EX1-WS

September 21, 2022

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1 CE 3354 Engineering Hydrology Fall 2022 Exam 1

LAST NAME, FIRST NAME

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1.0.1 Purpose :

Demonstrate ability to apply hydrologic and problem solving principles with respect to water balance, watershed delineation and measurements, and precipitation and streamflow.

1.0.2 Problem 1 Water Budget Concepts

A river reach has an initial inflow of 350 cfs and an initial outflow of 285 cfs. 90 minutes later the inflow and outflow are 250 cfs and 200 cfs, respectively, and the volume in storage is 10.8 acre-ft. Determine:

1. The change in storage over the 90 minute interval, and
2. The initial storage volume

```
[21]:  # solution here - use lesson02 script
       # prototype function
       def newS(t0,t1,I0,I1,O0,O1,S0):
           Ibar = 0.5*(I0 + I1)
           Obar = 0.5*(O0 + O1)
           dsdt = Ibar - Obar
           dsdt = dsdt*3600/43560 # convert to correct units
           deltat = t1-t0
           DS   = dsdt*deltat
           newS  = S0+DS
           return(newS)
       # input values
       t0 = 0 # hrs
```

```
t1 = 1.5 # hrs
I0 = 350 # cfs
I1 = 250 # cfs
O0 = 285 # cfs
O1 = 200 # cfs
S0 = 3.67 # acre-ft <<< Change this until storage out is 10.8
# echo inputs
print("Begin Time",t0," hours")
print("End Time",t1," hours")
print("Inflow at Begin Time",I0," cfs")
print("Inflow at End Time",I1," cfs")
print("Outflow at Begin Time",O0," cfs")
print("Outflow at End Time",O1," cfs")
print("Storage at Begin Time",S0," acre-feet")
S1   = newS(t0,t1,I0,I1,O0,O1,S0) # get new storage
# output results
print("Storage at End Time",round(S1,2)," acre-feet")
```

```
Begin Time 0  hours
End Time 1.5  hours
Inflow at Begin Time 350  cfs
Inflow at End Time 250  cfs
Outflow at Begin Time 285  cfs
Outflow at End Time 200  cfs
Storage at Begin Time 3.67  acre-feet
Storage at End Time 10.8  acre-feet
```

1.0.3 Problem 2 Volume and Flow Concepts

1. If water flows past an observation location at 1.0 cubic feet per second, for one hour, what incremental volume in cubic feet has passed the observation location?
2. If a basin has a surface area of 1 acre, and water is uniformly ponded at a depth of 1 foot, what is the total volume of water in cubic feet?
3. A reservoir with a constant surface area of 500 acres has an evaporation rate of 3.6 inches per day. The average outflow from the reservoir is 50 cubic feet per second, what is the change in water level in one day?

[24]:
```
# solution here
flowrate = 1.0 #cfs
duration = 1.0 #hour
totalvolume = flowrate*duration*(3600/1) # convert hour to seconds -␣
 ↪totalvolume is in ft^3
print("Volume past observation point in 1 hour is ",round(totalvolume,3),"␣
 ↪cubic feet")
area = 1 #acre
depth = 1 #foot
```

```
storedvolume = area*depth*(43560/1) #convert acre to sq. feet for volume in␣
 ↪cubic feet
print("Volume in Basin is ",round(storedvolume,3)," cubic feet")
area = 500 #acres
evap = 3.6 #inches/day
loss = area*evap*(1/12)*(43560/1) # convert inches to feet, acres to sq. feet ¬␣
 ↪result is in cubic feet per day
flowrate = 50.0 #cfs
duration = 24.0 #hour
totalflow = flowrate*duration*(3600/1) # convert hour to seconds - totalvolume␣
 ↪is in ft^3/day
deltah = (loss + totalflow)/(area*(43560/1))
print("Daily Water Level Change is ",round(deltah,3)," feet")
```

```
Volume past observation point in 1 hour is  3600.0  cubic feet
Volume in Basin is  43560.0  cubic feet
Daily Water Level Change is  0.498  feet
```

1.0.4 Problem 3. Watershed Metrics

Figure 1 is a topographic map of a small drainage basin. The drawn contour interval is 20 feet.
Many of the contours are labeled. A culvert structure is located on the Eastern portion of the
basin, near the outlet shown on Figure 3.

Figure 1. Topographic Map of a portion of the Earth. Elevations and linear distances are in f eet.
North (by convention) is up.

The red line is a highway alignment, beneath which the culvert structure is placed. Figure 2 is a
photograph of the culvert system that is comprised of 4-parallel , 4-foot diameter, 100-foot long
culverts. The lowest portion of the road near the culverts is at elevation 595 feet. The culverts are
laid on a dimensionless slope of 0.02.

