Baseflow Recession

Overview of baseflow recession

Do rivers have a characteristic decline in baseflow? In this project, you will investigate this question by analyzing several storm runoff events as captured by a stream gage (use https://waterdata.usgs.gov/nwis to find a gage), and by comparing gages from two completely different locations in the US. Think about why responses might be the same at a single gage site, and what could contribute to variability in base flow recession “constants”, or rather, the exponent and coefficient in the exponential decay curves fit to the data.

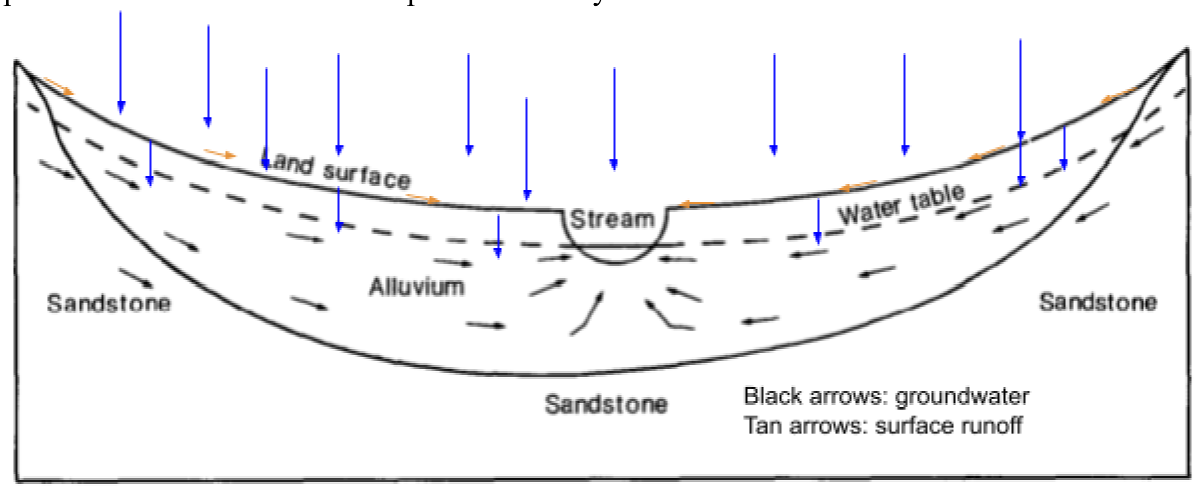

Figure 1. Generalized groundwater flow to a stream, showing the water table, and two geologic units--alluvium and sandstone. (modified from Fig. 11, Bingham, 1986).

In Figure 1, a simple model for precipitation-runoff-groundwater flow provides a framework for understanding streamflow. The groundwater flow into the stream is known as baseflow, and it’s what keeps streams flowing between rain events. Notice that the model has a shallow rock type, called alluvium, and a deeper rock type, called sandstone. Typically, alluvium consists of sand and gravel. Sandstone is usually cemented and has a lower porosity than alluvium, so it likely has a smaller storage volume for groundwater, as well as having a slower flow rate of groundwater. It’s within this backdrop that you should think about the way streamflow declines over time.

The rate of streamflow recession during base flow is controlled by the hydraulic characteristics of the aquifers. The streamflow-recession index can be estimated by the equation (Rorabaugh and Simons, 1966; Bingham 1986):

$$t = a^2 \frac{S}{T}$$

Where

- t= time in days per log cycle,
- a= distance from the stream to the hydrologic divide,
- S= storage coefficient of the aquifer or aquifers, and

T = transmissivity of the aquifer or aquifers

In this equation, the time scale for the stream to drop by a factor of 10 is related to watershed area, groundwater storage size and flow rate of groundwater. As watershed area increases, the decline in flow takes longer. As groundwater storage volume increases, the decline in flow takes longer. As flow rate and thickness of the aquifer (transmissivity) increases, the decline in streamflow happens more rapidly. These are useful general relationships to keep in mind when analyzing your streams.

There are more considerations. Frequency of rainfall, intensity of rainfall, and evapotranspiration effectiveness; water withdrawals for agriculture or municipal water supplies; storage of surface water for hydropower flood mitigation all play a role in the movement of water in a landscape, and can complicate the interpretation of baseflow declines.

