Takehome_test_2

November 17, 2021

[1]:
```
import os
BASE_DIR = os.path.dirname(os.path.dirname(os.path.abspath('__file__')))
print(BASE_DIR)

import math
import numpy as np
import pandas as pd

import bokeh.plotting as bp
from bokeh.models import tools as bmt

from bokeh.io import output_notebook, export_png
output_notebook()

from IPython.display import Image
```

```
/Users/biplovbhandari/UAH/Fall_2021/ESS_690_Hydrology/Test
```

[2]:
```
def initialize_fig(title: str = 'your_title',
                   x_axis_label: str = 'x_axis_label',
                   x_axis_type: str = 'auto',
                   y_axis_label: str = 'y_axis_label',
                   y_axis_type: str = 'auto',
                   tools: str = 'pan,wheel_zoom,box_zoom,reset',
                   tooltips: list = [],
                   formatters: dict = {},
                   plot_height: int = 300,
                   fig_sizing_mode: str = 'scale_width',
                   ) -> bp.figure:
    # bokeh style
    TOOLS = tools
    hover_tool = bmt.HoverTool(tooltips=tooltips, formatters=formatters)

    fig = bp.figure(title=title,
                    x_axis_label=x_axis_label,
                    x_axis_type=x_axis_type,
                    y_axis_label=y_axis_label,
                    y_axis_type=y_axis_type,
```

```
                    plot_height=plot_height,
                    tools=TOOLS,
                   )
    fig.add_tools(hover_tool)
    fig.sizing_mode = fig_sizing_mode

    return fig
```

0.0.1 Q1

The following weather data are available near a lake. Net radiation 90 W/m2 Wind speed 2.5 m/s at a height of 2.0 m Air pressure 85 kPa Air Temperature 22 C Specific humidity 0.009 kg/kg Surface roughness length zo = 3 x 10-4 m.

a) Indicate which| of the following methods you have sufficient information to use to calculate lake evaporation (or equilibrium PET) A. Priestley Taylor B. Mass Transfer/Aerodynamic C. Combination/Penman D. Energy balance/Bowen Ratio

b) Calculate the evaporation in mm/day using all the methods for which there is sufficient information.

[ ]:

```

```

Since mass transfer and energy balance need temperature at reference height and surface, the evaporation that can be computed given the information are the Priestley Taylor and the Penman

[3]:

```
# Given
K_L = 90 # net shortwave radiation (K) + net longwave radiation (L) in W / m2
K_L = K_L * 8.64e-2 # net shortwave radiation (K) + net longwave radiation (L)␣
 ↪in MJ/m2.d
zm = 2.0 # elevation in m
P = 85 # pressure in kPa
z0 = 3e-4 # roughness height in m
q = 0.009 # specific humidity in kg / kg
T = 22 # air temperature in degree Celsius
u = 2.5 # # wind-speed at 2m in m/s
```

[ ]:

```

```

[4]:

```
# We know
 w = 996 # # density of water in kg/m3
cp = 1.0e-3 # Air specific heat in MJ/kg.C
zm = 2 # m
# zd is the zero-plane displacement height
zd = 0
```

Priestley and Taylor Method

[5]:
```
pt = 1.26
```

[6]:
```
Δ_T = (2508.3 * math.exp((17.3 * T) / (T + 237.3))) / (math.pow((T + 237.3),␣
↪2)) # kPa/°C
Δ_T
```

[6]: 0.1618940846873898

[7]:
```
v = 2.5 - 2.36e-3 * T # latent heat of vaporization in MJ/kg
v
```

[7]: 2.44808

[8]:
```
 = (cp * P) / (0.622 *  v) # psychrometric constant in kPa/°C

```

[8]: 0.055821684157811295

[9]:
```
PET = ( pt * Δ_T * K_L) / ( w *  v * (Δ_T +  ))
PET # m/day
```

[9]: 0.002988016201373662

[10]:
```
PET = PET * 1000 # mm/day
PET
```

[10]: 2.988016201373662

[ ]:
```

```

[ ]:
```

```

Combination/Penman

[11]:
```
e_astrik = 0.611 * math.exp((17.3 * T) / (T + 237.3))
e_astrik # kPa
```

[11]: 2.6515373335539105

[12]:
```
e = (q * P) / (0.622)
e
```

[12]: 1.2299035369774918

[13]:
```
RH = e / e_astrik
RH
```

[13]: 0.46384545350867323

[14]:
```python
# KE from 6.11
KE = 1.2e-6 / (math.log((zm - zd) / z0))**2 # kPa-1
KE
```

[14]: 1.547871237980864e-08

[15]:
```python
# multiplying KE by 1e-3 m/mm to give consistent units (s/kPa.day)
numerator = Δ_T * (K_L) + (  * (KE * 1e-3) *  w *  v * u * e_astrik * (1. - RH))
numerator
```

[15]: 1.258888410016878

[16]:
```python
denominator =  w *  v * (Δ_T +  )
denominator
```

[16]: 530.8536769169816

[17]:
```python
E0 = numerator / denominator # m/day
E0
```

[17]: 0.0023714414437667184

[18]:
```python
E0 = E0 * 1000. # mm/day
E0
```

[18]: 2.3714414437667184

[ ]:
```python

```

[ ]:
```python

```

0.0.2 Q2. Briefly define each of the following terms and describe their differences: PET, ETo, and AET

The PET or Potential Evapotranspiration is the amount of evapotranspiration from growing vegetation in a large area in a given time such that the crop is completely shading the ground, and has adequate moisture at all times in the soil and without advection or heat-storage effects. This is the potential demand from the atmosphere and depend upon the energy coming in and the vapor pressure deficit. However this is limited by the amount of water that is available in the ground.

