Baseflow Separation

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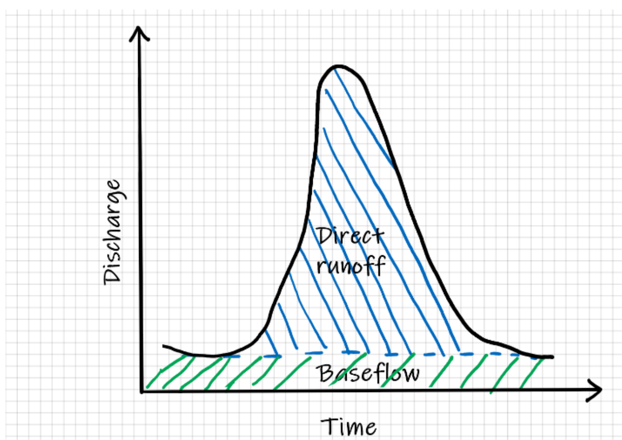
Objective

The main objective of this tutorial is to determine the baseflow so that direct (surface) runoff resulting from the excess rainfall can be obtained. In case of a perennial or continuous flow regime (characteristic of humid climate), a nearly non varying flow occurs even in a rainless period of the year. This delayed flow occurs due to the infiltrated water from a previous rainfall event and groundwater flow in the watershed. In order to study the effect of a current rainfall event, the baseflow component has to be separated from the total flow to get the direct runoff (total flow minus baseflow). A discharge hydrograph representing the direct runoff and baseflow is shown below.



Baseflow Separation Methods

The *first method* used in this tutorial is proposed by Arnold et al (1995). It uses a digital filter technique which was originally used in signal analysis and processing. The equation of the filter is given by:

$$q_t = \beta q_{t-1} + (1+\beta)/2 \times (Q_t - Q_{t-1})$$

where

- q_t - filtered surface runoff (quick response) at the t time step (one day)
- Q - original streamflow
- β- filter parameter (0.925)

The baseflow b_t is given by:

$$b_t = Q_t - q_t$$

In this method, filters are passed over the streamflow data three times (forward, backward and forward) depending on the user's selected estimates of baseflow. The consequence of each pass is that it will reduce the baseflow as a percentage of total flow.

The second method used in the tutorial is proposed by Eckhardt (2005). It is considered as a special separation technique which involve recursive digital filtering of hydrographs. The partition of streamflow into direct runoff and baseflow is represented by:

$$y_k = f_k + b_k$$

where,

- y - total streamflow
- f - direct runoff
- b - baseflow
- k - time step number

The general form is expressed in terms of one parameter filter (α) and BFI_{max}. It is given by:

$$b_k = \frac{(1 - BFI_{max}) \times \alpha \times b_{k-1} + (1 - \alpha) \times BFI_{max} \times y_k}{1 - \alpha \times BFI_{max}}$$

α varies between 0 and 1. BFI_{max} which is the maximum value of baseflow index (long-term ratio of baseflow to total streamflow) is always less than 1. In this tutorial, we will consider α as 0.98 and BFI_{max} as 0.8.

Data Source

For the manual calculation of baseflow separation, the daily streamflow can be obtained from USGS NWIS interface: https://waterdata.usgs.gov/nwis/sw. In this tutorial, you will get this data automatically using python.

You are also provided with a jupyter notebook, baseflow.ipynb, which you will be using to work on this module.

Overview of steps

1. Upload the notebook, baseflow.ipynb in your mygeohub account and open it.
2. First, import the packages/modules required for this tutorial. We need four packages: hydrofunctions (hf), pandas (pd), numpy (np), and pyplot (plt) from matplotlib. You will write the code to import these functions.

```
## Import the packages/modules required for this exercise
import hydrofunctions as hf
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np
```

3. Definition blocks to compute baseflow using the above discussed methods are provided to you. For both definitions, streamflow data will be used as input and the output will be baseflow series. Run these two blocks.
4. Next, you will create a cell that prompts the user to enter the following inputs: (i) USGS station code; (ii) start date (YYYY-MM-DD) and (iii) end date (YYYY-MM-DD) to perform the baseflow separation. The format for both dates including the hyphen must be followed. It would be better to select one year period to get a better view of the hydrograph. You will write the code to define these variables and assign them values. Use the following names: "USGS_StationCode", "Start_Date" and "End_Date" for storing the station number, start data and end date, respectively. Use Wabash River at Lafayette, IN (**03335500**) for a sample analysis period from **2017-01-01** to **2017-01-31**

```
## Input the required USGS Station and Analysis Period

USGS_StationCode=input(str("Enter the USGS Station Code: \n"))
Start_Date=input(str("Enter the starting date (in YYYY-MM-DD format): \n"))
End_Date=input(str("Enter the ending date (in YYYY-MM-DD format): \n"))
```

5. Next, use hydrofuctions to get the data. Use any of the two options suggest in the notebook. You will write the code to get the data.

```
## Obtain the data using hydrofunction from USGS NWIS
## One of the two approaches below may be used to obtain the daily value "dv" of the streamflow

### Approach01
#data = hf.NWIS('USGS_StationCode','dv',period='P365D') # P365D indicates past 365 days

### Approach02 (more useful as discharges for desired period can be obtained)
data = hf.NWIS(USGS_StationCode, 'dv', Start_Date,End_Date)
data.get_data()
```

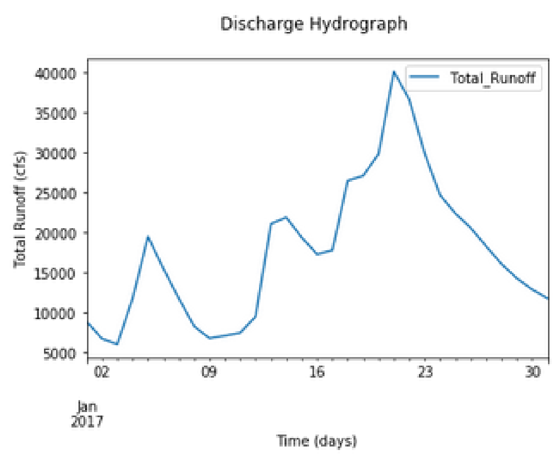
6. Next, check the data by printing the first n rows (default: 5). This is helpful for quickly testing if your object has the right type of data in it. You will write the code to perform this check.

```
print(data.df().head())
print("\n")
```

7. We get the output from the hydrofunction as "class 'function'". The next cell in the notebook stores the data into pandas dataframe to do the manipulations. This coded also drops the column containing the qualifiers, and change the column name of discharge from long name ("USGS:03335500:00060:00003") to short name ("Total_Runoff") for easy handling in the succeeding code.

8. Next, plot the Total Discharge Hydrograph (without baseflow separation) using pyplot. You will have to write the code for this plot.

```
## Plot the discharge hydrograph (without baseflow)
%matplotlib inline
strflow.plot()
plt.xlabel("Time (days)")
plt.ylabel("Total Runoff (cfs)")
plt.title("Discharge Hydrograph \n")
```

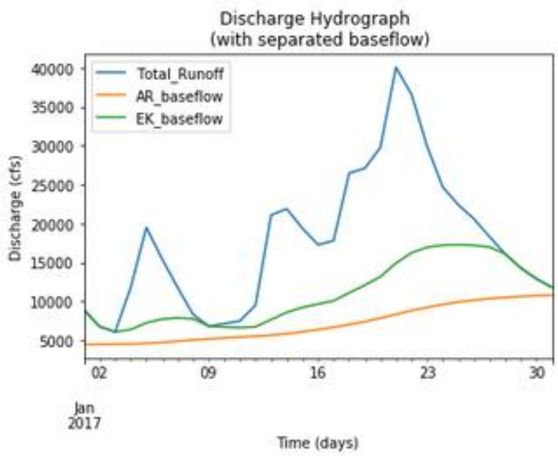


9. Next, use the definition blocks defined earlier (AR_baseflow and EK_baseflow) to separate the baseflow from the total runoff. You will also print the simple sum to check the results. The mean value of baseflow from the two methods for Wabash River at Lafayette, IN (03335500) for a sample analysis period from 2017-01-01 to 2017-01-31 are 7121.417 ft3/s (AR_baseflow) and 10941.493 ft3/s (EK_baseflow).

```
In [ ]: strflow['AR_baseflow'] = AR_baseflow(strflow['AR_baseflow'])
        strflow['EK_baseflow'] = EK_baseflow(strflow['EK_baseflow'])
        print(sum(strflow['AR_baseflow'])/len(strflow['AR_baseflow']))
        print(sum(strflow['EK_baseflow'])/len(strflow['AR_baseflow']))
```

10. After calculating the baseflow using both the methods, plot the discharge hydrograph showing the separated baseflow from two methods.

```
## Plot the discharge hydrograph (with baseflow)
strflow.plot()
plt.xlabel("Time (days)")
plt.ylabel("Discharge (cfs)")
plt.title("Discharge Hydrograph \n (with separated baseflow)")
```



Ok, you have completed the tutorial!

References

- J.G. Arnold and P.M Allen. Automated methods for estimating BFlow and groundwater recharge from streamflow records. Journal of the Americam Water Resources Association vol 35(2) (April 1999): 411-424.
- J.G. Arnold, P.M. Allen, R. Muttiah, and G. Bernhardt, Automated base flow separation and recession analysis techniques. Ground Water vol 33(6): 1010-1018.
- Eckhardt, Klaus., How to construct recursive digital filters for baseflow separation, Hydrological Processes: An International Journal 19, no. 2 (2005): 507-515

Homework

1. Separate baseflow by using the two methods for Cedar Creek (04180000) from March 01. 2019 to May 31, 2019.
2. Plot the total discharge hydrograph for Cedar Creek.
3. Plot the total discharge hydrograph showing and two two baseflow curves obtained using the two different methods.
4. Compute the mean baseflow value (cfs) using the two methods
5. Write code to compute the total streamflow volume, direct runoff volume and baseflow volume for the specified time period in cubic meter.

Turn in a pdf document with items 2-5 by 5 pm on April 02, 2020.