CE 3354 Engineering Hydrology
Exercise Set 5

Exercises

1. a 50-acre single-family residential subdivision receives a rainfall intensity of 3 inches per hour for one hour. The average runoff coefficient is 0.50. Using a rational triangular hydrograph [1]

   Determine:

   a) Maximum (peak) discharge rate for the watershed.

   b) A plot of the discharge hydrograph in 6-minute intervals.

   c) The total volume of runoff from the subdivision for the entire storm.

   Solution(s): Entire problem as Jupyter Notebook (ENGR-1330) on following pages.

[1] Essentially apply the Modified Rational Method with t_c equal to the storm duration

es5-worksheet

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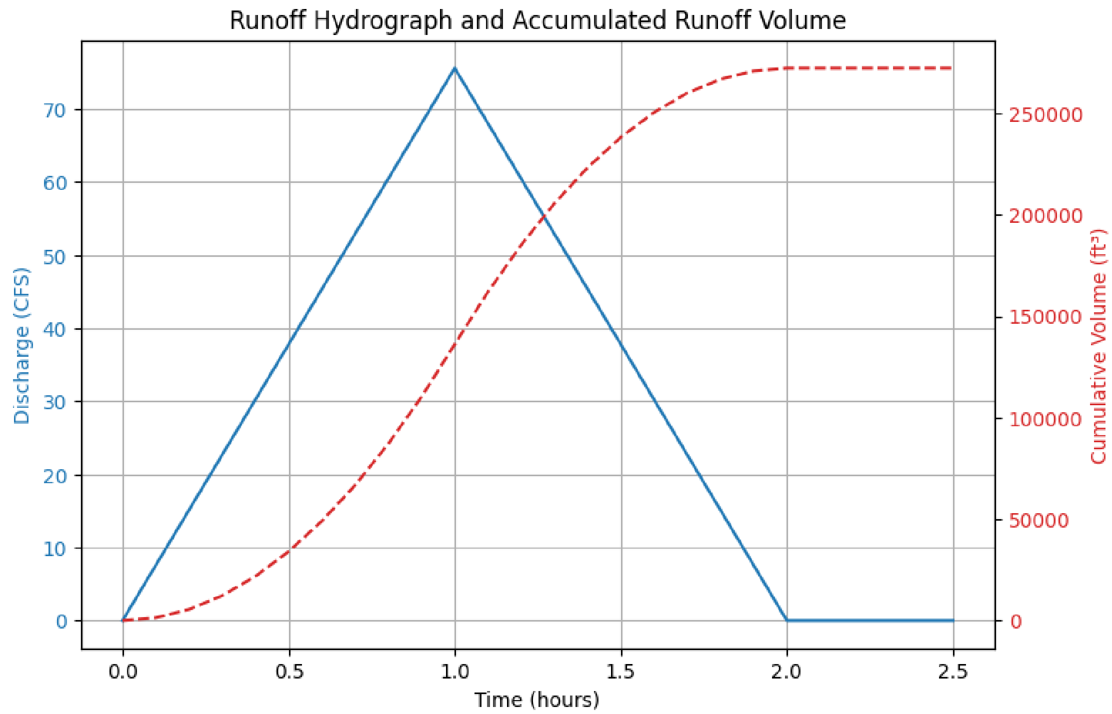
[64]:

```python
# Rational Method Tools
def qpeak(c,i,a,k=1):
    qpeak = k*c*i*a
    return qpeak
#################################
def triangle_hydrograph(qp, time, tc):
    if time < 0:
        triangle_hydrograph = 0.0
    elif 0 <= time <= tc:
        triangle_hydrograph = (qp / tc) * time
    elif tc < time <= 2 * tc:
        triangle_hydrograph = (qp / tc) * time - ( (qp / tc) * (time - tc) ) -
 ↪( (qp / tc) * (time - tc) )
    else:
        triangle_hydrograph = 0.0
    return triangle_hydrograph
#############################
# Problem 1
a = 50 # acres given
I = 3 # in/hr given
c = 0.5 # given
tc = 1.0 #hr implied(given)
k = 1.008 #unit conversion 1.008 for US  1/360 for SI
qp=qpeak(c,i,a,k)
print("Rational Method for Peak Discharge")
print(f"Area: {a:.2f} acres")
print(f"Intensity: {i:.2f} inches per hour")
print(f"Runoff Coefficient: {a:.2f} dimensionless")
print(f"Peak Discharge Rate: {qpeak(c, I, a, k):.2f} CFS")
# Recalculate discharge and cumulative runoff
qp = qpeak(c,I,a,k)
time = [] # empty list
discharge = [] #empty list
deltat = 0.1 # 6 minutes in hours
howmanysteps = 26
time.append(0.0)
discharge.append(0.0)
```

```python
for i in range(1,howmanysteps):
    time.append(time[i-1]+deltat)
    discharge.append(triangle_hydrograph(qp,time[i],tc))
# Trapezoidal integration to compute cumulative volume
cumulative_volume = [0.0]
for i in range(1, howmanysteps):
    deltaV = 0.5 * (discharge[i] + discharge[i-1]) * deltat * 3600  # ft³
    cumulative_volume.append(cumulative_volume[i-1] + deltaV)
# Plotting both discharge and accumulated volume
fig, ax1 = plt.subplots(figsize=(8, 5))
color = 'tab:blue'
ax1.set_xlabel("Time (hours)")
ax1.set_ylabel("Discharge (CFS)", color=color)
ax1.plot(time, discharge, color=color, label="Discharge (CFS)")
ax1.tick_params(axis='y', labelcolor=color)
ax1.grid(True)
ax2 = ax1.twinx()  # instantiate second axes sharing the same x-axis
color = 'tab:red'
ax2.set_ylabel("Cumulative Volume (ft³)", color=color)
ax2.plot(time, cumulative_volume, color=color, linestyle='--',␣
 ↪label="Accumulated Volume")
ax2.tick_params(axis='y', labelcolor=color)
fig.tight_layout()
plt.title("Runoff Hydrograph and Accumulated Runoff Volume")
plt.show()
# Final print
print(f"Total Runoff: {cumulative_volume[-1]:.2f} cubic feet")
```

```
Rational Method for Peak Discharge
Area: 50.00 acres
Intensity: 25.00 inches per hour
Runoff Coefficient: 50.00 dimensionless
Peak Discharge Rate: 75.60 CFS
```




```
Total Runoff: 272160.00 cubic feet
```