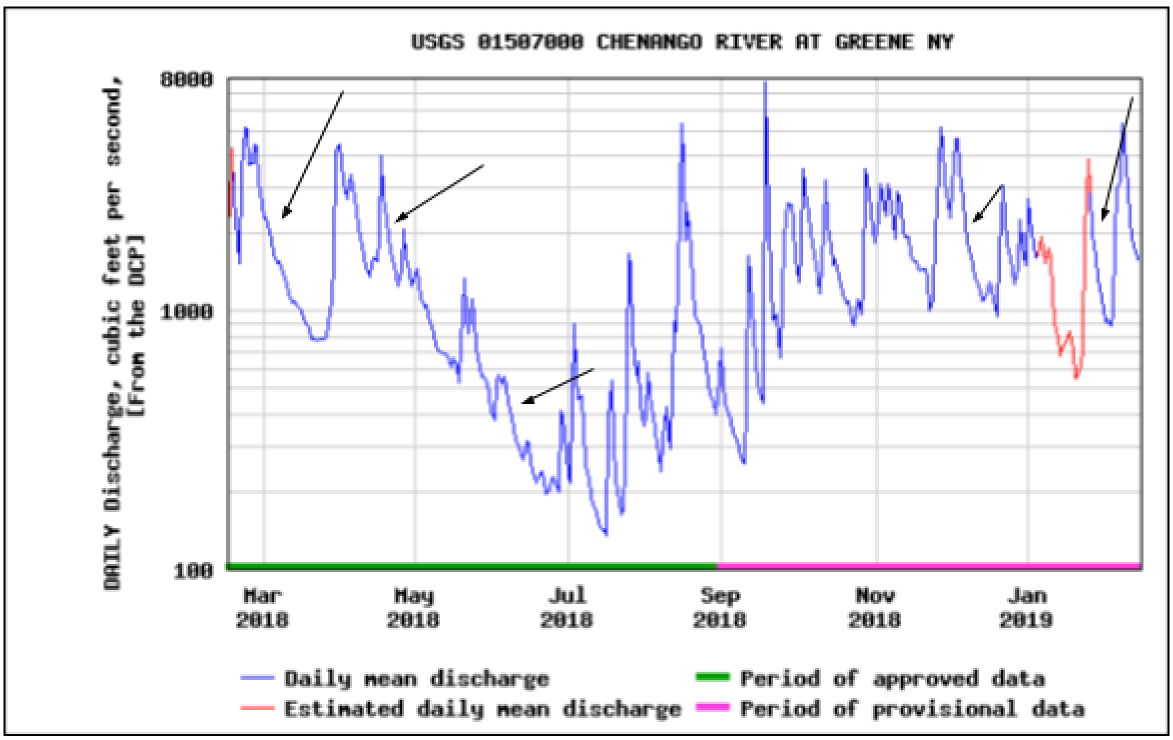

Figure 2. Daily discharge from March 2018 to February 2019 for the Chenango River at Greene, NY. Arrows point to recessions which appear to be continuous, and thus suitable for this analysis.

So, this lab introduces you to the richness contained in streamflow records. You will start by isolating streamflow data for single precipitation events (see Fig. 2 above for suitable events). You will then fit an exponential curve to each decline, determine the equation, and correlation coefficient. Once you have an ideal model for baseflow recession, you can also start looking for cases where the model doesn't fit the data. These mismatches can be quite instructive, as they force us to look for physical mechanisms that can explain model failure. This exercise will also draw us into the subsurface, where we will spend the remainder of the course--trying to understand how groundwater works.

Streamflow Modeling

The following exercise will help you build skills in analyzing time series data in a spreadsheet. It should also open your eyes to the variation in streamflow, both at a single location over a year, and between locations across the US. Data have been gathered from 6 locations across the US. Your task is to compare stream responses after precipitation events for any two of these locations.

1. Open the spreadsheet with streamflow data. Or, go to the USGS site for stream data, NWIS Mapper. Here are some tutorials to help you extract data from the stream gage data record. Part 1 and Part 2.
2. Create a plot of discharge vs time. If you are using NWIS, select the option to *Graph (with up to 3) parms*. You can easily spot recessions that look suitable, isolate the time period of interest, then download data for just the streamflow record during the recession of interest. See Fig. 2 above for a hydrograph with suitable types of recessions. They need to appear to be continuously declining.
3. Create a column of days since peak flow. Do this with a formula which subtracts each subsequent date from the date just after peak flow. The formula is "=A2-A$2", where column A is assumed to have date data. Note that the $ sign in a formula fixes the row or column as an absolute reference, so as formula is copied down, it computes the time (usually days) since the starting date.
4. Make a chart (choose *scatter*) with the x-values as "Days since peak" and the discharge as y-values (often called series in a spreadsheet). Fit an exponential trendline to the baseflow recession. Be sure to "show the equation" for the trendline, and include the R^2 value. The equation should take the form of $Q(t) = Q_0 e^{-kt}$.
5. Isolate stream flow for 4 to 5 peaks and declines. Label each flow by the date of its peak. Plot all of these recessions on the same chart. To highlight differences, change the vertical axis so that it is in Log scale. You should see straight lines. Change the range on the x-axis so that all of the recession trend lines intersect the x-axis.
6. Show the equations for each, and extract the parameters (Q_0 and k) for each, and place them in a table.