Figure 2. Multiple-barrel outlet structure

The watershed is delineated and the boundary is already drawn on the map.

The water surface area when the culvert system (like a dam, with 4 holes in the wall) impounds
water to a water surface elevation of 565 $feet$ is zero. (Zero pool area when the WSE is at 565
feet). Figure 3 is a schematic sketch (elevation view) of a culvert barrel.

Figure 3. Culvert system elevation view sketch

```
[25]: # solution below:
```

- Estimate the basin drainage area that drains to the culvert structure. Report the results in
    1. Square feet,
    2. Acres, and
    3. Square miles

Superimpose a grid and apply counting squares (or use software and determine distances and areas using measuring tools.)
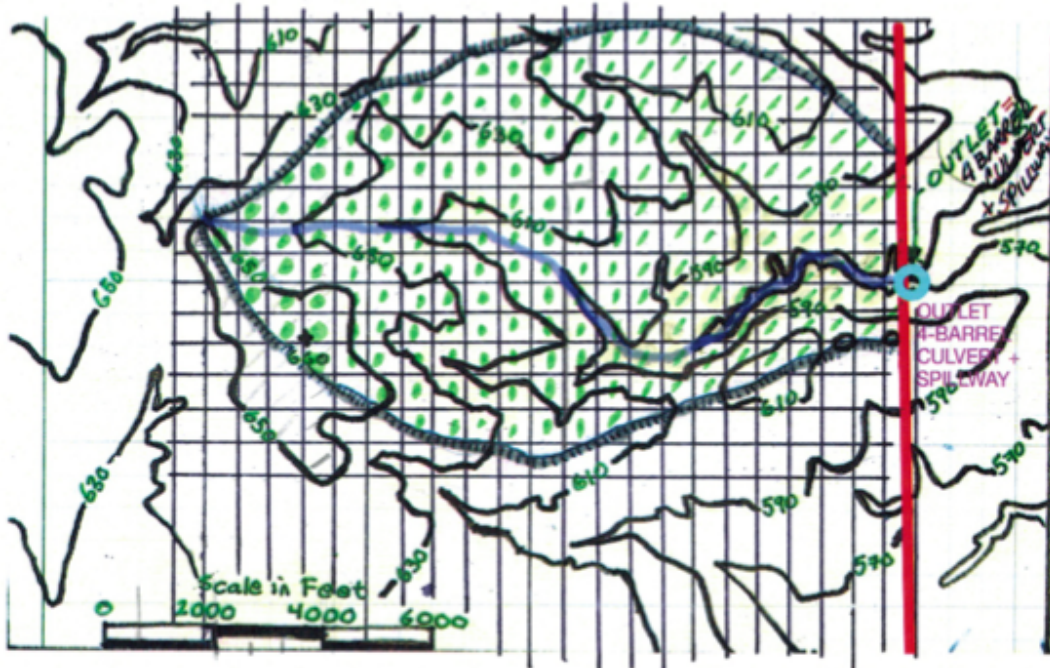

```
[26]:  # area
       areasquare = 443556 #ft^2 interpreted from the scane in feet on the drawing
       howmanysquares = 200


       areaft2 = howmanysquares*areasquare


       areaAc = areaft2*(1/43560) # 43560 ft^2 per acre


       areaSqMi = areaAc*(1/640) # 640 acres per sq.mi.


       print("Area in sq. feet : ",round(areaft2,3)," ft^2")
       print("Area in acres : ",round(areaAc,3)," acres")
       print("Area in sq. miles : ",round(areaSqMi,3)," sq.mi")
```
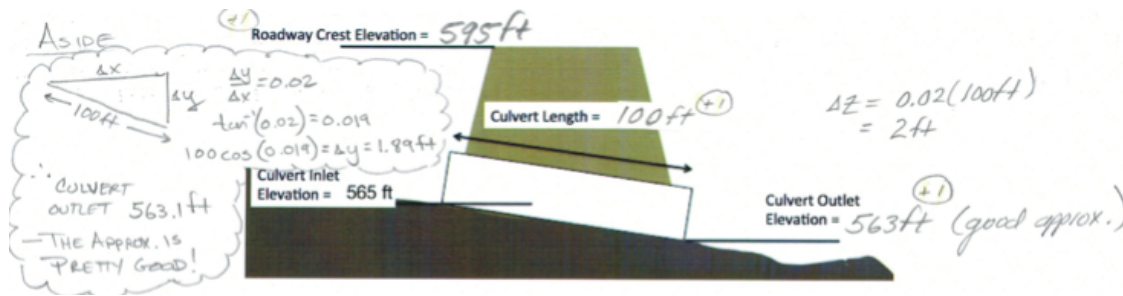
```
Area in sq. feet :  88711200  ft^2
Area in acres :  2036.529  acres
Area in sq. miles :  3.182  sq.mi
```
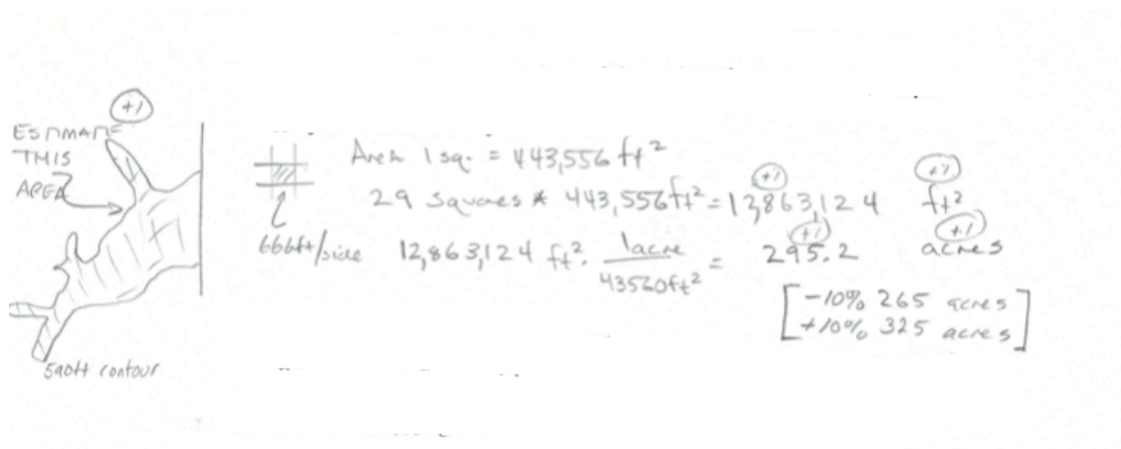
Numerical answers +/- 10% are "correct"