[ ]:

2. a 50-acre single-family residential subdivision receives a rainfall intensity of 3 inches per hour for one hour. The average runoff coefficient is 0.50. Using the NRCS triangular hydrograph [2]

   Determine:

   a) Maximum (peak) discharge rate for the watershed.

   b) A plot of the discharge hydrograph in 6-minute intervals.

   c) The total volume of runoff from the subdivision for the entire storm.

   Solution(s): Entire problem as Jupyter Notebook (ENGR-1330) on following pages.

[2] t_c is set equal to the storm duration

es5-ws1-Copy1

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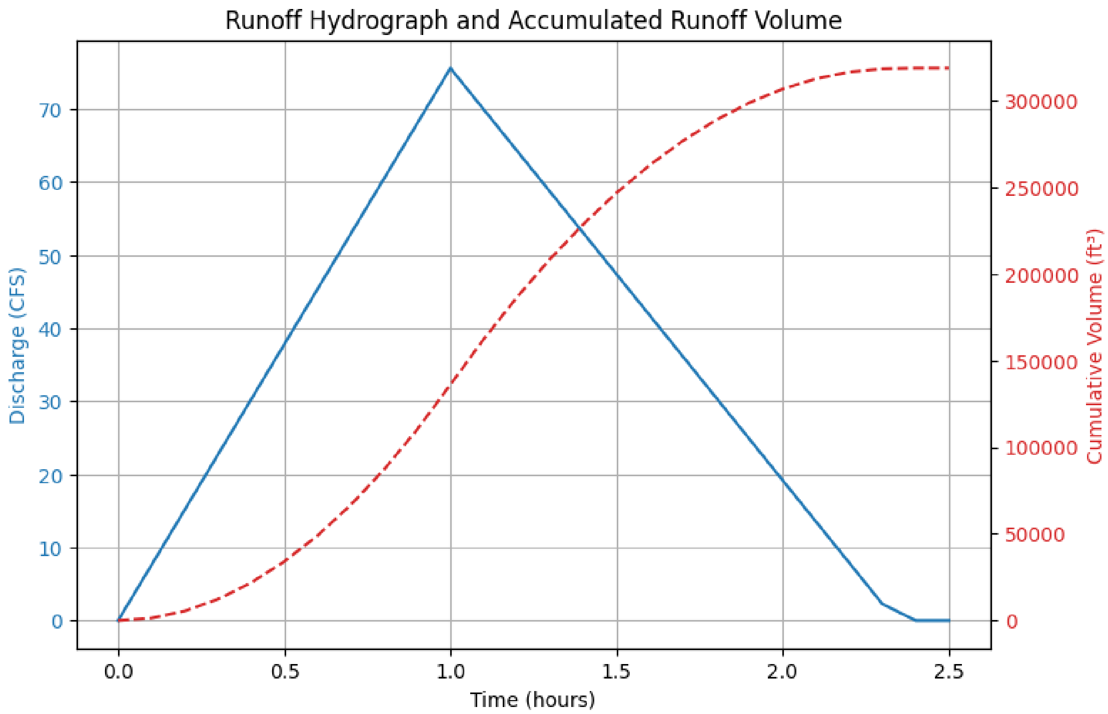
[6]:
```python
# NRCS Method Tools
import matplotlib.pyplot as plt
#
def qpeak(c,i,a,k=1):
    qpeak = k*c*i*a
    return qpeak
################################
def nrcs_triangle_hydrograph(qp, time, tc):
    if time < 0:
        nrcs_triangle_hydrograph = 0.0
    elif 0 <= time <= tc:
        nrcs_triangle_hydrograph = (qp / tc) * time
    elif tc < time <= 2.34 * tc:
        nrcs_triangle_hydrograph = (qp / tc) * time - ( (qp / tc) * (time - tc)␣
 ↪) - ( (qp /1.34*tc) * (time - tc) )
    else:
        nrcs_triangle_hydrograph = 0.0
    return nrcs_triangle_hydrograph
############################
# Problem 2
# NRCS Triangular uses same meanings, but recession limb is 1.34 tc
a = 50 # acres given
I = 3 # in/hr given
c = 0.5 # given
tc = 1.0 #hr implied(given)
k = 1.008 #unit conversion 1.008 for US  1/360 for SI
qp=qpeak(c,I,a,k)
print("NRCS Triangle Method for Peak Discharge (Duration == Tc)")
print(f"Area: {a:.2f} acres")
print(f"Intensity: {I:.2f} inches per hour")
print(f"Runoff Coefficient: {a:.2f} dimensionless")
print(f"Peak Discharge Rate: {qpeak(c, I, a, k):.2f} CFS")
# Recalculate discharge and cumulative runoff
qp = qpeak(c,I,a,k)
time = [] # empty list
discharge = [] #empty list
deltat = 0.1 # 6 minutes in hours
```

```python
howmanysteps = 26