The ETo or the Reference Crop Evapotranspiration or RET is the amount of evapotranspiration from a short green crop (usually grass) or some reference crop that is completely shading the ground, is of uniform height and never short of water. This is the PET for a reference crop in question.

Actual Evapotranspiration (AET) refers to the actual evapotranspiration coming from the surface and is dependendent on the soil characteristics, amount of water available, latent energy, storage in the soil, etc. This is the function of supply.

Usually the PET >= AET.

[ ]:

[ ]:

0.0.3 Q3. What is the difference in an Energy Limited environment vs a Water Limited environment?

In tropical and subtropical region or hot area in general, the amount of incoming solar radiation is much larger than the precipitation received. As a result, the potential evapotransiration is greater or equal to the average precipitation. This region or environment is the water-limited environment. In contrast, regions (for example Cherrapunji) that receives abundant amount of rainfall does not comparatively receive much solar radiation. As a result, evapotranspiration is limited by the available energy. Ths is the energy-limited region. If potential evapotranspiration is represented as PET and average precipitation as P, then for energy-limited environment, PET / P < 1 and for water-limited environment PET / P > 1.

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[ ]:

0.0.4 Q5

Develop a Hydrograph using the NRCS/SCS method for a rainfall event of duration 1.6 hours on a watershed with following properties: -Hydraulic Length: 18 miles -Average slope: 100ft/mi -The watershed consists of a permanent meadow in good condition with soil group D (Use table 10.11 in your book)

Sketch the resulting hydrograph and label all components

[19]:
```
d = 1.6 # hours
l = 18 # miles
l = l * 5280. # ft
A = 100 # sq-miles
m = 100 # ft/mi
m = 100 / 5280. # ft / ft
m = m * 100 # in %
m
```

[19]: 1.893939393939394

[20]:
```
# for permanent meadow in good condition for soil type D
cn = 78
```

[21]:
```
# storage
S = 1000. / cn - 10.
S # inches
```

[21]: 2.820512820512821

[22]:
```
# assume excess rainfall of 1 inch
P = 1.
Q = ((P - 0.2 * S)**2) / (P + 0.8 * S)
Q # inches
```

[22]: 0.058348475671310275

[23]:
```
# lag time
tL = (l**.8 * (S + 1.)**.7) / (1900. * m**.5) # hr
tL
```

[23]: 9.38369028998775

[24]:
```
# time to rise
TR = Tp = d / 2. + tL
TR # hr
```

[24]: 10.183690289987751

[25]:
```
# base duration
B = 1.67 * TR
B # min
```

[25]: 17.006762784279545

[26]:
```
# total duration
T = TR + B
T # min
```

[26]: 27.190453074267296

[27]:
```
Qp = 484. * A / TR # cfs
Qp
```

[27]: 4752.697560685363

[ ]:

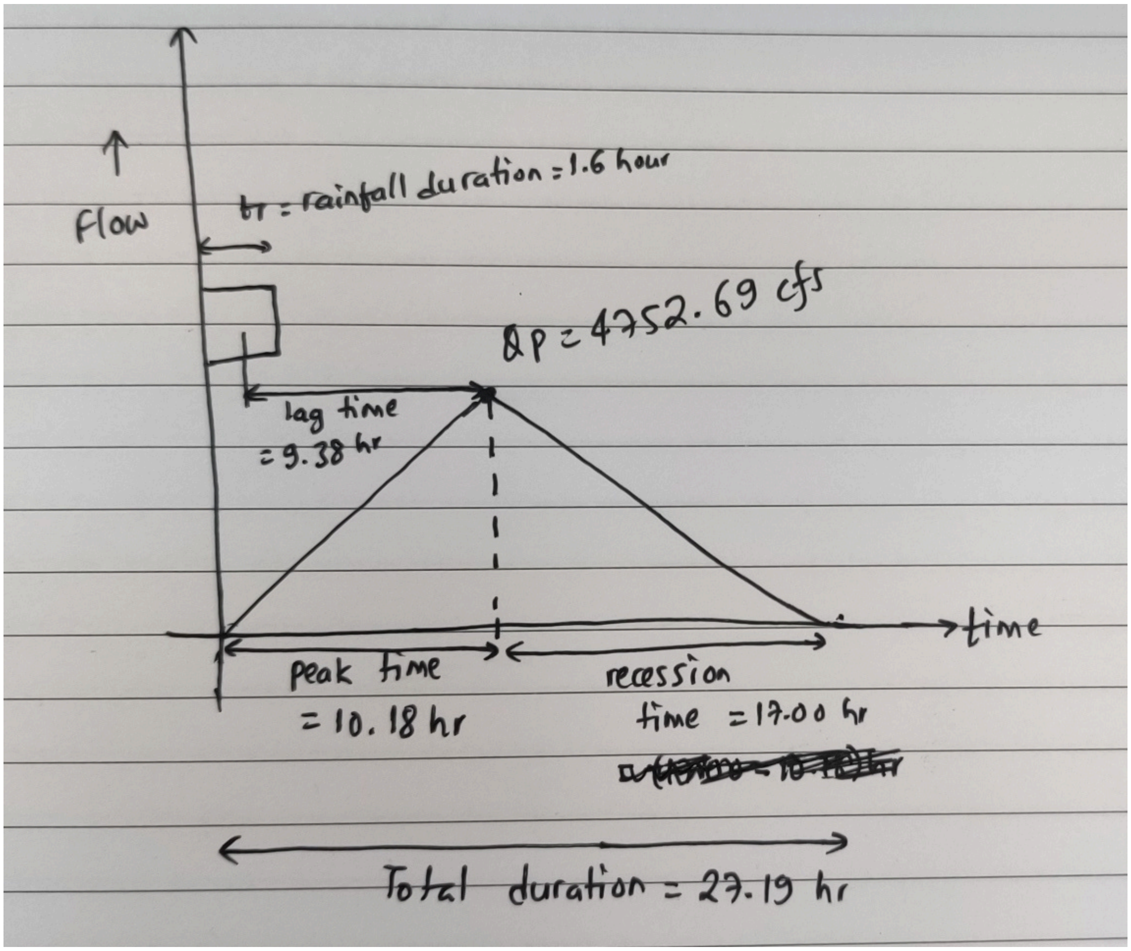
```

```

[28]:

```python
Image(f'{BASE_DIR}/Test#2/problem_5.jpg')
```

[28]:



