1510.09
1060.69	12.19	1751.20
1063.74	9.14	1528.17
1065.26	7.62	1536.86
1068.31	4.57	1538.54
1069.83	3.05	1548.06
1059.16	13.72	1176.53
1060.69	12.19	2244.00

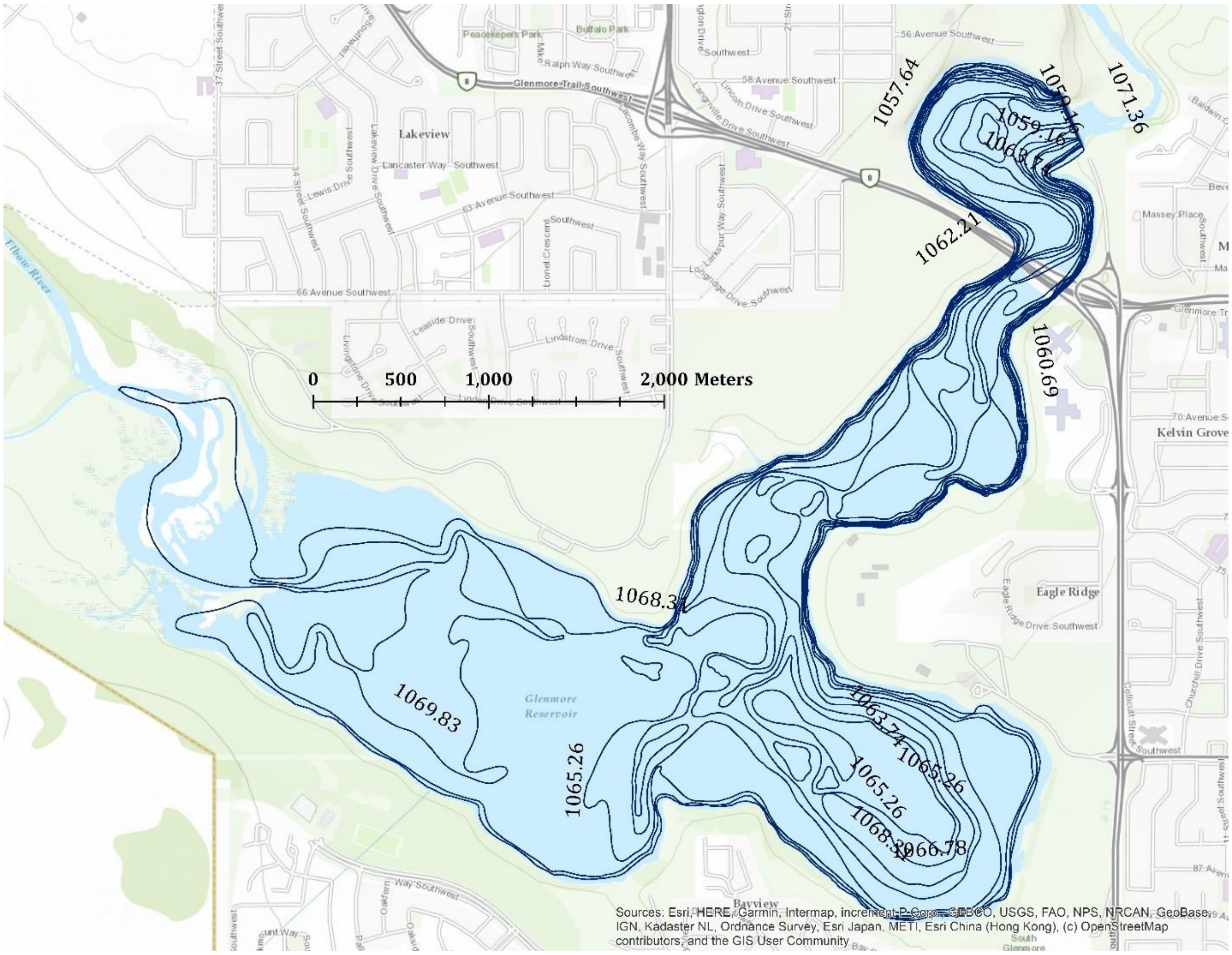

Figure 13.28 Bathymetric map of Glenmore Reservoir, Calgary, Alberta, Canada.

Chapter 14

Evaporation and Evapotranspiration

Exercise 14.1. The Muda Irrigation Project in western Malaysia is a paddy irrigation project covering 126,000 ha of area. There is a network of meteorological stations in the project area. Estimation of evapotranspiration is very important in an irrigation scheme. Ali and Shul (2009) provided monthly averaged daily values of temperature, wind speed, possible sunshine, solar radiation, relative humidity, and pan evaporation data recorded at Kepala Batas meteorological station for the period 1980-1997. The latitude and longitude of the station are 06°12' N and 100°25' E. Dr. Ali in his Ph. D. dissertation evaluated several models of evapotranspiration applicable to Muda Irrigation Project. One of his findings was that Penman-Monteith model could be selected as the best model for estimation of ET_P in Muda Irrigation Project. Table 14.7 gives the meteorological data, as given by Ali and Shul (2009), for the following tasks. Calculate monthly ET_P in mm/day using the following models:

1. Penman Model
2. Penman-Monteith Model
3. FAO 56 Penman-Monteith Model
4. Hargreaves Model
5. Extended Blaney-Criddle Model (Eq. 14.68)

From these evaluations make your conclusion about the best suitability of the model. It is recommended that some statistical tests are to be performed to support the conclusions.

Table 14.7. *Meteorological data from Muda Irrigation project, Malayasia*

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Avg. temp.(°C)	26.99	27.66	27.96	28.12	27.84	27.63	27.06	26.90	26.71	26.60	26.58	26.47
Avg. RH {mean} (%)	72.90	73.00	76.60	81.50	85.20	85.60	86.30	86.30	86.40	87.00	85.00	79.70
Avg.u_2 (ms^{-1}) at 2m altitude*	1.73	1.52	1.25	1.09	1.00	0.88	0.92	0.98	1.01	0.94	1.00	1.39
R_a (MJm^{-2} day^{-1})	33.81	35.98	37.47	37.54	36.82	35.88	36.36	37.10	37.30	36.52	34.55	33.31
Sunshine, n (h day^{-1})	8.70	9.00	8.50	8.70	7.70	7.10	6.60	6.70	5.70	5.70	6.10	7.00
G (MJm^{-2} day^{-1})	0.26	0.11	0.06	−0.11	−0.08	−0.22	−0.06	−0.07	−0.04	−0.01	−0.04	0.20
r_a (s m^{-1})	130.05	138.11	150.06	158.32	163.05	170.16	167.55	164.28	162.56	166.53	163.05	143.74
r_s (s m^{-1}) at average h_c = 0.4m	48.48	48.48	48.48	48.48	48.48	48.48	48.48	48.48	48.48	48.48	48.48	48.48
Pan E_p (mm day^{-1})*	5.74	6.14	5.97	5.10	4.16	3.78	3.80	3.80	3.74	3.76	3.59	4.29

Chapter 15

Snowmelt

Exercise 15.1. A watershed with a 25 km^2 area is 28% snow-covered. On a certain day during the ablation period, the average air temperature is 6 °C, the net radiation is 28 W m^{-2}, and the mean areal rainfall is 2.5 cm. Calculate the rate of snowmelt runoff.

Exercise 15.2. The Aksu River is located south of the Tianshan Mountains in the northern Tarim River basin of the Xinjiang Uygur Autonomous Region in western China. Table 15.5 gives the hypsometric and snow-cover data of the basin. Table 15.6 gives the parameters for snowmelt runoff computation and Table 15.7 gives the daily average temperature and rainfall during the snow melting period for the year 2004. The climate station is at 1000 m.

Compute daily snowmelt runoff and plot the hydrograph.

Table 15.5 Area of elevation zones and mean hypsometric elevation of Aksu River basin, China

Elevation zone	Elevation range (m)	Zone area (km^2)	*SCA* (%)	Mean hypsometric elevation (m)
A	1 412-1 925	150.54	1.17	1 668.5
B	1 925-2 438	348.45	2.71	2 181.4
C	2 438-2 951	974.66	7.58	2 694.3
D	2 951-3 464	2 500.87	19.45	3 207.2
E	3 464-3 977	4 221.52	32.84	3 720.1
F	3 977-4 490	3 287.05	25.57	4 233.0
G	4 490-5 003	1 029.96	8.01	4 745.9
H	5 003-5 516	269.33	2.1	5 258.8
I	5 516-6 029	58.28	0.45	5 771.7
J	6 029-6 541	15.13	0.12	6 284.6
The whole basin	1 412-6 541	12 855.78	100	3 830.0

Table 15.6 *Parameters for snowmelt runoff computation in Aksu River basin, China*

	Temperature lapse rate (℃/km)	**Degree-day factor (cm/(℃·d)**	**Runoff coefficient for snowmelt**	**Runoff coefficient for rainfall**	**Lag time (h)**	**Rainfall contributing area***	**Parameters of recession coefficient**	
Month							*x*	*y*
Apr.	6	0.35	0.45	0.60	18	0	0.998	0.065
May	8.0	0.30	0.45	0.60	28	0	0.998	0.065
Jun.	7.0	0.45	0.6	0.60	24	1	0.998	0.065
Jul.	8	0.15	0.7	0.60	36	1	0.998	0.065
Aug.	8.5	0.45	0.60	0.60	30	1	0.998	0.065
Sep.	7	0.35	0.60	0.60	30	1	0.998	0.065

* 0 indicates rain captured on snow, 1 indicates rain generated runoff.

Table 15.7 *Daily average temperature and rainfall for the year 2004 at Aksu River basin, China*

	April		May		June		July		August		September	
Day	**T (°C)**	**Rainfall (mm)**	**T (°C)**	**Rainfall (mm)**	**T (°C)**	**Rainfall (mm)**	**T (°C)**	**Rainfall (mm)**	**T (°C)**	**Rainfall (mm)**	**T (°C)**	**Rainfall**
1	11.4	0	11	4	20.8	0	27.4	0	28.1	0	17.4	1
2	15.2	0	13.6	0	19.3	0	24.9	0	28.8	0	20.6	0
3	15.8	0	17.2	0	20.7	0	29.2	0	24.6	4	20.1	0
4	14.8	0	21	0	24.3	0	31.3	0	22.8	4	21.8	0
5	12.6	0	22.6	0	28	0	22.7	5	27.2	0	22.8	0
6	17.4	0	24.1	0	29.4	0	19.7	4	27.5	0	24.4	0
7	16.1	0	20.9	10	22.4	0	21.4	0	20.4	3	26.9	0
8	10.9	5	11.8	5	21.4	0	26.1	0	18.1	3	17.1	-2
9	7.6	4	15.8	0	18.6	10	23.8	0	20.7	3	20.3	0
10	11	0	13.5	3	20.9	8	26.5	0	21.8	0	15.7	2
11	9.6	3	14.1	0	20.3	0	29.6	0	23.8	0	19.1	0
12	11	0	14.2	1	24.7	0	31.7	0	23.4	0	21.8	0
13	14.7	0	18.3	0	26.1	0	33.9	0	25.1	0	23.2	0
14	17.9	0	18.9	2	28.6	0	34.6	0	27.2	0	15.9	3
15	20.4	0	23.7	0	22.9	6	31.3	0	28.4	0	14.7	0
16	22.8	0	25.7	0	23.2	0	31.3	0	26.7	0	16.3	0
17	21.2	0	27.7	0	26.1	0	29.1	0	28.2	0	18.6	0
18	24.8	0	25	0	28.7	0	23.1	8	29.7	0	19.3	0
19	16.7	3	29.4	0	30.4	0	16.9	7	27.2	0	21	0
20	10.7	0	29.2	0	30.4	6	20.2	6	21.5	3	22.6	0
21	13.2	0	19.6	1	29.1	0	22.2	4	22.3	6	19.6	0
22	16.7	0	17.6	1	30	0	22.6	0	24.1	4	14.1	2
23	17.2	3	22.2	0	28.7	5	25.9	0	16.5	2	14.8	0
24	18	0	20.8	0	19.2	5	24.9	2	17.3	0	15.7	0
25	23.1	0	18.3	0	21.3	0	22.6	1	18.4	0	16.4	0
26	20.8	0	16.6	1	24.6	0	22.9	0	19.6	0	14.9	0
27	10.2	1	19.3	0	18.1	6	25.3	0	21.6	0	15.3	2

