hydrologic response of the watershed.

Example 6.1: Calculating Water Yield from a Hydrograph

From the U.S. Geological Survey site you downloaded a text file containing two columns, discharge (m^3/s) and date (*days*), and 42 rows, each with data for each day. You named it Flow.txt and saved it in C:/Sergio/Hydrology_Second_Book/Chapter6/Q.txt. Fit the hydrograph data to a smooth analytical curve, integrate it, and express the flow volume in m^3.

Solution

The following worksheet uses the linear algebra commands in Maple. The data file is first read into the program and given an array named flowdata. Next the data is converted into a matrix and transposed twice to place the first column as time and the second as flow rate. Next, cubic splines are used to fit a nice curve, $Q(t)$, to the data and integrated to obtain volume in m^3. Finally the $Q(t)$ is plotted.

Read a list of flow versus time data from a text file called Flow.txt, which has 2 columns and 42 rows; column 1 is flow, column 2 is time: [[Q1, t=1], [Q2, t=2], . . . [QN,t=N]]

```
> Restart: readlib(readdata):
  flowdata:=readdata("C:/Sergio/Hydrology_Second_Book
  /Chapter6/Flow.txt",float,2):
```

To swap columns, so that time is in the first column, convert this list into a matrix.

```
> flowdata:=convert(flowdata,matrix):
```

Now, manipulate matrix so that time is the first column. First, transpose matrix.

```
> t1:=linalg[transpose](flowdata):
```

Next exchange the flow and time (1 and 2) rows.

```
> t2:=linalg[swaprow](t1,1,2):
```

Finally, transpose again to original form.

```
> t3:=linalg[transpose](t2):
```

Interpolate data with a cubic spline.

```
> readlib(spline):
  s:=spline(linalg[col](flowdata,2),
      linalg[col](flowdata,1),t,cubic):
```

Convert to a piecewise function for future use and calculations.

```
> Q:=unapply(s,t):
```

text file. Modify the Maple program in Example 6.1 to read the data, fit it to a smooth function and plot the hydrograph. Calculate the total annual water yield in ft^3.

Table 6.10: Rainfall and Runoff Data for Problem 6.3

t (hour)	*p (mm/hour)*	*Q* (m^3/s)
7		4.24
8		4.01
9	0.0	3.78
10	10.0	3.55
11	17.0	6.70
12	15.0	11.85
13	8.0	15.10
14	0.0	12.40
15		9.80
16		8.00
17		6.80
18		5.90
19		5.12
20		4.68
21		4.32
22		4.02
23		3.76
24		3.54

6.2 Modify the program in problem 6.1 to enter time versus flow rate coordinates $[[t_1, Q_{g1}], [t_2, Q_{g2}],...]$ that define the groundwater hydrograph, fit them to a smooth curve, and plot it with the total hydrograph. Calculate the total groundwater flow volume for the year in ft^3. Write your observations on the relative importance of overland flow subsurface flow and groundwater flow in the watershed.

6.3 A watershed has a drainage area of $15\,km^2$. In May, 2009, a storm produced the rainfall-time distribution and the streamflow rate distribution given by Table 6.10. (1) Assuming that equation (6.4) is valid, find the inflection

6.5 In problem 6.3, (1) calculate the watershed-wide infiltration depth due to the storm. (2) Assuming that all infiltration became groundwater recharge, and an average specific yield of 0.35, estimate the mean increase in water table elevation due to the storm.

Table 6.11: Streamflow Data for Problem 6.6

t (*hour*)	Q (m^3/s)
9	13.7
10	12.5
11	11.2
12	50.0
13	120.0
14	156.0
15	172.0
16	144.0
17	125.0
18	107.0
19	88.0
20	68.0
21	55.0
22	41.0
23	28.0
24	20.0
1	12.0
2	6.5
3	6.0

6.6 The streamflow hydrograph of Table 6.11. was produced by a rainfall of an unknown intensity that lasted for a period of three hours. If the Watershed area is 250 km^2, (1) the effective precipitation depth in *mm*, and (2) derive the 3-*hour* UH. Assume that the last inflection point occurs at t_2=24*hour*

6.7 Assume that the streamflow data given in Example 6.6 (Table 6.3) was actually produced by a rainfall intensity of 7.5*mm/hour* [illegible] the last inflection point occurred at $t_2 = 70 hour$.

Table 6.3: Streamflow Data and Calculations for Example 6.6

Clock Time	t (hour)	Q (m^3/s)	Q_g (m^3/s)	SRH Q_r (m^3/s)	5-hour UH Q_{UH} ($\frac{m^3/s}{mm}$)
5:00 AM	0	11.4	11.4	0.0	
10:00 AM	5	11.3	11.3	0.0	
3:00 PM	10	11.1	11.1	0.0	0.0
8:00 PM	15	66.0	11.3	54.7	3.6
1:00 AM	20	72.0	11.6	60.4	4.0
6:00 AM	25	65.1	11.8	53.3	3.6
11:00 AM	30	57.2	12.0	45.2	3.0
4:00 PM	35	51.0	12.2	38.8	2.6
9:00 PM	40	43.5	12.5	31.0	2.1
2:00 AM	45	34.0	12.7	21.3	1.4
7:00 AM	50	26.8	12.9	13.9	0.0
12:00 Noon	55	21.0	13.1	7.9	
5:00 PM	60	18.5	14.3	4.2	
10:00 PM	65	15.1	13.6	1.5	
3:00 AM	70	13.8	13.8	0.0	
8:00 AM	75	13.0	13.0	0.0	
1:00 PM	80	11.2	11.2	0.0	
6:00 PM	85	11.0	11.0	0.0	
11:00 PM	90	10.6	10.6	0.0	

Solution

Following steps (1) through (4) for problem Type I, we proceed with the calculations as summarized in Table 6.3. The first inflection point is found by inspection to be at $t_1 = 10 hour$. Prior to the first inflection point and after the last one, the flow rate is assumed to be groundwater. Between the first and last inflection points, we assume the groundwater flow, Q_g, to vary linearly as shown in the fourth column from the left in Table 6.3, according to equation (6.14). The SRH ordinates, the fifth column, are obtained by subtracting the fourth from the third column. Since the precipitation and infiltration intensities are given, and the watershed area is not, we calculate the effective precipitation as $R_o = (p - \varphi) \times t_s$ = $(8.5 - 5.5)(mm/hour) \times 5 hour = 15.0 mm$. Finally the UH ordinates are calculated by dividing the SRH (the fifth column) by the effective precipitation depth, R_e.

Example 6.5: Derivation of a Unit Hydrograph

The streamflow hydrograph of Table 6.2 was produced by a rainfall of an unknown intensity that lasted for a period of two hours. If the watershed area is $20\,km^2$, derive the 2-*hour* UH. Assume that the last inflection point occurred at t_2=18*hour*.

Solution

Following steps (1) through (4) for problem Type I, we proceed with the calculations as summarized in Table 6.2. The first inflection point is found by inspection to be at t_1=9*hour*. Prior to the first inflection point and after the last one, the flow rate is assumed to be groundwater flow. Between the first and last inflection points, we assume the groundwater flow, Q_g, to vary linearly as shown in the third column of Table 6.2, according to the equation

$$Q_g = q_{t_1} + \left(\frac{q_{t_2} - q_{t_1}}{t_2 - t_1} \right)(t - t_1), \qquad t_1 \le t \le t_2 \qquad (6.14)$$

where q_{t_1} and q_{t_2} are the flow rates at t_1 and t_2, respectively. The SRH in the fourth column is simply $Q_r = Q - Q_g$. Since the effective precipitation depth is not given, we need to calculate it from the SRV. The SRV, S_r is calculated by numerically integrating the SRH and applying equation (6.6) with $\Delta t = 1$ *hour*:

$$S_r = c_1 \sum_{i=1}^{N} Q_{ri} \Delta t = 3600 \frac{s}{hour} \times 42.1 \frac{m^3}{s} \times 1\,hour = 151{,}560 m^3$$

The effective precipitation depth, R_o, is calculated from equation (6.7):

$$R_o = \frac{c_2 S_r}{A} = \frac{10^{-3} \dfrac{mm.km^2}{m^3} \times 151{,}560 m^3}{20 km^2} = 7.6 mm$$

Finally the 2-*hour* UH ordinates, Q_{UH}, the last column in Table 6.2, are calculated from equation (6.13) as the SRH ordinates divided by R_o.

Example 6.6: Derivation of a Unit Hydrograph

The streamflow hydrograph of Table 6.3 was produced by a storm that started at 10:00 AM with a rainfall intensity of 8.5*mm/hour*. It continued with the same intensity until it abruptly ended at 3:00 PM. If the estimated ... derive the 5-*hour* UH. Assume that

Example 6.6: Derivation of a Unit Hydrograph

The streamflow hydrograph of Table 6.3 was produced by a storm that started at 10:00 AM with a rainfall intensity of 8.5*mm/hour*. It continued with the same intensity until it abruptly ended at 3:00 PM. If the estimated φ index is 5.5*mm/hour*, derive the 5-*hour* UH. Assume that the last inflection point occurred at t_2=70*hour*.

Table 6.3: Streamflow Data and Calculations for Example 6.6

Clock Time	t (*hour*)	Q (m^3/s)	Q_g (m^3/s)	SRH Q_r (m^3/s)	5-*hour* UH Q_{UH} ($\frac{m^3/s}{mm}$)
5:00 AM	0	11.4	11.4	0.0	
10:00 AM	5	11.3	11.3	0.0	
3:00 PM	10	11.1	11.1	0.0	0.0
8:00 PM	15	66.0	11.3	54.7	3.6
1:00 AM	20	72.0	11.6	60.4	4.0
6:00 AM	25	65.1	11.8	53.3	3.6
11:00 AM	30	57.2	12.0	45.2	3.0
4:00 PM	35	51.0	12.2	38.8	2.6
9:00 PM	40	43.5	12.5	31.0	2.1
2:00 AM	45	34.0	12.7	21.3	1.4
7:00 AM	50	26.8	12.9	13.9	0.0
12:00 Noon	55	21.0	13.1	7.9	
5:00 PM	60	18.5	14.3	4.2	
10:00 PM	65	15.1	13.6	1.5	
3:00 AM	70	13.8	13.8	0.0	
8:00 AM	75	13.0	13.0	0.0	
1:00 PM	80	11.2	11.2	0.0	
6:00 PM	85	11.0	11.0	0.0	
11:00 PM	90	10.6	10.6	0.0	

Solution

Following steps (1) through (4) for problem Type I, we proceed with the calculations as summarized in Table 6.3. The first inflection point is found by inspection to be at t_1=10*hour*. Prior to the first inflection point and after the last one, the flow rate is assumed to be groundwater. Between the first and last inflection points, we assume the groundwater flow, Q_g, to vary linearly as shown in the fourth column from the left in Table 6.3, according to equation (6.14). The SRH ordinates, the fifth column, are obtained by subtracting the fourth from the third column. Since the precipitation and infiltration intensities are given, and the watershed area is not, we calculate the effective precipitation as $R_o=(p-\varphi)\times t_r$ = (8.5−5.5)(*mm/hour*)×5*hour*=15.0*mm*. Finally the UH ordinates are calculated by dividing the SRH (the fifth column) by the effective precipitation depth, R_o.