[ ]:

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[ ]:

```

```

[ ]:

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```

0.0.5 Q6. Why is the rising side of a storage vs discharge curve typically lower than the falling side? How does the Muskingum k and x parameters relate to this relationship?

For the storage-discharge relationship, in the rising limb, the inflow (I) is greater than the outflow (Q), and as we move downstream the change in storage decreases as the antecedent condition plays a role. Thus the curve is steeper as it reaches the peak.

For the falling limb, even after the inflow stops, the storage component is still in play as we have to drain larger area. Thus the outflow tends to stay longer.

Storage can be thought as a function of time (k) and the outflow (Q), i.e. S=kQ. For the rising limb, i.e. when the inflow occurs (where I > Q), in addition to the base storage (S=kQ), we need to take into account the some other components which is the weight component (x). Thus the storage then for the rising limb would be S=kQ + kxQ. Similar is the case for the falling limb where I < Q but in opposite direction. Thus the muskingum make use of these components as S = kQ + kx(I-Q)

[ ]:

[ ]:

0.0.6 Q7. Briefly discuss the differences between Muskingum and Muskingum -Cunge and why Muskingum-Cunge is preferred to kinematic wave river routing?

We are looking at the continuity equation and the change in storage in the Muskingum. However, in Muskingum-Cunge, in addition to the continuity, we are also looking at the momentum. This includes the friction slope, change in depth of the water with respect to distance and the change in the velocity of the water with respect to time. Muskingum is hydrologic routing, while Muskingum-cunge is hydraulic routing.

Muskingum-cunge produce the the routing parameters K and X based on the channel morphology, as represented by the prevailing channel slope and cross-sectional-shape characteristics as oppose to the steady-state flow. The kinematic wave celerity and the Manning's equation are used by Muskingum-cunge based on the kinematic factor. Thus Muskingum-cunge is a preferred approach to the kinematic wave river routing.

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[ ]:

0.0.7 Q8

The hydrograph at the upstream end of a river is given in the following table. The reach of interest is 10 km long. Determine the hydrograph at 4km downstream and 10 km downstream. The slope of the stream is 0.001, B = 50m and the cross-sectional area of the streamflow at Qp = 187.5 m2. Assume no lateral flow. Assume a t = 1.5 hr for a x 6km or below.

T (hr)	Q (m3/s)
0	12
1	14.4
2	21.6
3	34.2
4	60

T (hr)	Q (m3/s)
5	93.6
6	128.4
7	161.4
8	176.4
9	180
10	175.2
11	154.8
12	126
13	93.6
14	70.8
15	54
16	39.6
17	28.8
18	20.4
19	14.4
20	12

[29]:
```
# in hours
Ts = np.arange(0, 21, 1)

# in cms
Qs = [12., 14.4, 21.6, 34.2, 60., 93.6, 128.4, 161.4, 176.4, 180, 175.2, 154.8,␣
↪126., 93.6, 70.8, 54., 39.6, 28.8, 20.4, 14.4, 12.]
```

[30]:
```
So = 0.001

# cross-sectional area
Q_ref = max(Qs) # peak cms
A_ref = 187.5 # m2
B = 50 # m
Δt = 1.5 # hour



ΔX1 = 4 # km
ΔX1 = ΔX1 * 1e3 # m
ΔX1
```

[30]: 4000.0

[31]:
```
V = Q_ref / A_ref # m/sec
V # m/sec
```

[31]: 0.96

[32]:
```
# kinematic wave celerity
c = 5 / 3 * V # m/sec
c
```

[32]: 1.6

[33]:
```
K1 = ΔX1 / c # sec
K1 = K1 / (60 * 60) # hour
K1
```

[33]: 0.6944444444444444

[34]:
```
D1 = Q_ref / (2 * B * So)
D1 # m2/s
```

[34]: 1800.0

[35]:
```
X = (1 / 2) - (D1 / (c * ΔX1 ))
X
```

[35]: 0.21875

[36]:
```
denom = K1 * (1 - X) + 0.5 * Δt
denom # hr
```

[36]: 1.2925347222222223

[37]:
```
C0_num = K1 * X + 0.5 * Δt
C0 = C0_num / denom
C0
```

[37]: 0.6977837474815312

[38]:
```
C1_num = 0.5 * Δt - K1 * X
C1 = C1_num / denom
C1
```

[38]: 0.46272666218938885

[39]:
```
C2_num = K1 * (1 - X) - 0.5 * Δt
C2 = C2_num / denom
C2
```

[39]: -0.1605104096709201

[40]:
```
# sanity check
C0 + C1 + C2
```

[40]: 0.9999999999999999

[41]:
```
df = pd.DataFrame({'hour': Ts, 'Q_inflow': Qs})
df
```

[41]:

	hour	Q_inflow
0	0	12.0
1	1	14.4
2	2	21.6
3	3	34.2
4	4	60.0
5	5	93.6
6	6	128.4
7	7	161.4
8	8	176.4
9	9	180.0
10	10	175.2
11	11	154.8
12	12	126.0
13	13	93.6
14	14	70.8
15	15	54.0
16	16	39.6
17	17	28.8
18	18	20.4
19	19	14.4
20	20	12.0