	April		May		June		July		August		September	
Day	**T (oC)**	**Rainfall (mm)**	**T (oC)**	**Rainfall (mm)**	**T (oC)**	**Rainfall (mm)**	**T (oC)**	**Rainfall (mm)**	**T (oC)**	**Rainfall (mm)**	**T (oC)**	**Rainfall**
28	8.2	0	22.4	0	23.6	0	27.9	0	21	0	6.5	2
29	11.1	0	24.1	0	27.2	0	29.8	0	24.9	0	5.2	0
30	11.1	0	26.6	0	29.6	0	27.1	1	26.6	0	7.8	0
31			25.5				28.0		24.4			

Chapter 16

Erosion and Sedimentation

Exercise 16.1. Washpool Aldinga basin is a small coastal catchment near Adelaide in South Australia. The catchment is mostly covered by vegetation including woody native vegetation, orchards vineyards, irrigated non-woody dryland agriculture with slight urban areas. The average basin slope is 1.6%. Clay loam, loam, and sand are the chief soil types in the basin. Adhikari (2020)* derived the hydrological parameters of the basin from a careful evaluation of available data and information. These data are given in Table 16.5. He also developed the parameters to use in MSLUE and these are given in Table 16.6. The grain size distribution of the surface soil type is given in Table 16.7. The hyetograph of a rain event is given in Table 16.8. Use HEC-HMS to provide the estimates of sediment yield during the event, the peak sediment discharge of the total load and that for the clay, silt, and gravel. Plot the sedigraphs.

Table 16.5 *Hydrological parameters of Washpool Aldinga catchment, Australia*

Area (km^2)	47.9
Loss Method	Curve number
CN	67
Initial abstraction (mm)	23
Impervious area (%)	5.4
Transform method	NRCS
Lag time (minute)	288
PRF (Standard)	484
Baseflow	None
Canopy Method	Simple canopy
Initial storage (%)	0
Maximum storage (mm)	16
Crop coefficient	1
Evaporation	None

Table 16.6 *Parameters for MUSLE, Washpool Aldinga catchment, Australia*

K	0.49
LS	0.8
C	0.03
P	1
Threshold (m^3/s)	1
Exponent	0.6
Gradation Curve	
Sediment Characteristics	

Specific gravity	2.65
Dry density clay (kg/m^3)	480.55
Dry density silt (kg/m^3)	1041.2
Dry density sand (kg/m^3)	1489.7
Fall velocity model	Rubey
Grade scale	Clay-silt-sand-gravel

Table 16.7 *Grain size distribution of typical soils in Washpool Aldinga catchment, Australia*

Particles	Diameter (mm)	Percent finer
Clay	0.002	17.98
Silt	0.05	28.98
Sand	0.25	53.04

Table 16.8 *Rainfall data for a storm event in Washpool Aldinga catchment, Australia*

Time	Rainfall (mm)
12:00 AM	-
12:30 AM	2.37153
1:00 AM	5.00871
1:30 AM	1.84023
2:00 AM	0.38640
2:30 AM	1.86921
3:00 AM	4.49190
3:30 AM	11.08002
4:00 AM	3.03324
4:30 AM	1.52145
5:00 AM	1.19301
5:30 AM	0.66654
6:00 AM	1.67118
6:30 AM	1.68084
7:00 AM	2.49228
7:30 AM	2.50677
8:00 AM	2.83038
8:30 AM	3.12984
9:00 AM	0.87423
9:30 AM	0.00000

*Adhikari, Prakash. (2020). Application of HEC-HMS to the investigation of soil erosion and sediment yield by surface runoff. Master of Engineering Thesis. Flinders University, Australia.

Exercise 16.2. For a channel, the following data are given.

Temperature, T = 55°F; average velocity of flow, V = 5.46 ft/s; depth of flow, discharge, Q = 5000 ft^3/s; D = 22.9 ft; channel slope, S = 0.0001, channel width, B = 40 ft; and median particle diameter, d_{si} = 0.00232 ft; 84% particle diameter d_{84} = 0.00294 ft; overall d_{50} = 0.00306 ft; specific weight of water, γ_w = 62.385 lb/ft^3; kinematic viscosity, ν = 0.00001315 ft^2/s; and specific gravity of sediment, s = 2.65. Acceleration due to gravity, g = 32.2 ft/s^2.

Calculate sediment transport capacity using functions of (1) Engelund-Hansen, (2) Laursen-Copeland (3) Meyer-Peter & Müller, and (4) Yang.

Exercise 16.3. Suspended sediment concentration at a point on a river flowing at a velocity of 2.0 m/s is measured as 100000 mg/L. The dispersion coefficient of the suspended load is 1.77*10^2 m^2/s. Compute the longitudinal concentration profile at 200 m intervals for a 20 km length of the river. Use a time step of 30 s for a total period of 3 h.

Exercise 16.4. Table 16.9 gives the nominal diameters corresponding to U.S. standard sieve number. Table 16.10 gives the nominal diameters for the six broad sediment classes. Table 16.11 gives the results of laboratory sieve and hydrometer analysis of a surface sediment sample from an area in west Texas. Plot the gradation curve by plotting percent finer on the y-axis (ordinate on arithmetic scale) and grain size on the x-axis (abscissa on base 10 logarithmic scale) with decreasing grain size (to the right). Determine the clay-silt-sand-gravel fractions of the soil sample.

Table 16.9 *US standard sieve opening for sieve numbers*

Sieve No.	Opening (mm)	Sieve No.	Opening (mm)
4	4.75	35	0.500
5	4.00	40	0.425
6	3.35	45	0.355
7	2.80	50	0.300
8	2.36	60	0.250
10	2.00	70	0.212
12	1.70	80	0.180
14	1.40	100	0.150
16	1.18	120	0.125
18	1.00	140	0.106
20	0.85	200	0.075
25	0.71	270	0.053
30	0.60	400	0.038

Table 16.10 *Nominal diameters for the six broad classes of sediments*

Sediment Class	Nominal diameter, *D* (mm)	ϕ
Boulder	> 256	< -8
Cobble	256 - 64	- 8 to -6
Gravel	64 - 2	-6 to -1
Sand	2 - 0.062	-1 to +4
Silt	0.0625 - 0.004	+ 4 to +8
Clay	< 0.004	> +8

Table 16.11 *Laboratory determination of grain size distribution in surface soil sample from west Texas*

Sieve #	Particle size (mm)	Weight retained (g)	Cumulative Weight Retained (g)	Percent Retained (%)	Percent Passing (%)
3"	75	0	0	0.00	100.00
1½"	37.5	0	0	0.00	100.00
1"	25	0	0	0.00	100.00
$^{3}/_{4}$"	19	0	0	0.00	100.00
1/2"	12.5	4	4	1.05	98.95
3/8"	9.5	2	6	1.57	98.43
#4	4.75	8.9	14.9	3.91	96.09
#10	2	6.2	21.1	5.53	94.47
#40	0.425	80.6	101.7	26.66	73.34
#100	0.15	204.1	305.8	80.18	19.82
#200	0.075	29.2	335	87.83	12.17
Loss after washing		46.4	381.4	100.00	0
	0.052	4.150	45.850	89.0	11.0
	0.0368	0.810	46.660	90.6	9.4
	0.026	0.990	47.650	92.5	7.5
	0.0184	0.000	47.650	92.5	7.5
	0.0136	0.000	47.650	92.5	7.5
	0.0096	0.000	47.650	92.5	7.5
	0.0068	0.060	47.710	92.6	7.4
	0.0034	0.810	48.510	94.2	5.8
	0.0014	0.880	49.400	95.9	4.1
	Beyond 0.0014 mm	2.10	51.50	100.00	0.00

Chapter 17

Reservoir Operations

Exercise 17.1. From the data and graphs given for Somerville Dam and Lake in Example 17.1, construct a longitudinal section of the reservoir showing various storage allocations and answer the following questions.

1. What percentages of the total reservoir capacity are allocated to dead storage, conservation storage, and flood storage in the reservoir?
2. What is the siltation rate in the reservoir?

Exercise 17.2. Hurricane Harvey was a devastating Category 4 hurricane that made landfall on Texas and Louisiana on August 25, 2017, causing catastrophic flooding and more than 100 deaths. It is tied with Hurricane Katrina of 2005 as the costliest tropical cyclone on record, inflicting $125 billion (2017 USD) in damage, primarily from catastrophic rainfall-triggered flooding in the Houston metropolitan area (see Figure 17.10) and a large swath of land in Southeast Texas which made the storm the costliest natural disaster recorded in Texas at the time.