time.append(0.0)
discharge.append(0.0)
for i in range(1,howmanysteps):
    time.append(time[i-1]+deltat)
    discharge.append(nrcs_triangle_hydrograph(qp,time[i],tc))
# Trapezoidal integration to compute cumulative volume
cumulative_volume = [0.0]
for i in range(1, howmanysteps):
    deltaV = 0.5 * (discharge[i] + discharge[i-1]) * deltat * 3600  # ft³
    cumulative_volume.append(cumulative_volume[i-1] + deltaV)
# Plotting both discharge and accumulated volume
fig, ax1 = plt.subplots(figsize=(8, 5))
color = 'tab:blue'
ax1.set_xlabel("Time (hours)")
ax1.set_ylabel("Discharge (CFS)", color=color)
ax1.plot(time, discharge, color=color, label="Discharge (CFS)")
ax1.tick_params(axis='y', labelcolor=color)
ax1.grid(True)
ax2 = ax1.twinx()  # instantiate second axes sharing the same x-axis
color = 'tab:red'
ax2.set_ylabel("Cumulative Volume (ft³)", color=color)
ax2.plot(time, cumulative_volume, color=color, linestyle='--',␣
 ↪label="Accumulated Volume")
ax2.tick_params(axis='y', labelcolor=color)
fig.tight_layout()
plt.title("Runoff Hydrograph and Accumulated Runoff Volume")
plt.show()
# Final print
print(f"Total Runoff: {cumulative_volume[-1]:.2f} cubic feet")
```

```
NRCS Triangle Method for Peak Discharge (Duration == Tc)
Area: 50.00 acres
Intensity: 3.00 inches per hour
Runoff Coefficient: 50.00 dimensionless
Peak Discharge Rate: 75.60 CFS
```




```
Total Runoff: 318670.93 cubic feet
```

[ ]:

3. A watershed is comprised of sandy soil with a 500 foot path to an outlet. The slope on that path is 5-percent. The soil has a high water table limiting the potential watershed storage to 0.5 inches. Using the NRCS Lag Equation method[3]

$$T_c = L^{0.8}\frac{(S_r+1)^{0.7}}{1140Y^{0.5}} \tag{1}$$

where:
T_c = time of concentration, hr
L = flow length, ft
S_r = Potential storage (in.); $S_r = \frac{1000}{CN} - 10$
CN = NRCS runoff curve number
Y = average watershed slope, %

Determine:

a) Time of concentration (T_c).

