Problem: *Water Cycle Climatology for a Watershed*

Statement:

Using water balance concepts and historical observations, assess the “climatology” of water cycle variables (precipitation and streamflow) for a watershed. As part of this exercise, you will also learn about some available online sources for hydrologic data.

The National Weather Service (NWS) uses 30-year averages to define climate “normal” (or the climatology) for weather variables. The latest climate normal period is from 1981 to 2010. Use coincident observations of precipitation and streamflow for this period for your assessment.

Do the following steps in your analysis:

a. Pick a USGS stream-gage somewhere in the United States to define the outlet of a watershed. Report the USGS stream-gage number and the watershed drainage area (in mi^2). **Do not** select a watershed that does not have *Monthly Statistics* for the years 1981 to 2010. Report the station name and USGS ID number. Also report (verbatim) the REMARKS from the *Water-Year Summary* for a recent year. (If the remarks say that **flows are regulated**, choose another stream-gage).

   Note: To find a stream-gage, I recommend looking at the USGS Current Water Data for the Nation real-time data. Click on the State you are interested in on the map, and then click on the *Statewide Streamflow Current Conditions Table* for a list of real-time operating stream-gages. Follow the link to your chosen stream-gage. Under the Available data for this site pulldown menu, select *Location Map* (to get drainage area), select *Monthly Statistics* (to verify that there are monthly data for the 30-year period), and select Water-Year Summary (to get the REMARKS). The watershed you choose is up to you, but I suggest a watershed that is in the range of 10s to 1000s of square miles (HUC-8 size or smaller).

b. Create a table showing the average monthly discharge (in cfs) and the average monthly discharge depth (in inches) for the stream-gage you selected.

   Note: You will need to copy and paste the monthly mean discharge for 1981 to 2010 into a spreadsheet. Find the average of the 30-years for your table. You can compute the average monthly depth (volume/area) by first computing the volume (average discharge rate × time) and then dividing by the drainage area (keep track of units!).

c. Create a table showing the average monthly precipitation (in inches) for the watershed.

   Note: This step will be an approximation (with more time we could estimate the mean areal precipitation of the watershed more accurately). Go to the NOAA Climate Data Online Site and choose the *Mapping Tool*. From the Surface Maps tab choose *Normals*. From the Layers tab choose *Monthly Climate Normals*, and then zoom in to your selected watershed. Find the station that is closest to your watershed drainage area (within the watershed would be ideal, but that might not be possible). Use the tools (see wrench icon) to select the station. Add it to your cart and *Continue* with the defaults to submit your order. From the PDF download, you can retrieve the monthly precipitation means (these are for 1981 to 2010).

d. Plot the average monthly precipitation (in inches) and the average monthly discharge (in inches) versus month (on one graph).

e. Compute the average annual precipitation (in inches).

f. Compute the average annual discharge (in inches).

g. Compute the average annual evapotranspiration (in inches) using the long-term water budget assumption.

h. Compute the runoff coefficient (i.e., annual discharge as a fraction of precipitation) (in %).

Note: It is common in hydrology to consider the partitioning of precipitation (over long time scales) into (1) the portion that becomes discharge (or runoff), and (2) the portion returned to the atmosphere by evapotranspiration. Part h) asks you to determine the percentage of precipitation that becomes discharge.

Suggestion: After selecting a stream-gage in part a), it would be helpful to have a map of the watershed (especially for part c). Unfortunately, this is not provided with the stream-gage information. I suggest that you use the USGS StreamStats 4 application to create a watershed map.

Solution:

Project1: Water Cycle Climatology for a Watershed

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Part A) Pick a stream gauge.

Stream Gage: USGS 04045500 Tahquamenon River Near Paradise, MI
Summary Data Here

Description - Latitude 46°34'30", Longitude 85°16'10" NAD27 - Luce County, Michigan, Hydrologic Unit 04020202 - Drainage area: 790 square miles (22,023,620,000 ft^2) - Datum of gage: 698.03 feet above NGVD29.

Remarks from the latest Water-Year-Summary Report, 2017 make no mention to regulated flows of any kind. The earliest report availabe, 2006, states that "records good for estimated daily discharges, which are fair. Several measurements of water temperature were made during the year. Gage-height telemeter at station. Remarks are included verbatim in screenshot form below.

2006 Remarks:

USGS
science for a changing world

Water-Data Report 2006

04045500 TAHQUAMENON RIVER NEAR PARADISE, MI

Southeastern Lake Superior Basin
Tahquamenon Subbasin

LOCATION.--Lat 46°34'30", long 85°16'10" referenced to North American Datum of 1927, in NE ¼ sec.11, T.48 N., R.8 W., Luce County, MI, Hydrologic Unit 04020202, on left bank 0.7 mi upstream from Tahquamenon Falls (upper), 11.5 mi west of Paradise, and 19 mi northeast of Newberry.