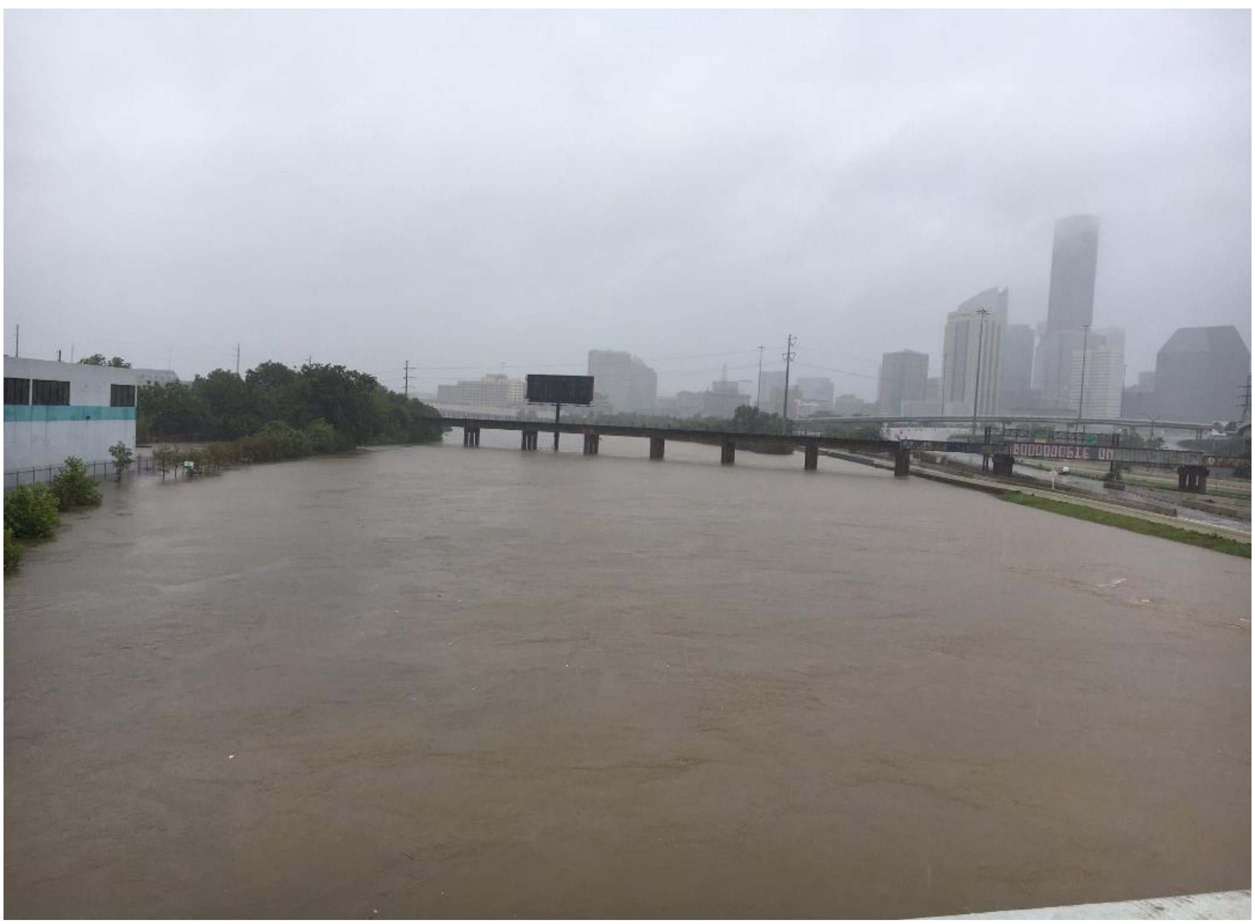

Figure 17.10 Flooding in Houston during Hurricane Harvey
(https://www.weather.gov/hgx/hurricaneharvey)

Table 17.4 gives the storage, outflow, and elevation data of Somerville Lake and Dam from August 25 to December 7, 2017. These data are from a database of 679 major reservoirs[3] across US, called ResOpsUS developed by Steyaer et al (2022)[4]. In Table 17.4, storage is in million cubic m, outflow is in m^3/s and elevation is in m as given in ResOpsUS database.

Table 17.4 *Storage* (million m^3), *outflow* (m^3/s), *and elevation* (m) *of Sommerville Lake at the aftermath of Hurricane Harvey*

Date	Storage	Outflow	Elevation	Date	Storage	Outflow	Elevation
8/25/2017	176.349	0.009	72.341	10/16/2017	301.469	61.447	74.743
8/26/2017	178.378	0.184	72.387	10/17/2017	296.197	61.164	74.655
8/27/2017	219.542	9.458	73.256	10/18/2017	291.154	61.164	74.569
8/28/2017	347.653	40.493	75.484	10/19/2017	286.16	60.881	74.484
8/29/2017	456.46	14.668	77.041	10/20/2017	281.212	60.881	74.399
8/30/2017	481.485	1.266	77.37	10/21/2017	276.313	60.881	74.313
8/31/2017	495.215	0.167	77.547	10/22/2017	272.842	61.447	74.252
9/1/2017	501.677	0.049	77.63	10/23/2017	268.71	60.881	74.179
9/2/2017	505.528	0.037	77.678	10/24/2017	263.933	60.598	74.094
9/3/2017	507.7	0.029	77.706	10/25/2017	258.867	60.598	74.002
9/4/2017	508.667	0.024	77.718	10/26/2017	254.022	60.315	73.914
9/5/2017	507.942	23.248	77.709	10/27/2017	249.063	60.032	73.823
9/6/2017	502.398	66.544	77.639	10/28/2017	243.673	59.748	73.722
9/7/2017	497.125	73.341	77.572	10/29/2017	238.99	59.465	73.634
9/8/2017	491.645	74.756	77.501	10/30/2017	234.04	59.182	73.539
9/9/2017	486.433	74.756	77.434	10/31/2017	229.776	59.465	73.457
9/10/2017	480.78	74.756	77.361	11/1/2017	226.802	59.182	73.399
9/11/2017	475.629	74.473	77.294	11/2/2017	222.461	58.333	73.314
9/12/2017	470.275	74.19	77.224	11/3/2017	218.472	49.271	73.234
9/13/2017	465.185	74.19	77.157	11/4/2017	215.733	38.794	73.179
9/14/2017	459.893	73.907	77.087	11/5/2017	212.864	38.228	73.122
9/15/2017	454.407	73.624	77.014	11/6/2017	209.868	37.945	73.061
9/16/2017	449.409	73.341	76.947	11/7/2017	206.897	37.945	73
9/17/2017	444.213	73.057	76.877	11/8/2017	203.802	37.661	72.936
9/18/2017	439.051	72.491	76.807	11/9/2017	201.172	31.715	72.881
9/19/2017	433.698	71.642	76.733	11/10/2017	199.283	21.832	72.841
9/20/2017	428.822	70.226	76.666	11/11/2017	197.695	21.521	72.808
9/21/2017	423.536	69.093	76.593	11/12/2017	196.112	21.549	72.774

[3] There are over 52, 000 dams in the contiguous USA ranging from 0.5 to 243 m high that collectively hold 600.000 million cubic meters of water.

[4] Steyaert, J. C., Condon, L. E., Turner, S. W. D., Voisin, N. (2022). *ResOpsUS, a dataset of historical reservoir operations in the contiguous United States*. Nature Scientific Data, 9 (1), 34.

Date	Storage	Outflow	Elevation	Date	Storage	Outflow	Elevation
9/22/2017	418.285	67.96	76.52	11/13/2017	194.823	16.905	72.747
9/23/2017	413.069	67.111	76.447	11/14/2017	193.966	10.704	72.728
9/24/2017	407.888	66.261	76.374	11/15/2017	193.112	10.562	72.71
9/25/2017	402.742	65.695	76.301	11/16/2017	192.402	10.647	72.695
9/26/2017	397.843	65.412	76.23	11/17/2017	191.976	10.874	72.686
9/27/2017	392.977	64.845	76.16	11/18/2017	191.268	11.1	72.67
9/28/2017	387.933	64.562	76.087	11/19/2017	189.857	11.355	72.64
9/29/2017	385.841	64.845	76.057	11/20/2017	189.014	8.778	72.622
9/30/2017	381.054	63.43	75.987	11/21/2017	188.452	5.125	72.609
10/1/2017	376.093	63.146	75.913	11/22/2017	188.032	2.917	72.6
10/2/2017	370.963	62.58	75.837	11/23/2017	187.612	2.888	72.591
10/3/2017	366.479	62.863	75.77	11/24/2017	187.332	2.888	72.585
10/4/2017	361.823	62.58	75.7	11/25/2017	186.913	2.818	72.576
10/5/2017	356.999	62.014	75.627	11/26/2017	186.774	2.803	72.573
10/6/2017	352.011	62.014	75.551	11/27/2017	186.495	2.818	72.567
10/7/2017	346.863	61.731	75.472	11/28/2017	186.217	2.823	72.561
10/8/2017	342.149	61.731	75.398	11/29/2017	186.078	1.39	72.558
10/9/2017	336.886	61.447	75.316	11/30/2017	185.938	0.06	72.555
10/10/2017	332.053	61.731	75.24	12/1/2017	185.8	0.045	72.552
10/11/2017	326.685	61.731	75.155	12/2/2017	185.8	0.041	72.552
10/12/2017	321.363	61.731	75.069	12/3/2017	186.078	0.029	72.558
10/13/2017	316.465	61.447	74.99	12/4/2017	186.913	0.029	72.576
10/14/2017	311.608	61.447	74.911	12/5/2017	187.052	0.018	72.579
10/15/2017	306.792	61.447	74.831	12/6/2017	187.332	0.033	72.585
				12/7/2017	187.891	0.074	72.597

Figure 17.11 (A) shows the elevation-outflow graphs constructed from ResOpsUS data and Figure 17.11 (B) shows the discharge hydrograph at USGS gauging station (8110000) on Yegua Creek. This is one of the downstream control points listed in Table 17.3. This point is located just downstream of the reservoir (See Figure 17.12).

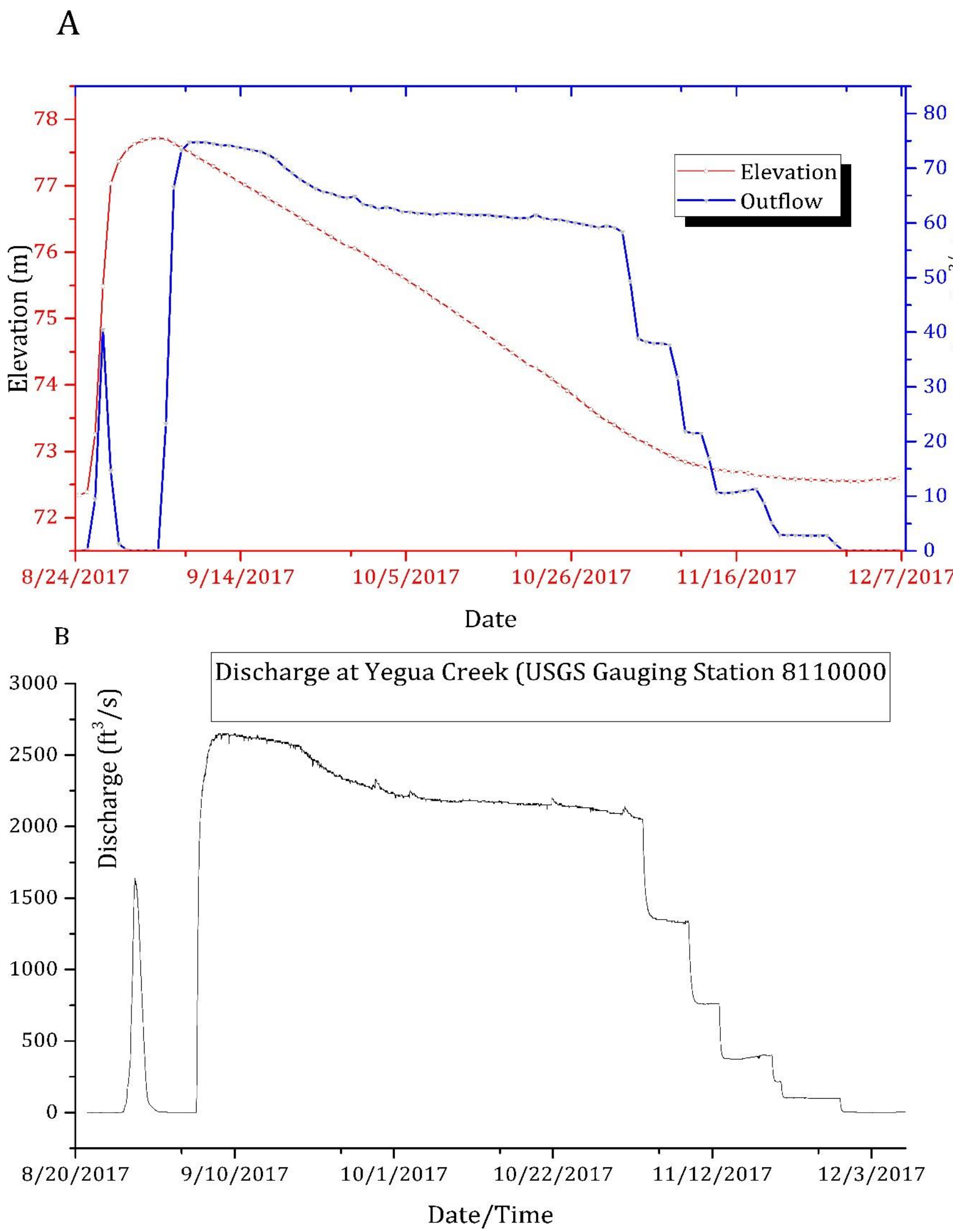

Figure 17.11 (A) Elevation-outflow curves of Somerville Lake and Dam (B) flow hydrograph at Yegua Creek during Hurricane Harvey

From the data and information provided above, do the following.