- Complete the elevation (side) view sketch of the road embankment and culvert system by indicating the missing elevations on the sketch of (show computations for the outlet elevation)
  1. The roadway crest in feet,
  2. The culvert outlet elevation in feet, and
  3. The culvert barrel length in feet.

4

ASIDE

Roadway Crest Elevation = 595 ft

$\frac{\Delta y}{\Delta x} = 0.02$

$\tan^{-1}(0.02) = 0.019$

$100 \cos(0.019) = \Delta y = 1.89 \, ft$

Culvert Length = 100 ft

$\Delta Z = 0.02(100ft)$
$= 2 ft$

Culvert Inlet Elevation = 565 ft

CULVERT OUTLET 563.1 ft

Culvert Outlet Elevation = 563 ft (good approx.)

— THE APPROX. IS PRETTY GOOD!

The "aside" balloon is FYI only , not part of an answer

- Estimate the water surface area (area of the pool on the upstream side of the road embankment) when the embankment impounds water to a water surface elevation of 590 $feet$. Show how you made the estimate.

ESTIMATE THIS AREA

590 ft contour

Area 1 sq. = 443,556 ft²

29 squares * 443,556 ft² = 12,863,124 ft²

666 ft/side $12,863,124 \, ft^2 \cdot \frac{1 \, acre}{43560 \, ft^2} = 295.2$ acres

$\begin{bmatrix} -10\% & 265 \text{ acres} \\ +10\% & 325 \text{ acres} \end{bmatrix}$

[27]:
```python
poolarea590 = (areasquare*29)*(1/43560)
print("590 Elevation Pool Area in acres : ",round(poolarea590,3)," acres")
```

590 Elevation Pool Area in acres : 295.297 acres

- Estimate the main channel length in feet. Show how you made the estimate.

The main channel traverses about 24 squares, each square has a side of 666 feet.

[28]:
```python
lengthsquare = areasquare**(0.5)  # square root should give us the side
chanellength = 24 * lengthsquare # one could get fancy and use the diagional,
→which would be 1.4 larger
print("Main channel length in feet : ",round(chanellength,3)," feet")
```

Main channel length in feet : 15984.0 feet

- Estimate the elevation at the most upstream portion of the main channel (where the main channel would intersect the watershed boundary), in feet.