DRAINAGE AREA.--790 mi².

SURFACE-WATER RECORDS

PERIOD OF RECORD.--August 1953 to current year. Prior to October 1989, published as "near Tahquamenon Paradise".

GAGE.--Water-stage recorder. Datum of gage is 698.03 ft above sea level.

REMARKS.--Records good except for estimated daily discharges, which are fair. Several measurements of water temperature were made during the year. Gage-height telemeter at station.

2017 Remarks:

Available Parameters
☑ 00060 Discharge(Mean)

Select a water year
2017
GO
Water year 2017:
2016-10-01 to
2017-09-30

04045500 TAHQUAMENON RIVER NEAR PARADISE, MI

Print this page

LOCATION - Lat 46°34'30", long 85°16'10" referenced to North American Datum of 1927, in NE 1/4 sec.11, T.48 N., R.8 W., Luce County, MI, Hydrologic Unit 04020202, on left bank 0.7 mi upstream from Upper Tahquamenon Falls (upper), 11.5 mi west of Paradise, and 19 mi northeast of Newberry.

DRAINAGE AREA - 790 mi².

SURFACE-WATER RECORDS

PERIOD OF RECORD - August 1953 to current year. Prior to October 1989, published as "near Tahquamenon Paradise".

GAGE - Water-stage recorder. Datum of gage is 698.03 ft above NGVD 1929.

EXTREMES FOR PERIOD OF RECORD - Maximum discharge, 6,990 ft³/s, May 10, 1960, gage height, 10.26 ft; minimum discharge, 122 ft³/s, Aug. 17, 2007.

Water-Data Report 2017

04045500 TAHQUAMENON RIVER NEAR PARADISE, MI -- Continued

Part B) Create a table showing the average monthly discharge for 1981 to 2010. Find the 30-year average for your table.

```
In [89]: import pandas as pd
         import numpy as np
         import datetime as dt
         import matplotlib.pyplot as plt
```

```
In [112]: Area_mi2 = 790
          Area_ft2 = Area_mi2 * 27878000
          date_range = (
              dt.datetime(year=1980,month=12,day=29),
              dt.datetime(year=2010,month=12,day=29)
          )
```

```
In [76]: data = pd.read_csv(
             'TahquamenonRiver_04045500_MonthlyStatistics.txt',
             sep = '\t',
             names = ['Agency','Site Number','Parameter Code','Timeseries ID',
                      'Year','Month','Mean Value [ cfs ]'],
             skiprows = 37,
             usecols = [4,5,6]
         )

         # Set Years and Months to Type String
         data.Year = data.Year.astype(str)
         data.Month = data.Month.astype(str)

         # Join the strings with a -01- for the day.
         a = data.Month + '-01-'+ data.Year

         # Convert to a datatime format
         data['Date'] = pd.to_datetime(a)

         # Add column for days in the month... includes leap years for February
```

```
data['DaysInMonth'] = data.Date.dt.daysinmonth

# Revert Month & Year back to type int
data.Year = data.Year.astype(str)
data.Month = data.Month.astype(str)

# Select for data in Normal Range
Data_Normal = data[data['Date']>date_range[0]]
Data_Normal =  Data_Normal[Data_Normal['Date']<date_range[1]]
```

CFS to Total Volume
Have flow in $\frac{ft^3}{s}$, want $\frac{ft^3}{month}$.
To accomplish do the following:

$$\frac{ft^3}{s} * \frac{60s}{1min} * \frac{60min}{1hr} * \frac{24hr}{1day} * \frac{DaysInMonth}{1month} = [\frac{ft^3}{month}]$$

```
In [107]: # Compute Monthly Discharges in Cubic Feet
          Data_Normal['Volume_ft3'] = Data_Normal['Mean Value [ cfs ]'] \
              * Data_Normal['DaysInMonth'] * 60 * 60 * 24
```

Total Volume to Depth in Inches
To calculate this volume in inches on the watershed:

$$\frac{ft^3}{month} * \frac{1}{WatershedArea} * \frac{12in}{1ft} = [\frac{in}{month}]$$

```
In [78]: # Compute Monthly Discharge in Inches
         Data_Normal['Volume [ in ]'] = Data_Normal['Volume_ft3'] / Area_ft2 * 12
```