1. Construct the mass curve.
2. What was the release from the reservoir on the date when stage of the reservoir was highest?
3. What was the stage of the reservoir on the date when the release from the reservoir was maximum?
4. When the release was the maximum, what was the volumetric flow rate from the outlet works and how were the control structures operating? Was the spillway engaged during that time?
5. From the observed data, was there any violation of the operation rules (as given in Example 17.1) of this reservoir?

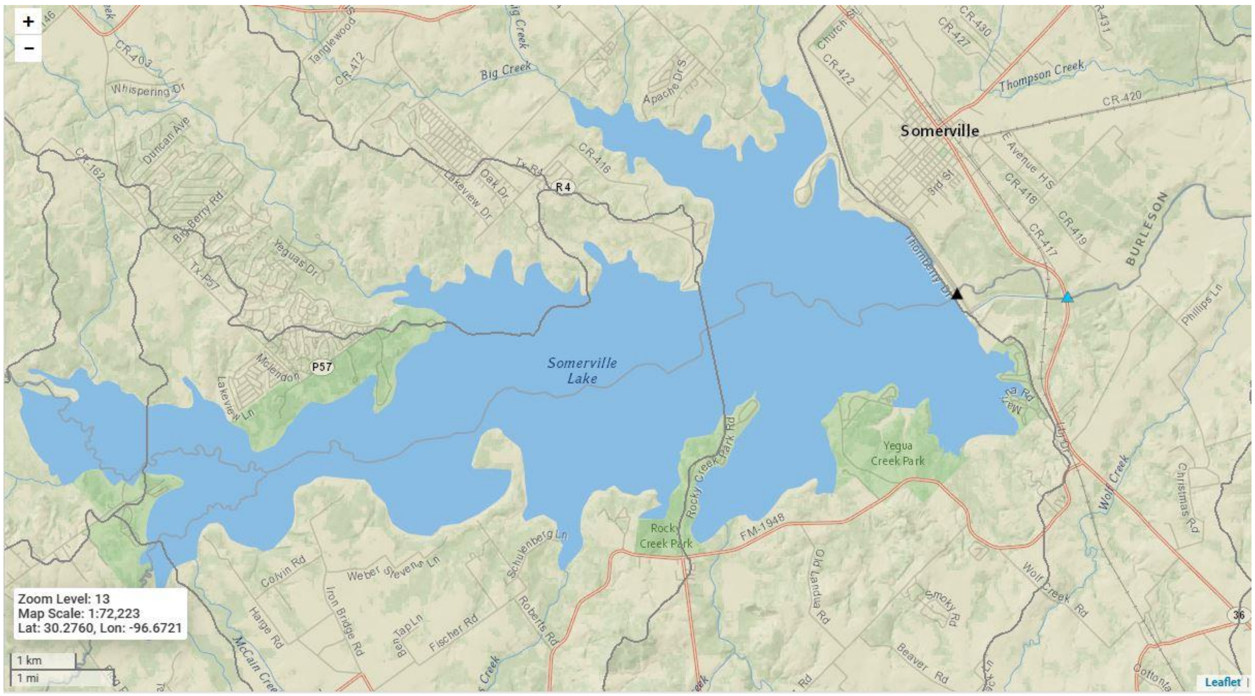

Figure 17.12 USGS Gauge 08110000 on Yegua Creek downstream of Somerville Dam (black triangle) is shown by the blue triangle.

Chapter 18

Climate Change

Notes: The Natural Resources Conservation Service of the United States Department of Agriculture developed a set of empirical formulae to calculate monthly effective rainfall ratios based on monthly average rainfall amounts. Accordingly,

$$p_0 = 1 - 0.0016P \text{ for } P \leq 250\,\text{mm} \tag{18.1}$$

$$p_0 = 0.1 + \frac{125}{P} \text{ for } P > 250\,\text{mm} \tag{18.2}$$

Exercise 18.1. Monthly average rainfall values at selected stations within middle Brahmaputra River basin are given in Table 18.3. These stations, listed from upstream to downstream are within the watershed numbered 10 in Figure 18.11, except Lumding which is in watershed numbered 15. See Figure 6.17 in the color plate section for the locations.

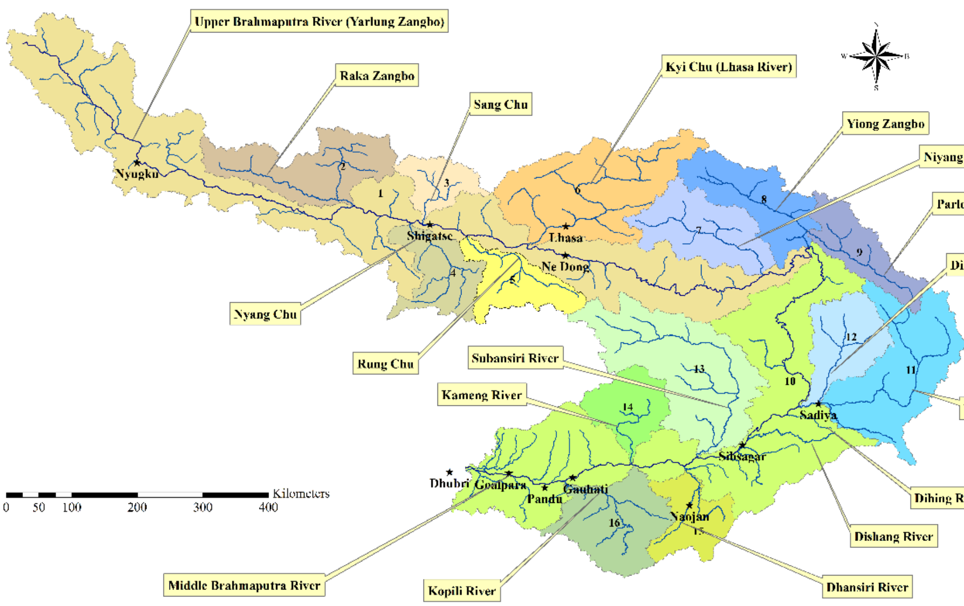

Figure 18.11 Watersheds of upper-middle Brahmaputra Basin (from Mukhopadhyay, 2013; reproduced with permission).

Table 18.3 *Monthly average rainfall (mm) at selected locations in the Brahmaputra Basin, India*

Month	**Mohonbari**	**Dibrugarh**	**Sibsagar**	**Tezpur**	**Lumding**	**Gauhati**	**Dhubri**
January	28	35	30	15	16	9	10
February	54	61	47	15	30	18	9
March	96	100	95	60	48	51	47
April	239	204	218	154	88	159	136
May	262	356	361	296	174	219	349
June	393	514	391	312	248	320	562
July	539	516	476	312	198	359	458
August	449	417	400	294	195	243	347
September	332	341	302	196	194	182	267
October	125	166	136	107	103	86	153
November	27	27	30	22	34	23	16
December	20	22	20	7	3	7	3
Total	**2564**	**2759**	**2506**	**1790**	**1331**	**1676**	**2357**

Sontakke et al. (2008) analyzed instrumental records of rainfall covering the period 1848 – 2006 from six stations located in Brahmaputra Valley of Assam (contained within watershed 10). They constructed area-averaged monthly, seasonal, and annual rainfall series. Time series analyses by 9-point Gaussian low-pass filtering detected trends for various sub-periods within the long-term trends. Broadly, the sub-periods can be generalized into two periods within which the seasonal and annual trends can be summarized as given in Table 18.4. The significant point that comes out of their analysis is that monsoonal precipitation that contributes the greatest portion to annual total rainfall shows a decreasing trend whereas all other seasonal rainfall, including annual pattern show increasing trends. In an earlier study, Mirza et al (1998) showed that for the period 1901 – 1981, the mean annual precipitation in Middle Brahmaputra basin, exhibited a decreasing trend that was statistically significant. Temporal changes in both temperature and precipitation at two stations within this watershed of the basin for the period 1973 – 2006 show positive trends (Pechstädt et al., 2009). The monsoonal rainfall data presented by Das et al (2009) for the period 1983 – 2009 from a recording station south of Gauhati show that since 2001, there has been a drastic rise in precipitation. During 1983 – 2000, the monsoonal (June – September) rainfall was, in general, below 1000 mm but during the years 2001 – 2009, it increased to 1103 – 1938 mm.

Table 18.4 *Long term trends of changes in precipitation patterns in Brahmaputra Valley, Assam, India*

Season	**Mean Rainfall (mm)**	**Contribution to Annual total (%)**	**Early Period**	**Trend**	**Late Period**	**Trend**	**Overall Trend**
Winter *Jan - Feb*	51.5 ± 24.7	2.3	1848 - 1978	–	1979 - 2006	+	Increasing
Summer *Mar – Apr - May*	549.4 ± 130.5	25.0	1848 - 1979	±	1979 - 2006	+	Increasing
Monsoon *Jun – Jul – Aug - Sep*	1443.2 ± 159.4	65.8	1848 - 1918	±	1919 - 2006	–	Decreasing
Post Monsoon *Oct – Nov - Dec*	152.2 ± 65.4	6.9	1848 - 1888	–	1889 - 2006	+	Increasing
Annual	2196.1 ± 226		1848 – 1978	±	1979 - 2006	+	Increasing

+ Increasing trend; − Decreasing trend; ± Cyclic pattern i.e. the period shows both increasing and decreasing sub-periods.

From the data given in Table 18.3 and using Equations 18.1 and 18.2 given in the boxed notes above, develop the runoff ratios of the middle Brahmaputra basin and from the information given in Table 18.4 write an essay on the pattern of relative changes in evapotranspiration and precipitation in this section of the basin.

Chapter 19

Water Resources Management

Exercise 19.1. Discuss the ways human interventions can impact evapotranspiration, storage, and river flows. What are the probable impacts?

Exercise 19.2. Through internet research write an essay on how the Connecticut Department of Energy and Environmental Protection has implemented IWRM in the State of Connecticut in the United States.

Exercise 19.3. Following the procedures given in Example 19.1, calculate annual cycles of the climatic variables and water availability for the data given below for Spokane, Washington state in CLIMWAT database. Compare the ET calculated in the water balance procedure with that given in CLIMWAT database (Longitude-latitude: -118°, 47.6°).