[42]:
```
CO__Qj_n = list(df.Q_inflow * CO)
CO__Qj_n = [np.nan] + list(CO__Qj_n)
CO__Qj_n = CO__Qj_n[:-1]
```

[43]:
```
df['CO__Qj_n'] = CO__Qj_n
df
```

[43]:

	hour	Q_inflow	CO__Qj_n
0	0	12.0	NaN
1	1	14.4	8.373405
2	2	21.6	10.048086
3	3	34.2	15.072129
4	4	60.0	23.864204
5	5	93.6	41.867025
6	6	128.4	65.312559
7	7	161.4	89.595433
8	8	176.4	112.622297
9	9	180.0	123.089053
10	10	175.2	125.601075

```
11     11      154.8   122.251713
12     12      126.0   108.016924
13     13       93.6    87.920752
14     14       70.8    65.312559
15     15       54.0    49.403089
16     16       39.6    37.680322
17     17       28.8    27.632236
18     18       20.4    20.096172
19     19       14.4    14.234788
20     20       12.0    10.048086
```

[44]:
```
C1_Qj__n_1 = df.Q_inflow * C1
C1_Qj__n_1[0] = np.nan
```

[45]:
```
df['C1_Qj__n_1'] = C1_Qj__n_1
df
```

[45]:

	hour	Q_inflow	C0__Qj_n	C1_Qj__n_1
0	0	12.0	NaN	NaN
1	1	14.4	8.373405	6.663264
2	2	21.6	10.048086	9.994896
3	3	34.2	15.072129	15.825252
4	4	60.0	23.864204	27.763600
5	5	93.6	41.867025	43.311216
6	6	128.4	65.312559	59.414103
7	7	161.4	89.595433	74.684083
8	8	176.4	112.622297	81.624983
9	9	180.0	123.089053	83.290799
10	10	175.2	125.601075	81.069711
11	11	154.8	122.251713	71.630087
12	12	126.0	108.016924	58.303559
13	13	93.6	87.920752	43.311216
14	14	70.8	65.312559	32.761048
15	15	54.0	49.403089	24.987240
16	16	39.6	37.680322	18.323976
17	17	28.8	27.632236	13.326528
18	18	20.4	20.096172	9.439624
19	19	14.4	14.234788	6.663264
20	20	12.0	10.048086	5.552720

[46]:
```
Q_outflow_4km = []
for i in range(len(df.Q_inflow)):
    if i == 0:
        Q_total = list(df.Q_inflow.values)[0]
    else:
        Q_before = Q_outflow_4km[-1]
        Q_part = C2 * Q_before
```

```
        Q_total = Q_part + C0__Qj_n[i] + C1_Qj__n_1[i]
    Q_outflow_4km.append(Q_total)
```

[47]:
```
df['Q_outflow_4km'] = Q_outflow_4km
df = df.drop(['C0__Qj_n', 'C1_Qj__n_1'], axis=1)
df
```

[47]:

	hour	Q_inflow	Q_outflow_4km
0	0	12.0	12.000000
1	1	14.4	13.110544
2	2	21.6	17.938603
3	3	34.2	28.018048
4	4	60.0	47.130615
5	5	93.6	77.613286
6	6	128.4	112.268922
7	7	161.4	146.259186
8	8	176.4	170.771158
9	9	180.0	178.969304
10	10	175.2	177.944350
11	11	154.8	165.319879
12	12	126.0	139.784922
13	13	93.6	108.795033
14	14	70.8	80.610871
15	15	54.0	61.451445
16	16	39.6	46.140702
17	17	28.8	33.552701
18	18	20.4	24.150238
19	19	14.4	17.021688
20	20	12.0	12.868648