River	**Peak flow date**	**Exponent**	**Coefficient**	**R^2**

7. Is the decay constant truly a constant between events? What physical conditions could help explain the variability or lack thereof in the decay constant?
8. How well does your regression model fit the data?
9. Can you improve the fit by eliminating data from the start of the data you selected? How might you explain an improved correlation if you neglected a few of the days close to the peak?
10. What about at the other end--can you improve the fit by neglecting days at the end of the regression? Are there cases where streamflow ceases to decline? Why might this be the case? Come up with some potential reasons for continuous decline, or for sustained low flow, if you encounter this.
11. How long would it take for your stream to dry up? The equation can help us answer this, sort of. Since it's an exponential decay equation, the stream will never quite dry up! As a first pass, find the time until the discharge is 1 cubic foot per second. An alternative is to report the time required for the flow to be equal to 1/10 of Q_0. This should be the same value as $t$in Rorabaugh's equation (the days per log cycle of recession) on page 1 above. Note that one can rearrange the exponential decay equation to solve for time:

$$Q(t) = Q_0 e^{-kt} \Rightarrow t = ln\left(\frac{Q(t)}{Q_0}\right)\frac{1}{-k}.$$

So, for $Q(t) = 1\ cfs,\ t = ln\left(\frac{1}{Q_0}\right)\frac{1}{-k}$

and for $Q(t) = 0.1Q_0,\ t = \frac{ln(0.1)}{-k}$

What to Hand In

A. Your spreadsheet with calculations and charts (or a link to your spreadsheet), submitted to the assignment on Blackboard.
B. A word document which provides an overview of the exercise, your chart and table of recession parameters, a discussion which addresses questions 7 to 10, an estimate for how long it would take the stream to dry up, and the significance of your time-to-dry-river.

Your report will be evaluated based on the rubric below.

Rubric Score	% Weight for report element	Report element
0-4	30	The chart of baseflow recessions. The chart must have a meaningful title, labeled axes with units, and a legend which shows recession equations.
0-4	20	Table of recession equation parameters

0-4	10	Correct estimates of time-to-dry
0-4	40	Analysis and discussion of streamflow recession results and implications

Rubric Scores for Projects

A rubric identifies key parts of an exercise which will be evaluated, or ranked, based on a scale from 0 = no credit to 4 = excellent. Guidelines for the ranking are:

0 = No Credit. This applies to an effort that would not receive a passing mark (below D-). There might be information provided, but the information is seriously flawed and the method of portraying that information (graphs, charts, maps, etc) obscures the true character of the subject material. Note that a failing mark for a set of right or wrong questions (calculation or multiple choice type questions) usually means that you have less than 60% of the answers correct.

1 = Partial credit. This applies to an effort that would receive a passing mark in the D range, and while passing, still has significant problems. Some necessary information is conveyed, but is missing pertinent details. The method of portrayal (graphs, charts, maps, etc.) is sloppy, incomplete, may be partially wrong, and lacks pertinent details. The analysis of the data, if one is asked for, is shallow and cursory. On a University % scale, you would have 60-70% of the answer correct.

2 = Fair, approaching competence. This applies to an effort that would receive a mark in the C range. The effort provides necessary and sufficient content to characterize the information, but it lacks a thorough analysis of the data, may not provide complete background information and needs improvement. Organization and portrayal of the information (graphs, charts, maps, etc.) could be improved. Titles and captions while present might be incomplete or insufficiently detailed. On a University % scale, you would have 70-80% of the answer correct.

3 = Good, competent effort. This applies to an effort that would receive a mark in the B range. The effort provides necessary content in a meaningful context, an adequate analysis in a clear fashion, and a useful portrayal of information (graphs, charts, maps, etc.) with titles and captions that adequately characterize the graphic.On a University % scale, you would have 80-90% of the answer correct.

4 = Excellent, exceeds expectations. This applies to an effort that would receive a mark in the A range. The effort displays clear, concise, accurate information that is organized and presented well, portrays the information clearly (graphs, charts, maps, etc), and provides a thorough and insightful analysis of the results. On a University % scale, you would have 90-100% of the answer correct.

References

The following documents provide background information on major influences on baseflow recessions, as well as descriptions of how working hydrologists have performed baseflow analyses in the past.

Bingham R. H, Regionalization of low-flow characteristics of Tennessee streams U.S. Geological Survey, Water-Resources Investigations Report 85-4191, 1986. https://pubs.usgs.gov/wri/wri85-4191/pdf/wrir_85-4191_a.pdf

Rorabaugh M.I., and W. D. Simons, Exploration of methods of relating ground water to surface water, Columbia River basin-Second phase, USGS Open-File Report 66-117, https://doi.org/10.3133/ofr66117.

Tallaksen, L.M. 1995. "A Review Of Baseflow Recession Analysis". Journal Of Hydrology 165 (1-4): 349-370. Elsevier BV. doi:10.1016/0022-1694(94)02540-r. https://www.sciencedirect.com/science/article/pii/002216949402540R