Table 19.3. Climatic data for Spokane, Washington, USA

Month:	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
T (max) °C	0.7	4.8	8.7	13.9	18.9	23.7	28.4	28.1	22.2	14.9	5.2	1
T (Min) °C	-6.2	-3.4	-1.3	1.5	5.5	9.6	12.4	12.4	7.7	2.2	-1.8	-5.7
P (mm/month)	50.3	37.9	37.9	30	35.9	32	17	18.3	18.5	25.1	54.6	61.5
ET_0 (mm/day)	0.34	0.81	1.71	2.91	4.14	5.46	6.8	6.21	4.27	2.09	0.69	0.27

Chapter 20

Geographic Information System

Exercise 20.1. Select an HUC 8 basin from the National Hydrography Dataset and download the geodatabase. Explore the feature class WBD (abbreviation for watershed boundary). Then, export the HUC 10 feature class to a shapefile. Clip the watersheds that constitute basin area of a major stream or river. Then, download the DEM of the selected watershed from National Elevation Dataset developed and maintained by the USGS [TNM Download v2 (nationalmap.gov)]. Delineate the catchments and streams at spatial resolutions smaller (finer) than HUC 12. Students in other countries can do this exercise if similar data are available in their countries.

Exercise 20.2. Derive the (A) Green-Ampt parameters and (B) Curve Numbers of the catchments delineated in Exercise 20.1 using geoprocessing tools and the relevant data (see Chapter 7) that are available in digital formats.

Exercise 20.3. The longitude and latitude of a location are 75°W, 35°N. Transform the geographic coordinates to Cartesian coordinates using Albers Equal Area Conic projection for the sphere. Given:

$$\text{Radius of sphere}, R = 1.0 \text{ unit; Standard paralles: } \varphi_1 = 29^0 30' \text{ N}, \varphi_2 = 45^0 30' \text{ N, Origin: } \varphi_0 = 23^0 \text{N}, \lambda_0 = 96^0 \text{W}.$$

Exercise 20.4. For the location in Exercise 20.3 transform the geographic coordinates to Cartesian coordinates using Lambert Conformal Conic projection for the sphere. Given:

$$\text{Radius of sphere}, R = 1.0 \text{ unit; Standard paralles: } \varphi_1 = 33^0 0' \text{ N}, \varphi_2 = 45^0 0' \text{ N, Origin: } \varphi_0 = 23^0 \text{N}, \lambda_0 = 96^0 \text{W}.$$

Chapter 21

Hydrologic Modeling

Exercise 21.1. A 24 h severe rain event that occurred on March 19, 2006 over much of Dallas, Texas, caused widespread flooding in various watersheds (Figure 21.20) in and around Dallas, Texas. In Exercise 4.1, we provided rainfall data from five rain gauge stations within White Rock Creek watershed (Figure 4.54). Similar flooding occurred in Turtle Creek watershed and Five Mile Creek watershed. Subsequently, the City of Dallas either improved the existing flood control measures or implemented new flood control systems. For example, several new flood control pump stations having capacities ranging from 400,000 to 800,000 gallons per minute were designed and built to replace the older pump stations on the dry side of the levee along Trinity River. The planning for reducing flood risks started before this event.

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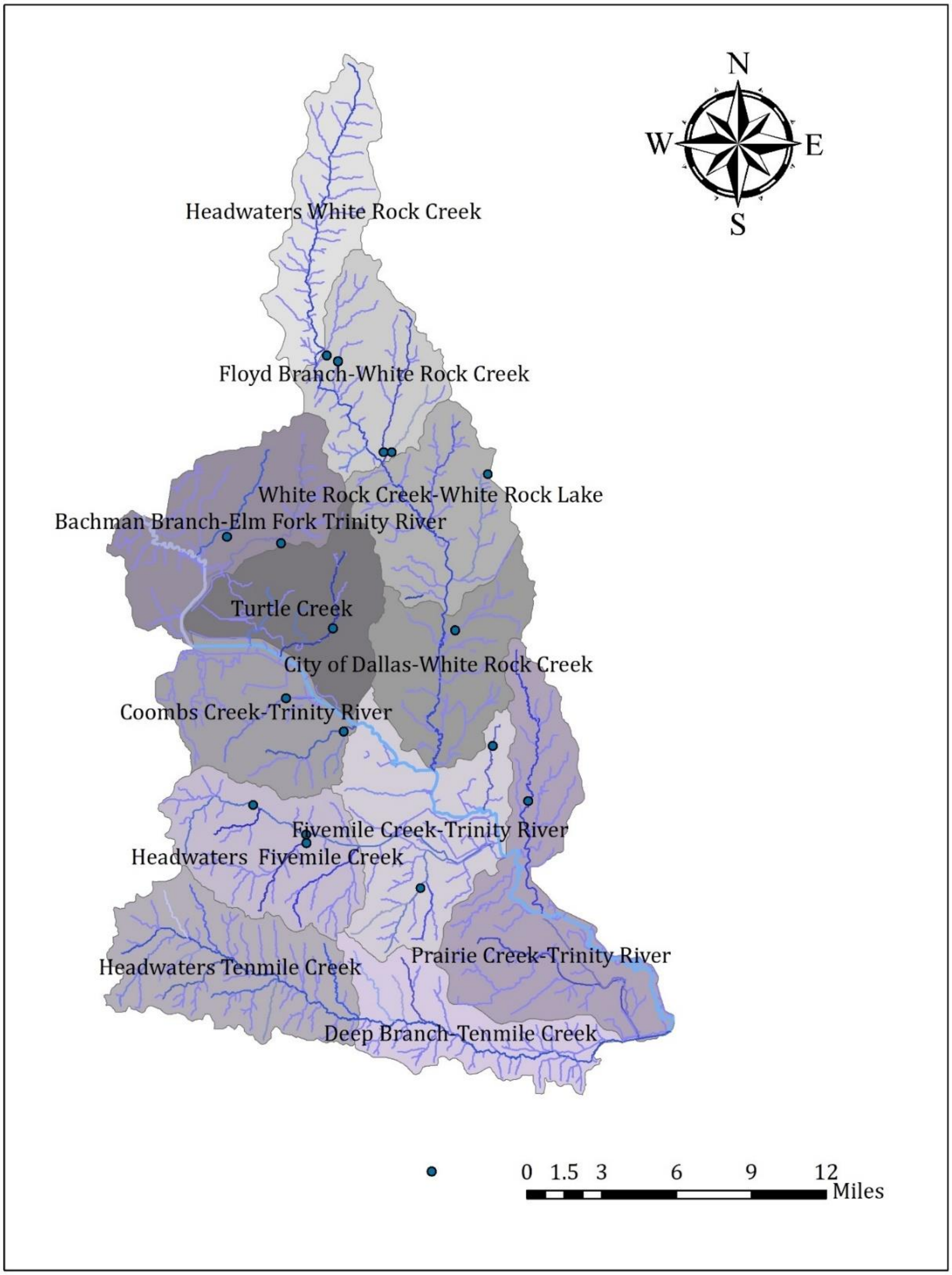

Figure 21.20 Watersheds of Dallas area in Texas, USA.

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In Five Mile Creek watershed major flooding occurred along Ricketts Branch shown in Figure 21.21. The flooding caused considerable damages. Subsequently, a major channel improvement project was designed and implemented along Rickets Branch.

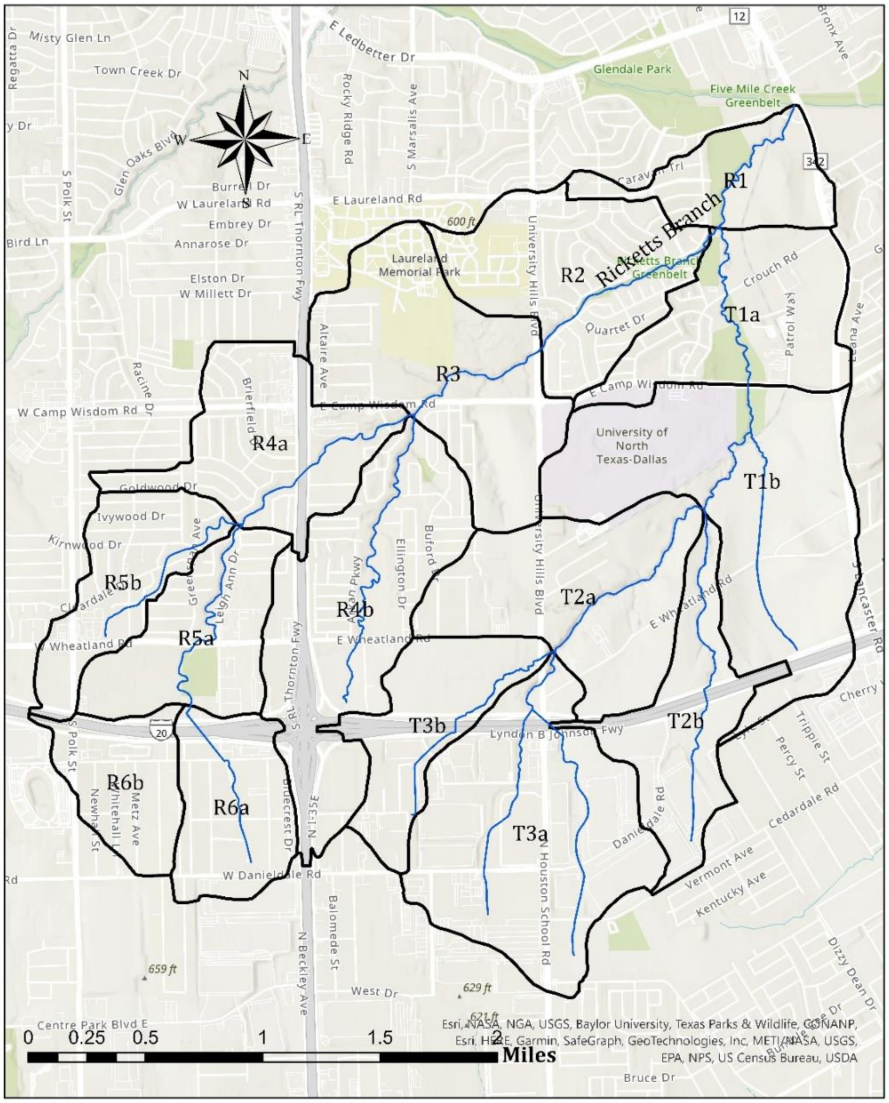

Figure 21.21 The catchment within Five Mile Creek watershed that is drained by Ricketts Branch, a tributary of Five Mile Creek.

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The stream gauging stations within the headwater catchments of Five Mile Creek watershed (Figure 21.22) ceased to operate in the late 1980s. However historical data are available.