[29]:
```python
highpoint = 650 # feet
```

- Estimate the elevation of the outlet point of the watershed (the culvert invert elevations).

```
[30]: outlet = 565 #feet
```

- Using these two elevation values, estimate the average watershed slope along the main channel.
  Express the result in
    1. Dimensionless slope, and
    2. Percent slope.

```
[31]: slopedim = (highpoint-outlet)/chanellength
      slopepercent = slopedim*100
      print("Dimensionless main channel slope : ",round(slopedim,4)," --- ")
      print("Percent main channel slope  : ",round(slopepercent,2)," percent")
```

```
Dimensionless main channel slope :  0.0053  ---
Percent main channel slope  :  0.53  percent
```

1.0.5 Problem 4. Rainfall and Runoff Data Reduction

A tabulation of an observed storm and associated runoff for the drainage area depicted by the map
in Figure 1 is listed below. The runoff was measured at the culvert system and indicated by the
blue circle on the map.

Time (hrs)	Accumulated Rain (inches)	Observed Discharge (cfs)	Incremental Volume (ft^3)	Cumulative Volume (ft^3)
0	0.000	0.00		
1	0.000	0.00		
2	0.000	0.00		
3	0.000	0.00		
4	0.000	0.00		
5	0.000	0.00		
6	0.000	0.00		
7	0.000	0.00		
8	0.101	1.40		
9	0.106	0.31		
10	0.111	0.31		
11	0.115	0.31		
12	0.120	0.31		
13	0.120	0.40		
14	0.150	0.40		
15	0.750	24.66		
16	2.750	588.23		
17	2.940	808.70		
18	3.030	154.28		
19	3.030	94.68		
20	3.030	27.56		
21	3.090	36.13		
22	3.210	19.65		

Time (hrs)	Accumulated Rain (inches)	Observed Discharge (cfs)	Incremental Volume (ft^3)	Cumulative Volume (ft^3)
23	3.300	7.00		
24	3.300	0.00		

Build a Jupyter Notebook (or use Excel) to:

1. Complete the column labeled Incremental Volume (ft^3).
2. Complete the column labeled Cumulative Volume (ft^3).
3. Determine the total **volume** of runoff in cubic feet from the storm (e.g. the Cumulative Volume at hour 24)
4. Convert the runoff volume from cubic feet into watershed feet (i.e divide by the watershed area), then from watershed feet into watershed inches.