[3] https://directives.nrcs.usda.gov/sites/default/files2/1712930818/31754.pdf

4. The runoff hydrograph below was produced by a 100 acre watershed.

Table 1: Somewhere USA Runoff Data

Time (hours)	Runoff (CFS)
0.0	0.0
1.0	70.0
2.0	160.
3.0	110.
4.0	80.0
5.0	60.0
6.0	45.0
7.0	30.0
8.0	20.0
9.0	12.0
10.	5.0
11.	0.0

Determine:

a) Excess precipitation in watershed inches for the hydrograph.

b) A unit hydrograph for the watershed.

c) A plot of the unit hydrograph.

5. An agricultural watershed was urbanized over a 20 year interval. A triangular one-hour unit hydrograph was developed for this watershed for an excess rainfall duration of one hour.

   Before urbanization, the average loss rate was 0.30 in/hr.

   Figure **??** is the unit hydrograph that has a peak discharge of 400 cfs/in occurring at 3 hours, and a base time of 9 hours.

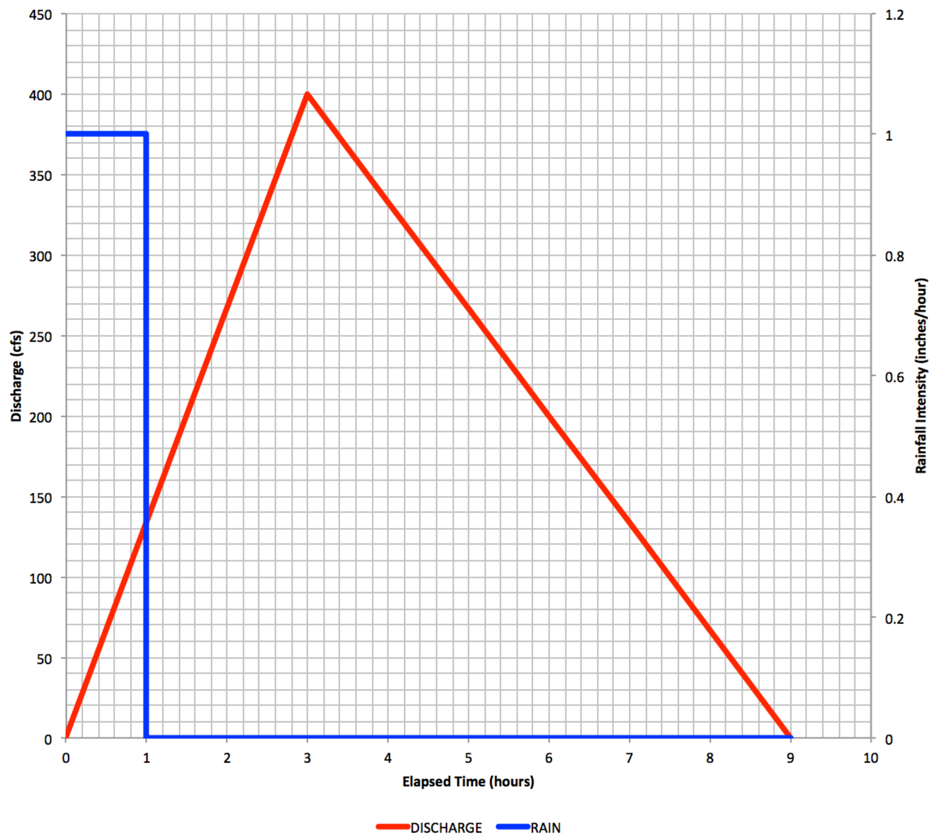


Figure 1: Pre-Urbanization unit hydrograph for excess rainfall of 1 in/hr for 1 hour.

After urbanization the loss rate was reduced to 0.15 in/hr and the peak discharge of the unit hydrograph increased to 600 cfs/in occurring at 1 hour, and the base time reduced to 6 hours. Figure ?? is the unit hydrograph with a peak discharge of 600 cfs occurring at 1 hours, and a time base of 6 hours.

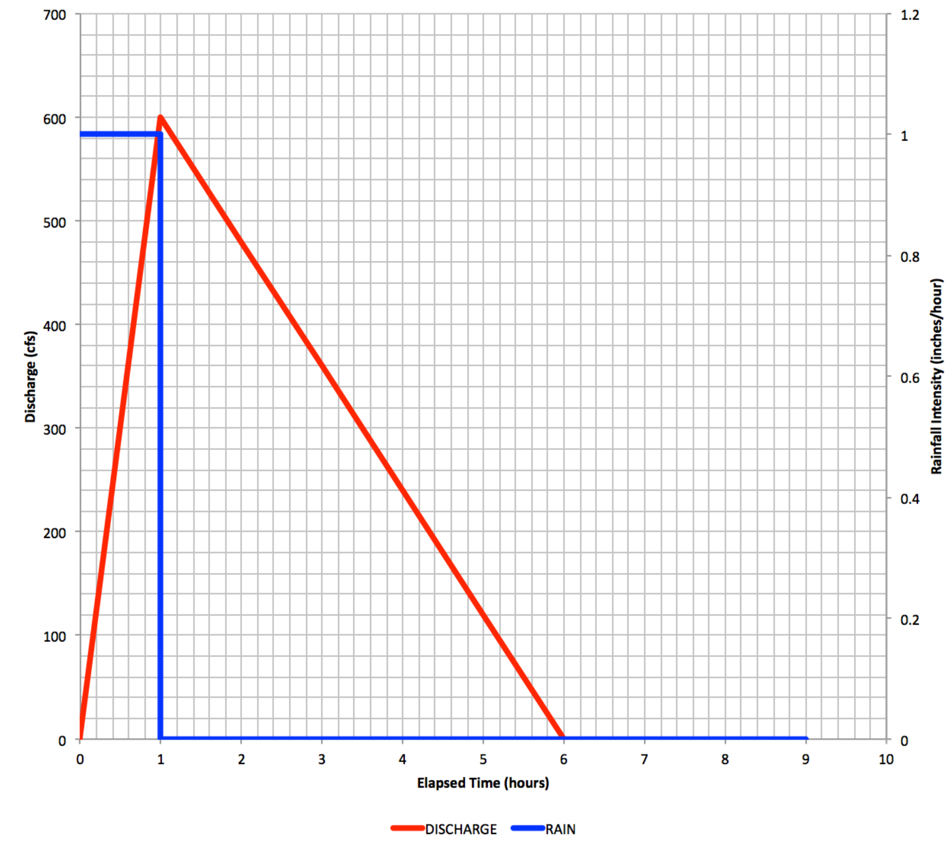


Figure 2: Post-Urbanization unit hydrograph for excess rainfall of 1 in/hr for 1 hour.

For a two hour storm in which 1 inch of rain fell in the first hour and 0.5 inch in the second hour, determine the direct runoff hydrographs before and after urbanization.[4]

[4]This exercise is the same as problem 7.5.7, pg. 238 in Chow, Maidment, Mays

6. A storm on April 16, 1977, on the Shoal Creek watershed at Northwest Park in Austin, Texas, resulted in the rainfall-runoff values in Figure ??.

   Use the linear regression method to determine the half-hour unit hydrograph for the watershed. The watershed drainage area is 7.03 mi^2. Assume that a uniform loss rate (constant loss model) is valid.[5]

TIME (HRS)	RAIN (IN)	DIRECT RUNOFF (CFS)
0.5	0.28	32.0
1.0	0.12	67.0
1.5	0.13	121.0
2.0	0.14	189.0
2.5	0.18	279.0
3.0	0.14	290.0
3.5	0.07	237.0
4.0		160.0
4.5		108.0
5.0		72.0
5.5		54.0
6.0		44.0
6.5		33.0
7.0		28.0
7.5		22.0
8.0		20.0
8.5		18.0
9.0		16.0

Figure 3: Observed storm rainfall incremental depths and observed direct runoff hydrograph

[5] This exercise is a hybrid of problems 7.6.2 and 7.6.5, pg 239 in Chow, Maidment, and Mays.

7. Table **??** is a 15-minute unit hydrograph for Somewhere Else USA. Table **??** is a precipitation input time-series for the watershed

Table 2: Somewhere Else USA Unit Hydrograph Tabulation

Time (hours)	Runoff (CFS)
0.00	0
0.25	70
0.50	182
0.75	137
1.00	68
1.25	33
1.50	16
1.75	9
2.00	5
2.25	2
2.50	1
2.75	0.0

Table 3: Somewhere Else USA Excess Rain Input

Time (hours)	Rainfall Excess (inches)
0.00	0
0.25	0.50
0.50	1.25
0.75	0.75

Determine:

a) The design (direct runoff hydrograph) for the excess rainfall input time series.

b) A plot of the design hydrograph.