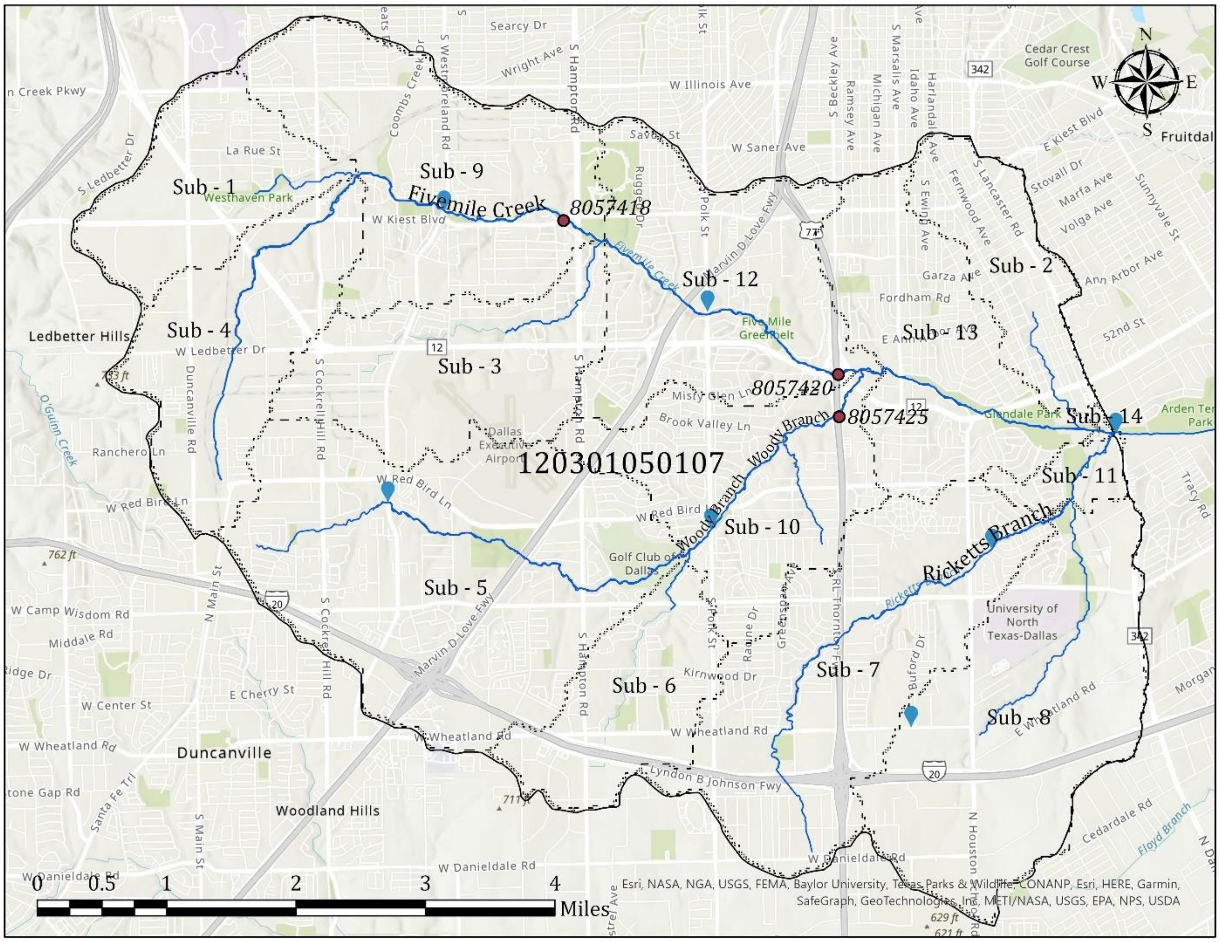

Figure 21.22 Previously existing stream gauges within headwater watershed of Five Mile Creek watershed, Dallas, Texas. The catchments delineated within this watershed are also shown and numbered as Sub-1, Sub-2, etc.

Table 21.14 gives the areal rainfall measurements at the five rain gauges for an event in March 1977. Table 21.15 provides the discharge measurements at the stream gauges.

(*continued onto the next page*)

Table 21.14 *Rainfall data at Five Mile Creek watershed, Dallas, Texas, USA*

For Stream Gauge 8057425					**For Stream Gauge 8057420**					
Date/Time	Hour lapsed	Gauge 1	Gauge 2	Weighted rainfall (inches)	Date/Time	Hour lapsed	Gauge 3	Gauge 4	Gauge 5	Weighted rainfall (inches)
03/26/1977@11:00:00	0	0	0	0	03/26/1977@11:00:00	0	0	0	0	0
03/26/1977@12:00:00	1	0.15	0.17	0.15	03/26/1977@11:30:00	0.5	0.11	0	0.05	0.04
03/26/1977@13:00:00	2	0.2	0.22	0.2	03/26/1977@12:00:00	1	0.15	0.14	0.17	0.15
03/26/1977@14:00:00	3	0.38	0.32	0.35	03/26/1977@12:30:00	1.5	0.15	0.21	0.19	0.19
03/26/1977@18:00:00	7	0.4	0.49	0.42	03/26/1977@13:00:00	2	0.2	0.22	0.22	0.22
03/26/1977@20:00:00	9	0.41	0.49	0.43	03/26/1977@13:30:00	2.5	0.32	0.29	0.25	0.29
03/26/1977@22:00:00	11	0.41	0.49	0.43	03/26/1977@14:00:00	3	0.36	0.34	0.31	0.34
03/26/1977@23:00:00	12	0.44	0.55	0.47	03/26/1977@15:00:00	4	0.39	0.41	0.38	0.4
03/26/1977@23:30:00	12.5	0.45	0.6	0.48	03/26/1977@16:00:00	5	0.4	0.41	0.39	0.4
03/27/1977@00:00:00	13	0.45	0.6	0.48	03/26/1977@17:00:00	6	0.4	0.44	0.41	0.42
03/27/1977@00:15:00	13.25	0.46	0.6	0.49	03/26/1977@18:00:00	7	0.4	0.48	0.49	0.46
03/27/1977@01:00:00	14	0.52	0.7	0.56	03/26/1977@22:00:00	11	0.41	0.49	0.49	0.47
03/27/1977@01:30:00	14.5	0.58	0.77	0.62	03/26/1977@23:00:00	12	0.44	0.5	0.55	0.49
03/27/1977@02:00:00	15	0.73	0.94	0.78	03/27/1977@00:00:00	13	0.45	0.55	0.6	0.53
03/27/1977@02:30:00	15.5	0.91	1.15	0.97	03/27/1977@01:30:00	14.5	0.68	0.7	0.78	0.71
03/27/1977@02:45:00	15.75	1.12	1.25	1.15	03/27/1977@02:30:00	15.5	0.91	1.06	1.15	1.04
03/27/1977@03:00:00	16	1.22	1.35	1.25	03/27/1977@02:45:00	15.75	1.12	1.14	1.25	1.15
03/27/1977@03:15:00	16.25	1.28	1.85	1.41	03/27/1977@03:00:00	16	1.22	1.31	1.35	1.3
03/27/1977@03:30:00	16.5	1.58	1.94	1.66	03/27/1977@03:15:00	16.25	1.28	1.4	1.85	1.45
03/27/1977@03:45:00	16.75	1.7	2.01	1.77	03/27/1977@03:30:00	16.5	1.59	1.54	1.94	1.62
03/27/1977@04:00:00	17	1.77	2.1	1.85	03/27/1977@03:45:00	16.75	1.7	1.76	2.01	1.79
03/27/1977@04:15:00	17.25	1.9	2.3	1.99	03/27/1977@04:00:00	17	1.77	1.87	2.1	1.89
03/27/1977@04:30:00	17.5	2.01	2.39	2.1	03/27/1977@04:15:00	17.25	1.9	1.98	2.3	2.02
03/27/1977@04:45:00	17.75	2.1	2.41	2.17	03/27/1977@04:30:00	17.5	2.01	2.12	2.39	2.14
03/27/1977@05:00:00	18	2.11	2.42	2.18	03/27/1977@04:45:00	17.75	2.1	2.29	2.41	2.27
03/27/1977@05:15:00	18.25	2.15	2.42	2.21	03/27/1977@05:00:00	18	2.11	2.36	2.42	2.31

For Stream Gauge 8057425					For Stream Gauge 8057420					
Date/Time	Hour lapsed	Gauge 1	Gauge 2	Weighted rainfall (inches)	Date/Time	Hour lapsed	Gauge 3	Gauge 4	Gauge 5	Weighted rainfall (inches)
03/27/1977@05:30:00	18.5	2.15	2.43	2.21	03/27/1977@05:15:00	18.25	2.15	2.39	2.42	2.34
03/27/1977@05:45:00	18.75	2.15	2.43	2.21	03/27/1977@05:30:00	18.5	2.15	2.39	2.43	2.34
03/27/1977@06:00:00	19	2.15	2.44	2.22	03/27/1977@05:45:00	18.75	2.15	2.4	2.43	2.35
03/27/1977@06:15:00	19.25	2.15	2.44	2.22	03/27/1977@06:00:00	19	2.15	2.4	2.44	2.35
03/27/1977@06:30:00	19.5	2.15	2.44	2.22	03/27/1977@06:15:00	19.25	2.15	2.4	2.44	2.35
03/27/1977@06:45:00	19.75	2.15	2.44	2.22	03/27/1977@06:30:00	19.5	2.15	2.4	2.44	2.35
03/27/1977@07:00:00	20	2.15	2.44	2.22	03/27/1977@06:45:00	19.75	2.15	2.4	2.44	2.35
03/27/1977@07:15:00	20.25	2.15	2.44	2.22	03/27/1977@07:00:00	20	2.15	2.41	2.44	2.35
03/27/1977@07:30:00	20.5	2.15	2.45	2.22	03/27/1977@07:15:00	20.25	2.15	2.41	2.44	2.35
03/27/1977@07:45:00	20.75	2.15	2.45	2.24	03/27/1977@07:30:00	20.5	2.15	2.41	2.45	2.36
03/27/1977@08:00:00	21	2.5	2.95	2.6	03/27/1977@07:45:00	20.75	2.18	2.41	2.45	2.36
03/27/1977@08:15:00	21.25	2.73	3.12	2.82	03/27/1977@08:00:00	21	2.5	2.48	2.95	2.57
03/27/1977@08:30:00	21.5	2.96	3.39	3.06	03/27/1977@08:15:00	21.25	2.73	2.76	3.12	2.82
03/27/1977@08:45:00	21.75	3.08	3.52	3.18	03/27/1977@08:30:00	21.5	2.96	2.94	3.39	3.03
03/27/1977@09:00:00	22	3.24	3.67	3.34	03/27/1977@08:45:00	21.75	3.08	3.15	3.52	3.2
03/27/1977@09:15:00	22.25	3.3	3.72	3.4	03/27/1977@09:00:00	22	3.24	3.25	3.67	3.32
03/27/1977@09:30:00	22.5	3.33	3.73	3.42	03/27/1977@09:15:00	22.25	3.3	3.37	3.72	3.42
03/27/1977@09:45:00	22.75	3.35	3.75	3.44	03/27/1977@09:30:00	22.5	3.33	3.41	3.73	3.45
03/27/1977@10:00:00	23	3.35	3.76	3.44	03/27/1977@09:45:00	22.75	3.35	3.43	3.75	3.47
03/27/1977@10:15:00	23.25	3.37	3.77	3.46	03/27/1977@10:00:00	23	3.35	3.44	3.76	3.48
03/27/1977@10:30:00	23.5	3.37	3.79	3.47	03/27/1977@10:15:00	23.25	3.37	3.45	3.77	3.49
03/27/1977@10:45:00	23.75	3.37	3.79	3.47	03/27/1977@10:30:00	23.5	3.37	3.46	3.79	3.5
03/27/1977@11:00:00	24	3.37	3.8	3.47	03/27/1977@10:45:00	23.75	3.37	3.47	3.79	3.5
03/27/1977@11:15:00	24.25	3.37	3.8	3.47	03/27/1977@11:00:00	24	3.37	3.48	3.8	3.51
03/27/1977@11:30:00	24.5	3.37	3.8	3.47	03/27/1977@11:15:00	24.25	3.37	3.48	3.8	3.51
03/27/1977@11:45:00	24.75	3.37	3.81	3.47	03/27/1977@11:30:00	24.5	3.37	3.48	3.8	3.51
03/27/1977@12:00:00	25	3.37	3.81	3.47	03/27/1977@11:45:00	24.75	3.37	3.49	3.81	3.52

For Stream Gauge 8057425

Date/Time	Hour lapsed	Gauge 1	Gauge 2	Weighted rainfall (inches)
03/27/1977@12:15:00	25.25	3.37	3.81	3.47
03/27/1977@12:30:00	25.5	3.37	3.81	3.47
03/27/1977@13:00:00	26	3.37	3.81	3.47
03/27/1977@14:00:00	27	3.37	3.81	3.47
03/27/1977@15:00:00	28	3.38	3.82	3.48
03/27/1977@16:00:00	29	3.39	3.82	3.49
03/27/1977@18:00:00	31	3.42	3.83	3.51
03/27/1977@20:00:00	33	3.42	3.83	3.51
03/27/1977@22:00:00	35	3.43	3.88	3.53
03/28/1977@00:00:00	37	3.43	4.05	3.57

For Stream Gauge 8057420

Date/Time	Hour lapsed	Gauge 3	Gauge 4	Gauge 5	Weighted rainfall (inches)
03/27/1977@12:00:00	25	3.37	3.49	3.81	3.52
03/27/1977@12:15:00	25.25	3.37	3.49	3.81	3.52
03/27/1977@12:30:00	25.5	3.37	3.49	3.81	3.52
03/27/1977@12:45:00	25.75	3.37	3.49	3.81	3.52
03/27/1977@13:00:00	26	3.37	3.49	3.81	3.52
03/27/1977@13:15:00	26.25	3.37	3.49	3.81	3.52
03/27/1977@13:30:00	26.5	3.37	3.49	3.81	3.52
03/27/1977@13:45:00	26.75	3.37	3.49	3.81	3.52
03/27/1977@14:00:00	27	3.37	3.49	3.81	3.52
03/27/1977@14:15:00	27.25	3.37	3.49	3.81	3.52
03/27/1977@14:30:00	27.5	3.37	3.49	3.82	3.52
03/27/1977@14:45:00	27.75	3.37	3.49	3.82	3.52
03/27/1977@15:00:00	28	3.38	3.49	3.82	3.52
03/27/1977@15:30:00	28.5	3.38	3.5	3.82	3.53
03/27/1977@16:00:00	29	3.39	3.5	3.82	3.53
03/27/1977@16:30:00	29.5	3.42	3.5	3.82	3.54
03/27/1977@17:00:00	30	3.42	3.5	3.82	3.54
03/27/1977@18:00:00	31	3.42	3.5	3.83	3.54
03/27/1977@19:00:00	32	3.42	3.5	3.83	3.54
03/27/1977@21:00:00	34	3.42	3.5	3.83	3.54
03/27/1977@22:00:00	35	3.43	3.5	3.88	3.55
03/27/1977@23:00:00	36	3.43	3.6	4.02	3.63
03/28/1977@00:00:00	37	3.43	3.66	4.05	3.67

Table 21.15. *Runoff data at Five Mile Creek watershed, Dallas, Texas, USA*

Gauge 8057425			**Gauge 8057420**			**Gauge 8057418**		
Date/Time	Hours lapsed	Discharge (cfs)	Date/Time	Hours lapsed	Discharge (cfs)	Date/Time	Hours lapsed	Discharge (cfs)
03/26/1977@23:30:00	0	0	03/26/1977@23:00:00	0	0	03/26/1977@23:00:00	0	0
03/27/1977@00:00:00	0.5	5	03/27/1977@00:00:00	1	5	03/27/1977@00:00:00	1	5
03/27/1977@00:15:00	0.75	5	03/27/1977@01:30:00	2.5	5	03/27/1977@00:15:00	1.25	5
03/27/1977@01:00:00	1.5	5	03/27/1977@02:30:00	3.5	5	03/27/1977@00:30:00	1.5	5
03/27/1977@01:30:00	2	5	03/27/1977@02:45:00	3.75	40	03/27/1977@00:45:00	1.75	5
03/27/1977@02:00:00	2.5	5	03/27/1977@03:00:00	4	291	03/27/1977@01:00:00	2	5
03/27/1977@02:30:00	3	120	03/27/1977@03:15:00	4.25	440	03/27/1977@01:15:00	2.25	5
03/27/1977@02:45:00	3.25	549	03/27/1977@03:30:00	4.5	515	03/27/1977@01:30:00	2.5	5
03/27/1977@03:00:00	3.5	689	03/27/1977@03:45:00	4.75	565	03/27/1977@01:45:00	2.75	17
03/27/1977@03:15:00	3.75	724	03/27/1977@04:00:00	5	690	03/27/1977@02:00:00	3	153
03/27/1977@03:30:00	4	759	03/27/1977@04:15:00	5.25	865	03/27/1977@02:15:00	3.25	178
03/27/1977@03:45:00	4.25	899	03/27/1977@04:30:00	5.5	1150	03/27/1977@02:30:00	3.5	228
03/27/1977@04:00:00	4.5	1040	03/27/1977@04:45:00	5.75	1480	03/27/1977@02:45:00	3.75	282
03/27/1977@04:15:00	4.75	1390	03/27/1977@05:00:00	6	1830	03/27/1977@02:50:00	3.8333	285
03/27/1977@04:30:00	5	1830	03/27/1977@05:15:00	6.25	2070	03/27/1977@02:55:00	3.9167	312
03/27/1977@04:45:00	5.25	2060	03/27/1977@05:30:00	6.5	1990	03/27/1977@03:00:00	4	336
03/27/1977@05:00:00	5.5	2010	03/27/1977@05:45:00	6.75	1830	03/27/1977@03:15:00	4.25	377
03/27/1977@05:15:00	5.75	1750	03/27/1977@06:00:00	7	1790	03/27/1977@03:30:00	4.5	396
03/27/1977@05:30:00	6	1510	03/27/1977@06:15:00	7.25	1790	03/27/1977@03:45:00	4.75	753
03/27/1977@05:45:00	6.25	1270	03/27/1977@06:30:00	7.5	1750	03/27/1977@04:00:00	5	1240
03/27/1977@06:00:00	6.5	1000	03/27/1977@06:45:00	7.75	1600	03/27/1977@04:05:00	5.0833	1480
03/27/1977@06:15:00	6.75	794	03/27/1977@07:00:00	8	1450	03/27/1977@04:10:00	5.1667	1660
03/27/1977@06:30:00	7	549	03/27/1977@07:15:00	8.25	1240	03/27/1977@04:15:00	5.25	1580
03/27/1977@06:45:00	7.25	444	03/27/1977@07:30:00	8.5	1070	03/27/1977@04:20:00	5.3333	1330
03/27/1977@07:00:00	7.5	304	03/27/1977@07:45:00	8.75	890	03/27/1977@04:25:00	5.4167	1290
03/27/1977@07:15:00	7.75	250	03/27/1977@08:00:00	9	740	03/27/1977@04:30:00	5.5	1130
03/27/1977@07:30:00	8	200	03/27/1977@08:15:00	9.25	690	03/27/1977@04:45:00	5.75	1140

Gauge 8057425			Gauge 8057420			Gauge 8057418		
Date/Time	Hours lapsed	Discharge (cfs)	Date/Time	Hours lapsed	Discharge (cfs)	Date/Time	Hours lapsed	Discharge (cfs)
03/27/1977@07:45:00	8.25	170	03/27/1977@08:30:00	9.5	590	03/27/1977@05:00:00	6	1200
03/27/1977@08:00:00	8.5	140	03/27/1977@08:45:00	9.75	715	03/27/1977@05:15:00	6.25	1490
03/27/1977@08:15:00	8.75	350	03/27/1977@09:00:00	10	890	03/27/1977@05:30:00	6.5	1710
03/27/1977@08:30:00	9	1190	03/27/1977@09:15:00	10.25	1360	03/27/1977@05:45:00	6.75	1560
03/27/1977@08:45:00	9.25	1880	03/27/1977@09:30:00	10.5	1830	03/27/1977@06:00:00	7	1340
03/27/1977@09:00:00	9.5	2920	03/27/1977@09:45:00	10.75	2630	03/27/1977@06:15:00	7.25	1160
03/27/1977@09:15:00	9.75	4320	03/27/1977@10:00:00	11	3050	03/27/1977@06:30:00	7.5	889
03/27/1977@09:30:00	10	4820	03/27/1977@10:15:00	11.25	3550	03/27/1977@06:45:00	7.75	668
03/27/1977@09:45:00	10.25	4920	03/27/1977@10:30:00	11.5	3500	03/27/1977@07:00:00	8	506
03/27/1977@10:00:00	10.5	4270	03/27/1977@10:45:00	11.75	2950	03/27/1977@07:15:00	8.25	431
03/27/1977@10:15:00	10.75	3420	03/27/1977@11:00:00	12	2430	03/27/1977@07:30:00	8.5	347
03/27/1977@10:30:00	11	2460	03/27/1977@11:15:00	12.25	1720	03/27/1977@07:45:00	8.75	280
03/27/1977@10:45:00	11.25	1750	03/27/1977@11:30:00	12.5	1390	03/27/1977@08:00:00	9	230
03/27/1977@11:00:00	11.5	1350	03/27/1977@11:45:00	12.75	1180	03/27/1977@08:15:00	9.25	328
03/27/1977@11:15:00	11.75	1040	03/27/1977@12:00:00	13	994	03/27/1977@08:30:00	9.5	824
03/27/1977@11:30:00	12	829	03/27/1977@12:15:00	13.25	890	03/27/1977@08:45:00	9.75	1260
03/27/1977@11:45:00	12.25	724	03/27/1977@12:30:00	13.5	740	03/27/1977@09:00:00	10	1550
03/27/1977@12:00:00	12.5	584	03/27/1977@12:45:00	13.75	690	03/27/1977@09:15:00	10.25	1680
03/27/1977@12:15:00	12.75	444	03/27/1977@13:00:00	14	640	03/27/1977@09:30:00	10.5	2010
03/27/1977@12:30:00	13	339	03/27/1977@13:15:00	14.25	540	03/27/1977@09:45:00	10.75	1730
03/27/1977@13:00:00	13.5	200	03/27/1977@13:30:00	14.5	490	03/27/1977@10:00:00	11	1580
03/27/1977@14:00:00	14.5	90	03/27/1977@13:45:00	14.75	440	03/27/1977@10:15:00	11.25	1300
03/27/1977@15:00:00	15.5	41	03/27/1977@14:00:00	15	415	03/27/1977@10:30:00	11.5	1030
03/27/1977@16:00:00	16.5	19	03/27/1977@14:15:00	15.25	390	03/27/1977@10:45:00	11.75	800
03/27/1977@18:00:00	18.5	5	03/27/1977@14:30:00	15.5	340	03/27/1977@11:00:00	12	668
03/27/1977@20:00:00	20.5	5	03/27/1977@14:45:00	15.75	291	03/27/1977@11:15:00	12.25	569
03/27/1977@22:00:00	22.5	5	03/27/1977@15:00:00	16	243	03/27/1977@11:30:00	12.5	500
03/28/1977@00:00:00	24.5	5	03/27/1977@15:30:00	16.5	198	03/27/1977@11:45:00	12.75	443

Gauge 8057425			**Gauge 8057420**			**Gauge 8057418**		
Date/Time	Hours lapsed	Discharge (cfs)	Date/Time	Hours lapsed	Discharge (cfs)	Date/Time	Hours lapsed	Discharge (cfs)
			03/27/1977@16:00:00	17	158	03/27/1977@12:00:00	13	374
			03/27/1977@16:30:00	17.5	125	03/27/1977@12:15:00	13.25	312
			03/27/1977@17:00:00	18	100	03/27/1977@12:30:00	13.5	301
			03/27/1977@18:00:00	19	64	03/27/1977@12:45:00	13.75	277
			03/27/1977@19:00:00	20	40	03/27/1977@13:00:00	14	240
			03/27/1977@21:00:00	22	17	03/27/1977@13:15:00	14.25	220
			03/27/1977@22:00:00	23	11	03/27/1977@13:30:00	14.5	200
			03/27/1977@23:00:00	24	7	03/27/1977@13:45:00	14.75	180
			03/28/1977@00:00:00	25	5	03/27/1977@14:00:00	15	160
						03/27/1977@14:30:00	15.5	128
						03/27/1977@15:00:00	16	103
						03/27/1977@15:30:00	16.5	83
						03/27/1977@16:00:00	17	67
						03/27/1977@17:00:00	18	44
						03/27/1977@18:00:00	19	28
						03/27/1977@19:00:00	20	18
						03/27/1977@20:00:00	21	12
						03/27/1977@21:00:00	22	10
						03/27/1977@22:00:00	23	10
						03/27/1977@23:00:00	24	10
						03/28/1977@00:00:00	25	10

Available DEM, maps of soil texture class and land cover types are used in GIS to make initial estimates of the model parameters. Table 21.16 gives the catchment areas (Figure 21.22), initial estimates of Green-Ampt infiltration parameters and Clark unit hydrograph parameters. Tables 21.17 and 21.18 give the parameters for reach routing by the Muskingum-Cunge method.

Table 21.16 *Catchment areas and initial estimates of parameters for infiltration and transformation*

Catchment area		Green-Ampt parameters				Surface	Clark UH parameters	
Catchment	Area (sq. mi)	Initial content	Saturated content	Suction (in)	Conductivity (in./h)	Impervious (%)	T_c (h)	*R* (h)
Sub - 1	1.86	0.3	0.52	12.6	0.1	42.53	2	3.75
Sub - 10	2.75	0.39	0.475	10.8	0.0242	26.15	1.8	1.08
Sub - 11	0.39	0.374	0.473	10.1	0.0284	15.39	1.92	1.15
Sub - 12	3.34	0.37	0.472	10.2	0.0291	36.72	2.55	1.53
Sub - 13	2.72	0.391	0.475	10.7	0.0252	29.39	3.35	2.01
Sub - 14	0.03	0.42	0.479	11.5	0.02	23.10	1.16	0.69
Sub - 2	1.39	0.412	0.478	11.4	0.021	36.42	3.32	1.99
Sub - 3	2.55	0.376	0.473	10.3	0.0285	32.18	2.29	1.37
Sub - 4	2.56	0.388	0.55	17	0.028	33.73	1.15	0.71
Sub - 5	5.81	0.385	0.475	10.8	0.0249	34.12	2.58	1.55
Sub - 6	1.73	0.377	0.474	10.6	0.0243	38.96	1.6	0.96
Sub - 7	4.21	0.397	0.477	11.2	0.0216	23.02	2.44	1.46
Sub - 8	4.09	0.378	0.474	10.4	0.0261	8.94	1.87	1.12
Sub - 9	3.73	0.3	0.5	12.5	0.04	31.81	1.8	1

Table 21.17 *Channel characteristics*

Reach	Length (ft)	Slope (ft/ft)	Manning's *n*
Reach - 7	12110.52	0.00157	0.04
Reach - 4	13922.52	0.00081	0.04
Reach - 6	12255.25	0.00123	0.04
Reach - 3	9782.414	0.00141	0.04
Reach - 2	892.5312	0.00179	0.03
Reach - 5	3740.669	0.00136	0.03
Reach - 1	94.8288	0.00288	0.03

Table 21.18 *Representative eight-point cross sectional data*

Reach 1		Reach 2		Reach 3		Reach 4	
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)
400	48.5	120	53	720	53	410	96
600	46.25	190	50.5	800	48	500	87
880	46	320	50	920	47	560	84.5
980	39	525	35	1070	36.25	685	76
1080	35	580	37	1170	39	740	78
1190	42.5	700	46.5	1250	45	795	82
1280	47.75	800	47.5	1350	48.5	900	85
1375	51	900	50	1480	51	950	89
Reach 5		Reach 6		Reach 7			
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)		
510	59	175	77	196.5	126.84		
650	53	200	75	350	109		
750	50.5	250	73.5	492	106.35		
900	42	285	70	586.4	100.75		
1000	46	320	67	690	99.73		
1050	48	380	70.5	775	104.5		
1350	52	400	72	847.1	105.97		
1500	52	480	76	1038.071	116.38		

Table 21.19 gives the parameters that can be used for NRCS method for calculation of abstraction and unit hydrograph.

Table 21.19 *Parameters for NRCS method*

Catchment	**Initial abstraction (in)**	**Curve Number**	**Lag time (min)**
Sub - 4	0.25	89	0.71
Sub - 1	0.25	89	2.09
Sub - 9	0.27	88	1.44
Sub - 3	0.27	88	1.37
Sub - 5	0.25	89	1.55
Sub - 6	0.22	90	0.96
Sub - 12	0.25	89	1.53
Sub - 10	0.3	87	1.08
Sub - 13	0.3	87	2.01
Sub - 2	0.35	85	1.99

Catchment	Initial abstraction (in)	Curve Number	Lag time (min)
Sub - 7	0.33	86	1.46
Sub - 8	0.35	85	1.12
Sub - 11	0.38	84	1.15
Sub - 14	0.41	83	0.69

Build a HEC-HMS model of the watershed and optimize all parameters based on the observed flows that can be deciphered at the most downstream junction. Use the optimized parameters to validate the model based on upstream observations. Now use the NRCS method to compute the hydrographs and compare the results.

Exercise 21.2. The City of Dallas conducted a study to determine the impacts of hydraulics of Ricketts Branch (Figure 21.21), a Tributary to Five Miles Creek, on certain homes on the floodplain that had been inundated by flood producing rainfall events in the past and developed certain plans to mitigate the potential of inundation of those areas where habitable structures were characterized as flood-prone during the investigation. Figure 21.21 shows the subbasins and major streams of the watershed drained by Ricketts branch and its tributaries. The highest order tributary to the east of Ricketts Branch is Runyon Springs Branch. The area around the confluence of these two streams was found to be maximum flood prone.

Table 21.20 gives the parameters for calculations of surface runoff and NRCS dimensionless unit hydrographs.

Table 21.20 *Subbasin parameters of Rickets Branch watershed*

Subbasin	Area (sq. mi)	CN (Present)	CN (Future)	Lag time (min)
R1	0.32	79	80	25.2
R2	0.62	85	86	28.7
R3	0.77	83	89	24.6
R4a	0.54	88	89	16.3
R4b	0.85	86	90	24.5
R5a	0.43	85	90	19.1
R5b	0.36	87	89	16.7
R6a	0.37	87	89	15.2
R6b	0.29	88	90	14.6
T1a	0.55	78	82	14.7
T1b	1.07	79	89	20.4

Subbasin	Area (sq. mi)	CN (Present)	CN (Future)	Lag time (min)
T2a	0.68	80	89	24.5
T2b	0.44	82	87	23
T3a	0.95	85	89	21.4
T3b	0.38	78	88	22.3

The modified Puls method is used for flood routing through each of the twelve reaches present in the model (Table 21.21 and Table 21.22). The reaches are named by the junction numbers (from to to).

Table 21.21 *Channel routing through the reaches present in the model*

Reach	Initial condition	Storage-discharge table
Reach 12-11	Discharge = Inflow	Table MP12-11
Reach 11-10	Discharge = Inflow	Table MP11-10
Reach 1-Outlet	Discharge = Inflow	Table MP 1-Outlet
Reach 4-3	Discharge = Inflow	Table MP4-3
Reach 5-4	Discharge = Inflow	Table MP5-4
Reach 2-1	Discharge = Inflow	Table MP2-1
Reach 8-7	Discharge = Inflow	Table MP8-7
Reach 10-1	Discharge = Inflow	Table MP10-1
Reach 3-2	Discharge = Inflow	Table MP3-2
Reach 7-6	Discharge = Inflow	Table MP7-6
Reach 6-5	Discharge = Inflow	Table MP6-5
Reach 9-8	Discharge = Inflow	Table MP9-8

Table 21.22 *Storage-discharge functions for the reaches in the model*

MP12-11		MP11-10		MP1-Outlet		MP4-3	
Storage (acre-ft)	Discharge (cfs)	Storage (acre-ft)	Discharge (cfs)	Storage (acre-ft)	Discharge (cfs)	Storage (acre-ft)	Discharge (cfs)
0	1	0.31	1	46.81	1	0.11	1
16	1000	17.13	1000	92.68	5000	15.22	1000
25	2000	27.6	2000	125	10000	42.41	4000
41	4000	120	10000	151.65	16000	77.63	8000
61	7000	160	15000	164.15	20000	109.31	13000
86	11000	199.79	20000	185	27000	125.94	16000
118	17000			203	33000	138.83	19000
124	18000			224.77	40000	149.48	22000
129	19000					154.82	23000
136	20000					161.66	24000
Table MP5-4		Table MP2-1		Table MP8-7		Table MP10-1	
Storage (acre-ft)	Discharge (cfs)	Storage (acre-ft)	Discharge (cfs)	Storage (acre-ft)	Discharge (cfs)	Storage (acre-ft)	Discharge (cfs)
0.11	1	0.09	1	0.11	1	0.23	1
5	1000	23.44	2000	10.11	500	24.69	1000
9	2000	51.16	5000	37.93	3000	41.16	2000
11	2837	76.32	10000	58.67	6000	69.42	4000
14	3876	96.54	16000	76.03	9000	106.58	7000
16	4503	106.67	20000	88.96	12000.1	151.8	11000
20	5571	117.5	25000			213.13	17000
30	8000	126.89	30000			222.55	18000
		134.73	35000			231.97	19000
		141.87	40000			241.57	20000
						275.96	24000
						315.4	29000
						352.91	34000
Table MP3-2		Table MP7-6		Table MP6-5		Table MP9-8	
Storage (acre-ft)	Discharge (cfs)	Storage (acre-ft)	Discharge (cfs)	Storage (acre-ft)	Discharge (cfs)	Storage (acre-ft)	Discharge (cfs)
0.03	1	0.06	1	0.14	1	0.05	1
7.59	1000	8.87	500	10.86	1000	4.78	500
16.4	4000	22.49	3000	33.26	4000	18.06	3000
37.3	13000	34.72	6000	52.1	8000	25.19	6000
54.53	24000	43.57	9000	66.73	13000	29.27	9000
		46.86	12000	72.9	16000	32.22	12000.1

				78.19	19000		
				81.02	22000		
				82.21	23000		
				83.53	24000		

Do the following:

1. Obtain the rainfall data from NOAA Atlas 14 and develop 24 h frequency-based design storms for 2-, 5-, 10-, 25-, 50-, 100-, and 500-year return periods.
2. For flood mitigation evaluate two alternatives: (1) Alternative 1 – An in-line detention basin within subbasin R2 along reach from junction J3 to Junction J2. (2) A diversion channel from J4 to J2.
3. Develop the flood frequency functions for the present and future conditions with and without projects.
4. Write an engineering report stating purpose of the investigation, methodologies used, findings, recommendations for flood mitigation, and conclusions.