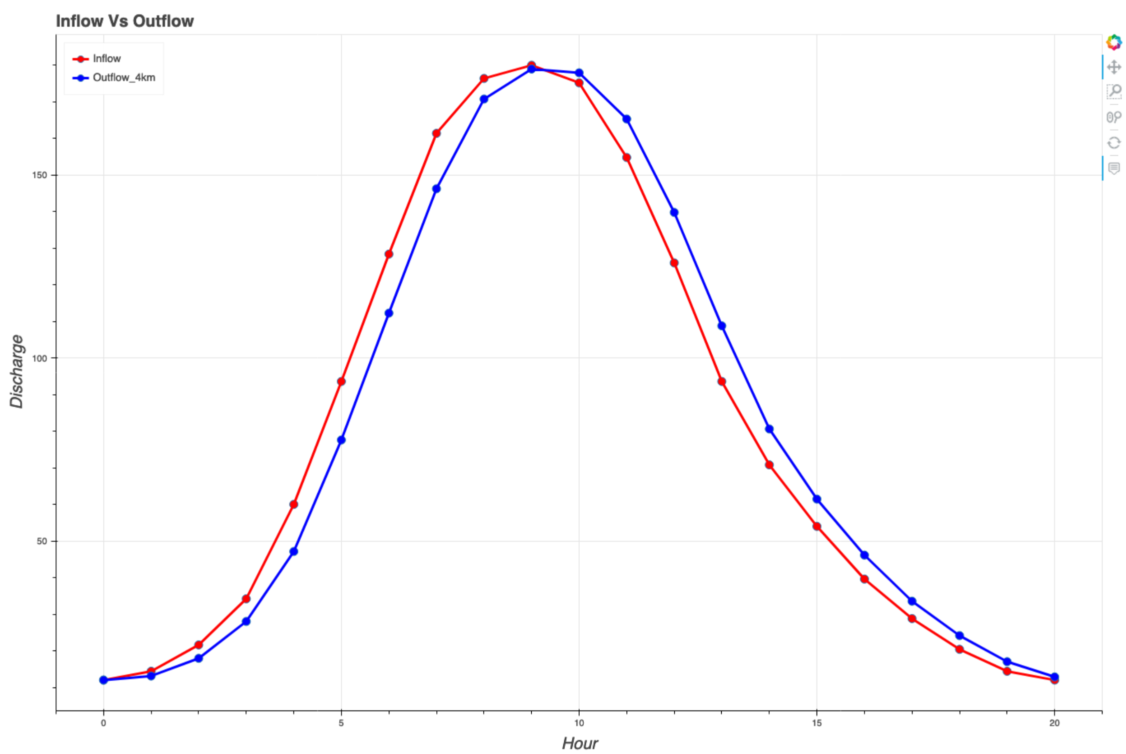
[48]:
```
fig = initialize_fig(title = 'Inflow Vs Outflow',
                     x_axis_label = 'Hour',
                     y_axis_label = 'Discharge',
                     tooltips = [
                         ('hour',       '$x'),
                         ('discharge' , '$y'),
                     ],
                     plot_height = 300,
                    )

fig.title.text_font_size = '15pt'
fig.xaxis.axis_label_text_font_size = '15pt'
fig.yaxis.axis_label_text_font_size = '15pt'

fig.circle(df.hour, df.Q_inflow, fill_color='red', size=10,␣
 ↪legend_label='Inflow')
```

```python
fig.line(df.hour, df.Q_inflow, line_width=3, line_color='red', legend_label='Inflow')

fig.circle(df.hour, df.Q_outflow_4km, fill_color='blue', size=10, legend_label='Outflow_4km')
fig.line(df.hour, df.Q_outflow_4km, line_width=3, line_color='blue', legend_label='Outflow_4km')

fig.legend.location = 'top_left'
fig.legend.click_policy='hide'
bp.show(fig)

export_png(fig, filename=f'{BASE_DIR}/Test#2/problem_8_part_1.png', height=200, width=300)
Image(f'{BASE_DIR}/Test#2/problem_8_part_1.png')
```

[48]:



[ ]:

```python
```

[ ]:

```python
```

[49]:

```python
# For further routing 6km from 4km point (total 10km), we use the discharge at 4km point
# as the inflow to the 6km down
```

```
# in cms
Qs = df.Q_outflow_4km.tolist()
```

[50]:
```
# cross-sectional area
Q_ref = max(Qs) # peak cms
# and we can still use Δt as 1.5 hour
Δt = 1.5 # hour

ΔX2 = 6 # km
ΔX2 = ΔX2 * 1e3 # m
ΔX2
```

[50]: 6000.0

[51]:
```
c
```

[51]: 1.6

[52]:
```
K2 = ΔX2 / c # sec
K2 = K2 / (60 * 60) # hour
K2
```

[52]: 1.0416666666666667

[53]:
```
D2 = Q_ref / (2 * B * So)
D2 # m2/s
```

[53]: 1789.693036838701

[54]:
```
X = (1 / 2) - (D2 / (c * ΔX2 ))
X
```

[54]: 0.31357364199596865

[55]:
```
denom = K2 * (1 - X) + 0.5 * Δt
denom # hr
```

[55]: 1.4650274562541994

[56]:
```
C0_num = K2 * X + 0.5 * Δt
C0 = C0_num / denom
C0
```

[56]: 0.7348935378762333

[57]:
```
C1_num = 0.5 * Δt - K2 * X
C1 = C1_num / denom
```

```python
C1
```

[57]: 0.2889780582474453

```python
C2_num = K2 * (1 - X) - 0.5 * Δt
C2 = C2_num / denom
C2
```

[58]: -0.023871596123678774

```python
C0 + C1 + C2
```

[59]: 0.9999999999999999

```python
C0__Qj_n = list(df.Q_outflow_4km * C0)
C0__Qj_n = [np.nan] + list(C0__Qj_n)
C0__Qj_n = C0__Qj_n[:-1]
```

```python
df['C0__Qj_n'] = C0__Qj_n
df
```

[61]:

	hour	Q_inflow	Q_outflow_4km	C0__Qj_n
0	0	12.0	12.000000	NaN
1	1	14.4	13.110544	8.818722
2	2	21.6	17.938603	9.634854
3	3	34.2	28.018048	13.182963
4	4	60.0	47.130615	20.590283
5	5	93.6	77.613286	34.635985
6	6	128.4	112.268922	57.037502
7	7	161.4	146.259186	82.505705
8	8	176.4	170.771158	107.484931
9	9	180.0	178.969304	125.498621
10	10	175.2	177.944350	131.523385
11	11	154.8	165.319879	130.770153
12	12	126.0	139.784922	121.492511
13	13	93.6	108.795033	102.727036
14	14	70.8	80.610871	79.952766
15	15	54.0	61.451445	59.240408
16	16	39.6	46.140702	45.160270
17	17	28.8	33.552701	33.908503
18	18	20.4	24.150238	24.657663
19	19	14.4	17.021688	17.747854
20	20	12.0	12.868648	12.509128

```python
C1_Qj__n_1 = df.Q_outflow_4km * C1
C1_Qj__n_1[0] = np.nan
```

[63]:
```python
df['C1_Qj__n_1'] = C1_Qj__n_1
df
```

[63]:

	hour	Q_inflow	Q_outflow_4km	C0__Qj_n	C1_Qj__n_1
0	0	12.0	12.000000	NaN	NaN
1	1	14.4	13.110544	8.818722	3.788660
2	2	21.6	17.938603	9.634854	5.183863
3	3	34.2	28.018048	13.182963	8.096601
4	4	60.0	47.130615	20.590283	13.619714
5	5	93.6	77.613286	34.635985	22.428537
6	6	128.4	112.268922	57.037502	32.443255
7	7	161.4	146.259186	82.505705	42.265696
8	8	176.4	170.771158	107.484931	49.349118
9	9	180.0	178.969304	125.498621	51.718202
10	10	175.2	177.944350	131.523385	51.422013
11	11	154.8	165.319879	130.770153	47.773818
12	12	126.0	139.784922	121.492511	40.394775
13	13	93.6	108.795033	102.727036	31.439377
14	14	70.8	80.610871	79.952766	23.294773
15	15	54.0	61.451445	59.240408	17.758119
16	16	39.6	46.140702	45.160270	13.333650
17	17	28.8	33.552701	33.908503	9.695994
18	18	20.4	24.150238	24.657663	6.978889
19	19	14.4	17.021688	17.747854	4.918894
20	20	12.0	12.868648	12.509128	3.718757

[64]:
```python
Q_outflow_10km = []
for i in range(len(df.Q_outflow_4km)):
    if i == 0:
        Q_total = list(df.Q_outflow_4km.values)[0]
    else:
        Q_before = Q_outflow_10km[-1]
        Q_part = C2 * Q_before
        Q_total = Q_part + C0__Qj_n[i] + C1_Qj__n_1[i]
    Q_outflow_10km.append(Q_total)
```

[65]:
```python
df['Q_outflow_10km'] = Q_outflow_10km
df = df.drop(['C0__Qj_n', 'C1_Qj__n_1'], axis=1)
df
```

[65]:

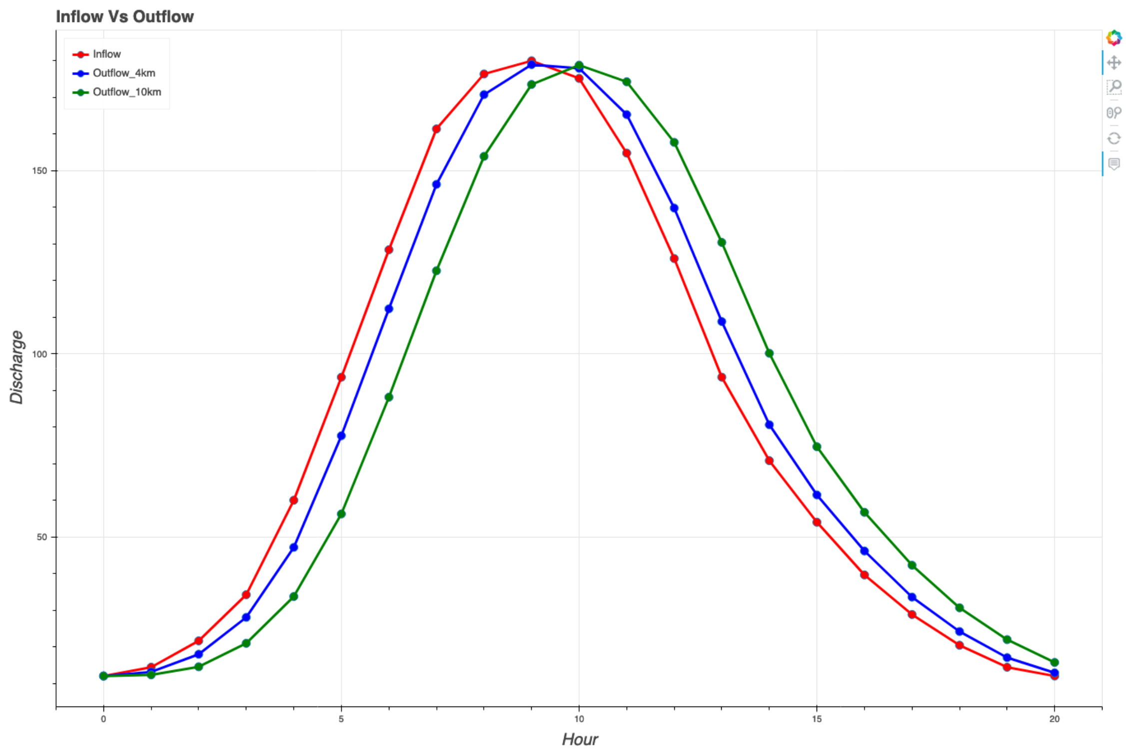
	hour	Q_inflow	Q_outflow_4km	Q_outflow_10km
0	0	12.0	12.000000	12.000000
1	1	14.4	13.110544	12.320923
2	2	21.6	17.938603	14.524597
3	3	34.2	28.018048	20.932839
4	4	60.0	47.130615	33.710296
5	5	93.6	77.613286	56.259803

6	6	128.4	112.268922	88.137746
7	7	161.4	146.259186	122.667412
8	8	176.4	170.771158	153.905781
9	9	180.0	178.969304	173.542846
10	10	175.2	177.944350	178.802653
11	11	154.8	165.319879	174.275666
12	12	126.0	139.784922	157.727048
13	13	93.6	108.795033	130.401217
14	14	70.8	80.610871	100.134654
15	15	54.0	61.451445	74.608154
16	16	39.6	46.140702	56.712905
17	17	28.8	33.552701	42.250670
18	18	20.4	24.150238	30.627961
19	19	14.4	17.021688	21.935610
20	20	12.0	12.868648	15.704247

[66]:
```
fig = initialize_fig(title = 'Inflow Vs Outflow',
                     x_axis_label = 'Hour',
                     y_axis_label = 'Discharge',
                     tooltips = [
                         ('hour',       '$x'),
                         ('discharge' , '$y'),
                     ],
                     plot_height = 300,
                    )

fig.title.text_font_size = '15pt'
fig.xaxis.axis_label_text_font_size = '15pt'
fig.yaxis.axis_label_text_font_size = '15pt'

fig.circle(df.hour, df.Q_inflow, fill_color='red', size=10,␣
 ↪legend_label='Inflow')
fig.line(df.hour, df.Q_inflow, line_width=3, line_color='red',␣
 ↪legend_label='Inflow')

fig.circle(df.hour, df.Q_outflow_4km, fill_color='blue', size=10,␣
 ↪legend_label='Outflow_4km')
fig.line(df.hour, df.Q_outflow_4km, line_width=3, line_color='blue',␣
 ↪legend_label='Outflow_4km')

fig.circle(df.hour, df.Q_outflow_10km, fill_color='green', size=10,␣
 ↪legend_label='Outflow_10km')
fig.line(df.hour, df.Q_outflow_10km, line_width=3, line_color='green',␣
 ↪legend_label='Outflow_10km')

fig.legend.location = 'top_left'
```

```
fig.legend.click_policy='hide'
bp.show(fig)

export_png(fig, filename=f'{BASE_DIR}/Test#2/problem_8.png', height=200,␣
 ↪width=300)
Image(f'{BASE_DIR}/Test#2/problem_8.png')
```

[66]:



[ ]:

[ ]:

0.0.8 Q4

Consider a storm having excess rainfall of 2 cm for the first 2 hours and 3 cm for the second 2 hours. The 2 hour unit hydrograph of a watershed is given below. This watershed drains into a detention basin that has an area of 10 km2

T (hr)	Q (m3/s/cm)
0	0
2	1.8
4	30.9
6	85.6
8	41.8

T (hr)	Q (m3/s/cm)
10	14.6
12	5.5
14	1.8
16	0

[67]:
```python
# Given
Qs = [0, 1.8, 30.9, 85.6, 41.8, 14.6, 5.5, 1.8, 0]
# Total volume for 5 cm excess rainfall will be
Q = sum(Qs) # m3/s
Q = round(Q, 4)
Q
```

[67]: 182.0

[68]:
```python
# volume is given as
# A * Δl = Q * Δt
# m2 * m = m3/s * s
# A = Q * Δt / Δl
Δt = 2 # hours
Δt = Δt * 60 * 60 # sec
Δl = 1 # cm
Δl = Δl * 0.01 # m
A = Q * Δt / Δl # m2
A = A / 1e+6 # km2
A
```

[68]: 131.04

[69]:
```python
Pn = np.array([ 2., 3. ]) # cm
# filling up with np.nan that would be used later
UH = [0, 1.8, 30.9, 85.6, 41.8, 14.6, 5.5, 1.8, 0] # cms/cm
UH_nan = [np.nan for _ in range(len(Pn)-1)]
UH = np.array(UH + UH_nan)
UH
```

[69]: array([0. , 1.8, 30.9, 85.6, 41.8, 14.6, 5.5, 1.8, 0. , nan])

[70]:
```python
hr = np.arange(0., 18., 2.)
hr
```

[70]: array([0., 2., 4., 6., 8., 10., 12., 14., 16.])

[71]:
```python
expand_by_Pn = len(UH) - len(Pn)
expand_by_hr = len(UH) - len(hr)
```

```
Pn = np.pad(Pn, ((0, expand_by_Pn)), mode='constant', constant_values=np.nan)
hr = np.pad(hr, ((0, expand_by_hr)), mode='constant', constant_values=np.nan)
hr
```

[71]: array([0., 2., 4., 6., 8., 10., 12., 14., 16., nan])

[72]:
```
df = pd.DataFrame({'UH': UH, 'Pn': Pn, 'hr': hr})
df
```

[72]:

	UH	Pn	hr
0	0.0	2.0	0.0
1	1.8	3.0	2.0
2	30.9	NaN	4.0
3	85.6	NaN	6.0
4	41.8	NaN	8.0
5	14.6	NaN	10.0
6	5.5	NaN	12.0
7	1.8	NaN	14.0
8	0.0	NaN	16.0
9	NaN	NaN	NaN

[73]:
```
df['P1Un'] = Pn[0] * df.UH
df
```

[73]:

	UH	Pn	hr	P1Un
0	0.0	2.0	0.0	0.0
1	1.8	3.0	2.0	3.6
2	30.9	NaN	4.0	61.8
3	85.6	NaN	6.0	171.2
4	41.8	NaN	8.0	83.6
5	14.6	NaN	10.0	29.2
6	5.5	NaN	12.0	11.0
7	1.8	NaN	14.0	3.6
8	0.0	NaN	16.0	0.0
9	NaN	NaN	NaN	NaN

[74]:
```
P2Un = np.array(Pn[1] * df.UH)
P2Un = [np.nan] + list(P2Un)
P2Un = P2Un[:-1]
```

[75]:
```
df['P2Un'] = P2Un
df
```

[75]:

	UH	Pn	hr	P1Un	P2Un
0	0.0	2.0	0.0	0.0	NaN
1	1.8	3.0	2.0	3.6	0.0
2	30.9	NaN	4.0	61.8	5.4

3	85.6	NaN	6.0	171.2	92.7
4	41.8	NaN	8.0	83.6	256.8
5	14.6	NaN	10.0	29.2	125.4
6	5.5	NaN	12.0	11.0	43.8
7	1.8	NaN	14.0	3.6	16.5
8	0.0	NaN	16.0	0.0	5.4
9	NaN	NaN	NaN	NaN	0.0

[76]:
```
df['Qn'] = df[['P1Un', 'P2Un']].sum(axis=1)
df
```

[76]:

	UH	Pn	hr	P1Un	P2Un	Qn
0	0.0	2.0	0.0	0.0	NaN	0.0
1	1.8	3.0	2.0	3.6	0.0	3.6
2	30.9	NaN	4.0	61.8	5.4	67.2
3	85.6	NaN	6.0	171.2	92.7	263.9
4	41.8	NaN	8.0	83.6	256.8	340.4
5	14.6	NaN	10.0	29.2	125.4	154.6
6	5.5	NaN	12.0	11.0	43.8	54.8
7	1.8	NaN	14.0	3.6	16.5	20.1
8	0.0	NaN	16.0	0.0	5.4	5.4
9	NaN	NaN	NaN	NaN	0.0	0.0

[77]:
```
# peak direct runoff
Qp = np.max(df.Qn) # cms
Qp
```

[77]: 340.4

[78]:
```
A
```

[78]: 131.04

[79]:
```
# Total volume of water going into the retention basin
V = ( 2. / 100. + 3. / 100. ) * A # m-km2
V
```

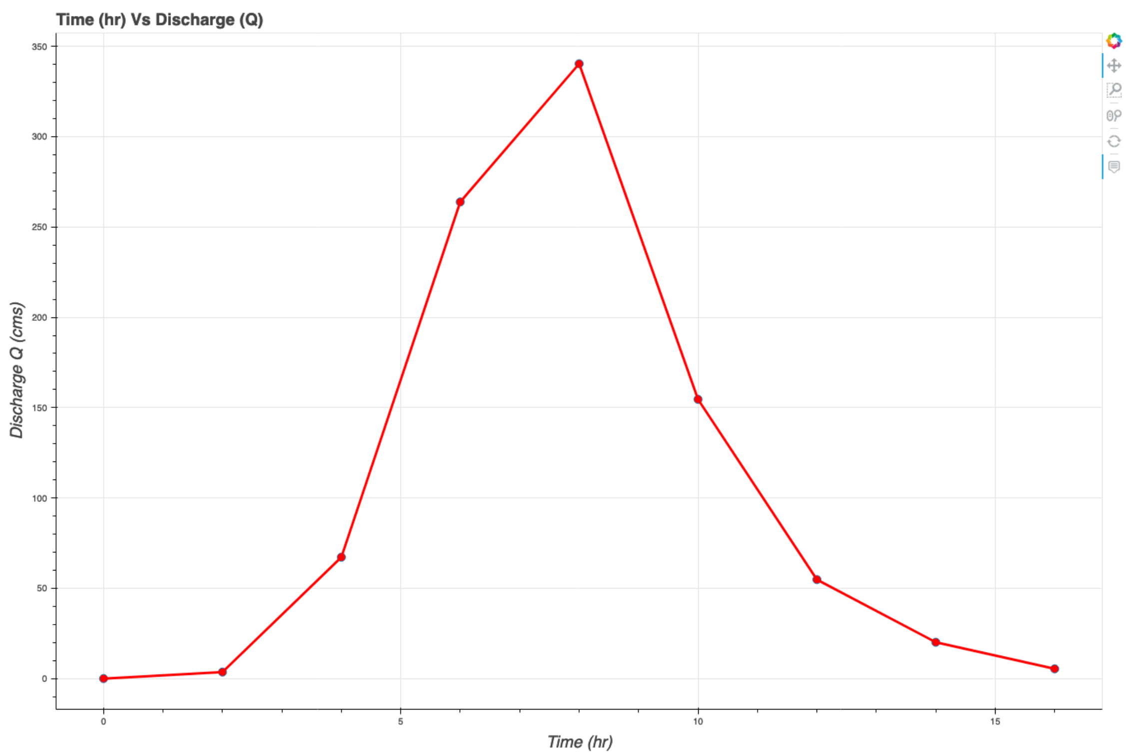
[79]: 6.552

[80]:
```
A_detention = 10 # km2
# depth of water
Δd = V / A_detention
Δd # m
```

[80]: 0.6552

[81]:
```python
fig = initialize_fig(title = 'Time (hr) Vs Discharge (Q)',
                     x_axis_label = 'Time (hr)',
                     y_axis_label = 'Discharge Q (cms)',
                     tooltips = [
                         ('time(hr)', '$x'),
                         ('discharge(cms)'    , '$y'),
                     ],
                     plot_height = 300,
                    )

fig.title.text_font_size = '15pt'
fig.xaxis.axis_label_text_font_size = '15pt'
fig.yaxis.axis_label_text_font_size = '15pt'

fig.circle(df.hr, df.Qn, fill_color='red', size=10)
fig.line(df.hr, df.Qn, line_width=3, line_color='red')

bp.show(fig)

export_png(fig, filename=f'{BASE_DIR}/Test#2/problem_4.png', height=200,␣
 ↪width=300)
Image(f'{BASE_DIR}/Test#2/problem_4.png')
```

[81]:



[82]:
```python
# total excess rainfall duration
D = 2 + 2 # hr
# lag time is the time difference between the peak precip and peak discharge
# peak precip occurs at 2nd hour
# peak discharge occurs at 8th hour
tL = 8 - 2 # hr
tL
```

[82]: 6

[83]:
```python
# time of concentration
tc = tL / 0.6
tc # hour
```

[83]: 10.0

[84]:
```python
# time to rise
TR = D / 2 + tL
TR # hour
```

[84]: 8.0

[85]:
```python
# duration of hydrograph
B = 1.67 * TR
B # hour
```

[85]: 13.36

Time of concentration is the function of watershed characteristics. It will vary depending upon slope and character of the watershed and the flow path. Thus for the same watershed the time of concentration remains same given the variation in the rainfall event.

[ ]:
```python

```

[ ]:
```python

```