Prepare Table

```
In [109]: Months = Data_Normal.drop(columns=['DaysInMonth','Volume_ft3']).groupby('Month')
          Months = Months.mean()

          # Need to reorder the table by month now
          Month_str = Months.reindex(
              index=['January','October','November','December',
                     'February','March','April','May',
                     'June','July','August','September']
          )
          for i in range(0,12):
              Month_str.iloc[i] = Months.iloc[i]
          Month_str = Month_str.reindex(
              ['January','February','March','April',
               'May','June','July','August',
               'September','October','November','December']
          )
          Month_str
```

```
Out[109]:            Mean Value [ cfs ]  Volume [ in ]
          Month
          January              548.5       0.80
          February             495.5       0.66
          March                855.5       1.26
          April               2636.5       3.72
          May                 1251.0       1.83
          June                 579.5       0.82
          July                 420.0       0.61
          August               377.3       0.55
          September            494.4       0.70
          October              859.1       1.25
          November             992.8       1.40
          December             783.8       1.14
```

Part C) Create a table showing the average monthly precipitation (in inches) for the watershed.

Tahquamenon Falls State Park Weather Station (USC00208042) is located approximately 3 miles from the USGS stream gage. The 1981-2010 Precipitation normals in inches for each month are located below.

```
In [113]: months = [
              'January','February','March','April',
              'May','June','July','August',
              'September','October','November','December'
          ]
          precip = [
              3.12, 1.91, 2.16, 2.34,
              2.74, 2.93, 3.04, 3.41,
              3.72, 4.10, 3.27, 3.44
          ]

          Precip_Normal = dict(zip(months,precip))
          Precip_Normal = pd.DataFrame.from_dict(Precip_Normal, orient='index', )
          Precip_Normal = Precip_Normal.rename(
              index=str,
              columns={0:'Precip Normals [ in ]'}
          )
          Precip_Normal
```

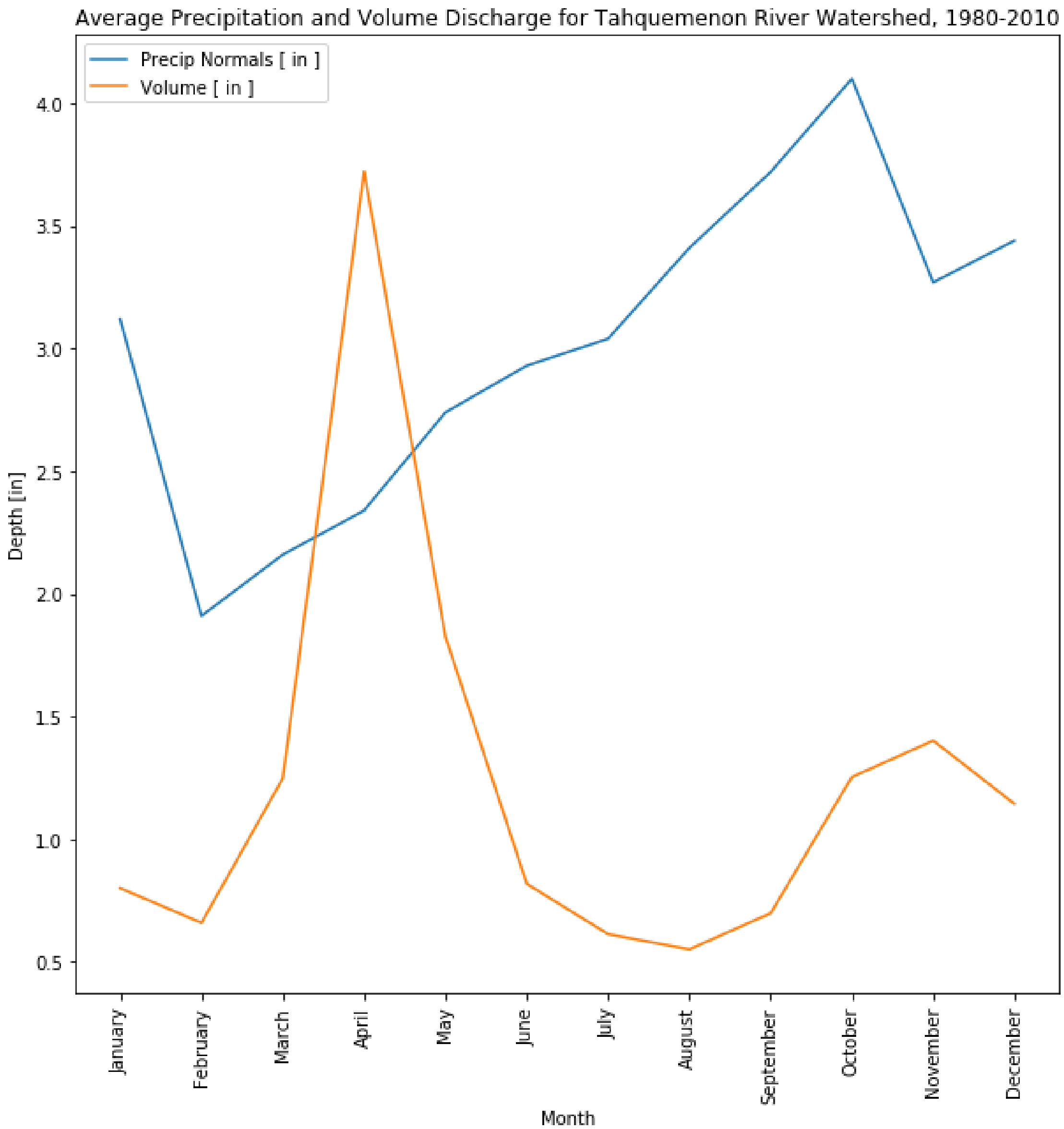
```
Out[113]:            Precip Normals [ in ]
          January                     3.12
          February                    1.91
          March                       2.16
          April                       2.34
          May                         2.74
          June                        2.93
          July                        3.04
          August                      3.41
          September                   3.72
          October                     4.10
          November                    3.27
          December                    3.44
```

Part D) Plot the average monthly precipitation (in inches) and the average monthly discharge (in inches) versus month.

```
In [117]: fig, ax = plt.subplots(figsize=(10,10))

          Precip_Normal.plot(ax=ax,xticks=np.arange(12),legend=True)
          Month_str['Volume [ in ]'].plot(ax=ax,xticks=np.arange(12),legend=True)

          plt.xticks(rotation='vertical')
          plt.ylabel('Depth [in]')
          plt.xlabel('Month')
          plt.title(
              'Average Precipitation and Volume Discharge for Tahquemenon River\
           Watershed, 1980-2010'
          )
          plt.show()
```



Part E) Compute the average annual precipitation (in inches).

From the Tahquemon Falls State Park Station report, **annual precipitation is 36.18 inches**. This is confirmed when taking the sum of the monthly averages.

Part F) Compute the average annual discharge (in inches).

Below is a table of the total volume discharge per year. Taking the average of this table, we find that the **average annual discharge is 14.74 inches.**

```
In [99]: Year = Data_Normal.drop(columns=['DaysInMonth','Volume_ft3']).groupby('Year')
```

```
Year.sum()
```

Out[99]:

```
      Mean Value [ cfs ]  Volume [ in ]
Year
1981             10196.6          14.57
1982             13152.0          18.86
1983             10354.7          14.85
1984             11219.5          16.05
1985             12486.7          17.88
1986              9667.7          13.79
1987              8357.6          11.99
1988             11649.8          16.65
1989              8904.8          12.71
1990             11330.1          16.25
1991              9893.3          14.14
1992             10411.8          14.94
1993             12254.2          17.56
1994              9527.6          13.64
1995              9691.4          13.90
1996             13820.0          19.87
1997             10017.1          14.32
1998              7512.9          10.70
1999              8631.1          12.29
2000              6980.8          10.04
2001             12527.3          17.95
2002             12118.5          17.36
2003              9728.4          13.91
2004             11810.8          16.92
2005              8804.2          12.57
2006              8881.9          12.71
2007              8515.1          12.19
2008             11128.1          15.94
2009             10017.8          14.35
2010              9222.6          13.21
```

In [87]:

```
Year.sum().mean()
```

Out[87]:

```
Mean Value [ cfs ]    10293.8
Volume [ in ]            14.74
dtype: float64
```

Part G) Compute the average annual evapotranspiration (in inches) using the long-term water budget assumption.

The long-term water budget assumption is that precipitation is equal to the sum of the basin's evapotranspiration and the surface (river) discharge, or

$$P = E + Q_0$$

Solving for our evapotranspiration term, E:

$$E = P - Q_0$$

Plugging in our numbers to this equation we find that:

$$E = 36.18 - 14.74$$

$$E = 21.44 inches$$

Part H) Compute the runoff coefficient (i.e., annual discharge as a fraction of precipitation), in percent.

$$C_{runoff} = \frac{Depth_{discharge}}{Depth_{precipitation}} * 100\%$$

$$C_{runoff} = \frac{14.74}{36.18} * 100\%$$

$$C_{runoff} = 41.74\%$$

Considering that this watershed is almost completely forested in a national forest and state park, it makes sense that the number would be lower.

Note: Streamstats isn't available in Michigan.