5. Determine the fraction (percent) of rainfall that becomes runoff.
6. Plot the cumulative precipitation in inches and the cumulative runoff in watershed inches on the same plot. Use the time for the x-axis, and the respective cumulative depths for the y-axis. Plot precipitation in BLUE and runoff in RED.

```
[67]:  # solution here
       dataframe=[[0,0.000,0.00],[1,0.000,0.00],[2,0.000,0.00],[3,0.000,0.00],[4,0.
       ↪000,0.00],[5,0.000,0.00],[6,0.000,0.00],[7,0.000,0.00],[8,0.101,1.40],[9,0.
       ↪106,0.31],[10,0.111,0.31],[11,0.115,0.31],[12,0.120,0.31],[13,0.120,0.
       ↪40],[14,0.150,0.40],[15,0.750,24.66],[16,2.750,588.23],[17,2.940,808.
       ↪70],[18,3.030,154.28],[19,3.030,94.68],[20,3.030,27.56],[21,3.090,36.
       ↪13],[22,3.210,19.65],[23,3.300,7.00],[24,3.300,0.00]]
       # set equivalents
       time=[]
       accrain=[]
       obsflow=[]
       for irow in range(len(dataframe)):
           time.append(dataframe[irow][0])
           accrain.append(dataframe[irow][1])
           obsflow.append(dataframe[irow][2])

       incvol = [0 for i in range(len(time))]
       accvol = [0 for i in range(len(time))]
       accrun = [0 for i in range(len(time))]
       for irow in range(1,len(dataframe)):
           incvol[irow]=obsflow[irow-1]*3600 # convert cfs to ft3 in 1 hour -␣
       ↪increment from end of previous hour
           accvol[irow]=incvol[irow]+accvol[irow-1]


       print("Total Runoff Volume",accvol[-1]," cubic feet")
       print("Total Runoff Volume",round(accvol[-1]/areaft2,3)," watershed feet")
       print("Total Runoff Volume",round(12*accvol[-1]/areaft2,3)," watershed inches")
```

```python
print("\nTotal Precipitation Volume",round(accrain[-1]*areaft2/12,3),"cubic␣
  ↪feet")
print("Fraction of Rain that appears as runoff",round(100*accvol[-1]/
  ↪(accrain[-1]*areaft2/12),1)," percent")

#time=[0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24]
increment=[0.121,0.121,0.132,0.154,0.165,0.187,0.198,0.242,0.297,0.374,0.594,4.
  ↪708,1.199,0.528,0.374,0.286,0.253,0.209,0.176,0.154,0.132,0.132,0.132,0.
  ↪132,0]
accumulate=[0 for i in range(len(time))]

for i in range(0,len(time)):
    accrun[i] = 12*accvol[i]/areaft2

    print(time[i],accrain[i],obsflow[i],incvol[i],accvol[i])

import matplotlib.pyplot as plt # the python plotting library
plottitle ='Precipitation for Somewhere USA '
mydata = plt.figure(figsize = (10,5)) # build a square drawing canvass from␣
  ↪figure class
plt.plot(time, accrain, c='blue',drawstyle='default') # step plot
plt.plot(time, accrun, c='red',drawstyle='default') # step plot
plt.xlabel('Time (hours)')
plt.ylabel('Depth (inches)')
plt.legend(['Precipitation','Runoff'])
plt.title(plottitle)
plt.show()
```
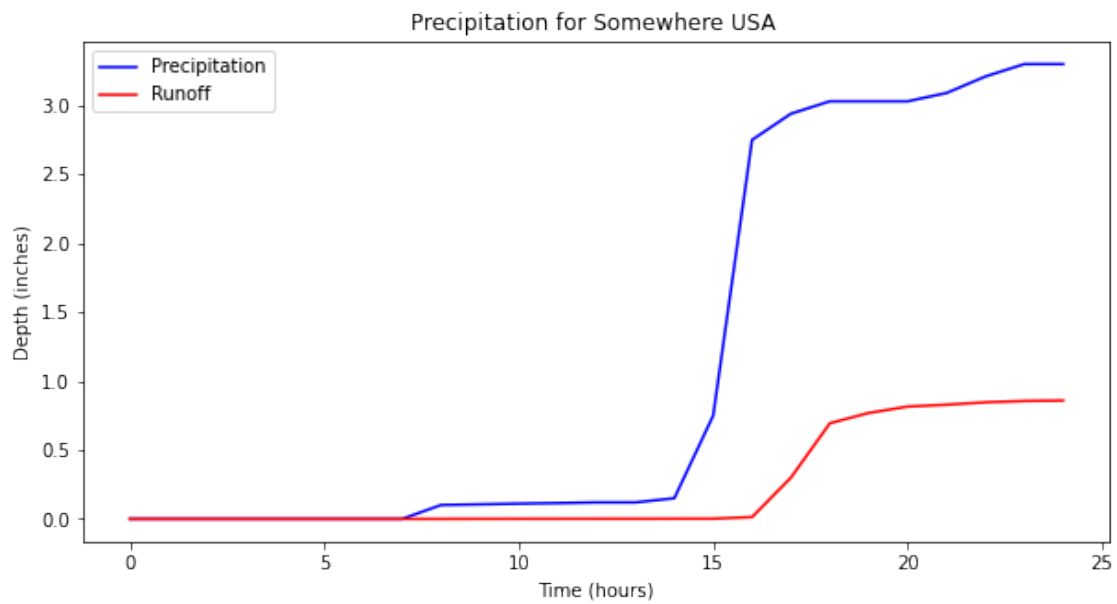
```
Total Runoff Volume 6351588.0  cubic feet
Total Runoff Volume 0.072  watershed feet
Total Runoff Volume 0.859  watershed inches

Total Precipitation Volume 24395580.0 cubic feet
Fraction of Rain that appears as runoff 26.0  percent
0 0.0 0.0 0 0
1 0.0 0.0 0.0 0.0
2 0.0 0.0 0.0 0.0
3 0.0 0.0 0.0 0.0
4 0.0 0.0 0.0 0.0
5 0.0 0.0 0.0 0.0
6 0.0 0.0 0.0 0.0
7 0.0 0.0 0.0 0.0
8 0.101 1.4 0.0 0.0
9 0.106 0.31 5040.0 5040.0
10 0.111 0.31 1116.0 6156.0
11 0.115 0.31 1116.0 7272.0
12 0.12 0.31 1116.0 8388.0
```

```
13 0.12 0.4 1116.0 9504.0
14 0.15 0.4 1440.0 10944.0
15 0.75 24.66 1440.0 12384.0
16 2.75 588.23 88776.0 101160.0
17 2.94 808.7 2117628.0 2218788.0
18 3.03 154.28 2911320.0 5130108.0
19 3.03 94.68 555408.0 5685516.0
20 3.03 27.56 340848.0 6026364.0
21 3.09 36.13 99216.0 6125580.0
22 3.21 19.65 130068.00000000001 6255648.0
23 3.3 7.0 70740.0 6326388.0
24 3.3 0.0 25200.0 6351588.0
```


[ ]: