   

**Project EDDIE: STREAM DISCHARGE**

**Instructor’s Manual**

This module was initially developed by Bader, N.E., T. Meixner, C.A. Gibson, C.M. O’Reilly, and D.N. Castendyk. 26 June 2015. Project EDDIE: Stream Discharge. Project EDDIE Module 5, Version 2. <http://cemast.illinoisstate.edu/data-for-students/modules/stream-discharge.shtml>. Module development was supported by NSF DEB 1245707.

Overall description:

Stream discharge is a fundamental measure of water supply in stream systems. Low discharge may cause problems with water supply and fish passage, while high discharge may mean flooding. In this module, students explore real-time stream discharge data available from the United States Geologic Survey. Students use this data to assess changes in discharge with time, calculate flood frequency, and see the effects of urbanization and flood control.

Pedagogical connections:

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| **Phase** | **Functions** | **Examples from this module** |
| Engagement | Introduce topic, gauge students’ preconceptions, call up students’ schemata | Pre-class readings, reflection questions, short introductory lecture, in-class discussions of readings |
| Exploration | Engage students in inquiry, scientific discourse, evidence-based reasoning | Students follow as instructor demonstrates data retrieval and analysis, then repeat exercise independently for another location. |
| Explanation | Engage students in scientific discourse, evidence-based reasoning | Visualization of the data, addressing questions posed in handout, in-class discussion. |
| Expansion | Broaden students’ schemata to account for more observations | Incorporation of additional sites. Assessing changes in flood frequency due to urbanization and flood control |
| Evaluation | Assess students’ understanding, formatively and summatively | Visually present and explain the results of the analysis |

# Learning objectives:

* Students will download, organize and analyze streamflow data.
* Students will use data to compare short-term and long-term discharge variability, and quantify climate change impacts on water quantity in their region.
* Students will calculate flood frequency from peak discharge data, and will calculate the effects of urbanization and flood control on flood frequency.
* Students will develop an understanding of the following scientific concepts:
  + Stream discharge
  + Variability and trends in time series data
  + Peak flow and flood events
  + Flood probability and recurrence interval
  + Effects of urbanization on discharge events
* Students will develop an understanding of the following statistical concepts:
  + Detecting variation and trends on short and long timescales
  + R-squared
  + Peak event probability

## How to use this module:

This is probably too much material to cover in a three-hour lab period. You will need to select components of the modules based on your interests and the skill level of your students. For example, an introductory course may do a quick lab with just A and B, whereas an upper-level course might skip A and go straight to B and C. It is also possible to do different activities on different days, or to assign some components as homework.

We have set aside some data for Activities A and B so that you could run the activities if you lost network access for some reason. However, we intend for the instructor and students to access up-to-date data directly from the websites,, especially because this allows the students to explore and incorporate their own sites independently. Some parts of the activities are impossible without access to this online data.

## Quick overview of the activities in this module

* *Activity A*: Introduction to variability in real stream data, using data from the USGS Hydrologic Benchmark Network
* *Activity B*: Identifying changes in discharge over time, using data from the USGS Hydrologic Benchmark Network
* *Activity C*: Calculating flood frequency from peak discharge data, and assessing the effects of urbanization and flood control on flood frequency, using data from the USGS real-time streamflow network

## Workflow for this module:

1. Select and assign readings prior to the day of the activity.
2. Introduce the activity using the included Powerpoint and the notes below. Make sure that the importance of stream discharge comes across.
3. Give the students the handout.
4. Students explore the USGS Hydrologic Benchmark Network (HBN) website and make some graphs as a way of thinking about variability (*Activity A*)
5. Either provide data to students or help students download data from the HBN website. Guide the students through the plotting of winter and summer data from the Neversink River in New York. In the second part, students will be repeating these steps for a location of their choice (*Activity B*).
6. Students use the larger USGS stream monitoring network to calculate flood probability and recurrence interval for the Mississippi River at St Louis *(Activity C*).
7. As a possible take-home assignment, or in class if time allows, students can use their skills to estimate their own flood risk (*Activity C*).

## Potential pre-class readings

There are probably more resources here than you will want to assign; choose readings that will complement the activities you will use.

1. National Hydrologic Benchmark Data Fact Sheet- Murdoch, P. S., McHale, M. R., Mast, M. A., & Clow, D. W. (2005). The US Geological Survey Hydrologic Benchmark Network: US Geological Survey Fact Sheet 2005–3135, 6 p. Also available at <http://ny.water.usgs.gov/pubs/fs/fs20053135/>. The HBN fact sheet is an introduction to the USGS network of relatively undisturbed sites that are intensively monitored. (*Activities A and B*)
2. National Climate Assessment Report for your region of interest <http://nca2014.globalchange.gov/> (NE US which goes with Neversink case example found at - <http://nca2014.globalchange.gov/report/regions/northeast>) The NCAR report is useful for thinking about how climate change will affect particular regions of the world (*Activity B*)
3. Lins, H.F., and J.R. Slack. 1999. Streamflow trends in the United States. *Geophysical Research Letters*, 26 (2), 227-230. This is an optional reading, perhaps for the instructor. It discusses the results of a study that is similar to what the students will attempt in *Activity B*.
4. Campbell, J.L., C.T. Driscoll, A. Pourmokhtarian, and K. Hayhoe. 2011. Streamflow responses to past and projected future changes in climate at the Hubbard Brook Experimental Forest, New Hampshire, United States, *Water Resour. Res*., 47, W02514, doi:10.1029/2010WR009438. This paper describes the results of a study of discharge through time in Hubbard Brook, similar to the *Activity B*.
5. Holmes, R.R., Jr., and K. Dinicola. 2010.[100-Year flood–it's all about chance](http://pubs.usgs.gov/gip/106/pdf/100-year-flood-handout-042610.pdf): U.S. Geological Survey General Information Product 106, 1 p. This is an introduction to thinking about flood frequency and recurrence interval (*Activity C*). brochure: <http://pubs.usgs.gov/gip/106/pdf/100-year-flood-handout-042610.pdf>, one-page version: <http://pubs.usgs.gov/gip/106/pdf/100-year-flood_041210web.pdf>
6. Konrad, C.P. 2003. Effects of urban development on floods. USGS Fact Sheet FS-076-03. This short reading describes the increase in flashiness associated with urbanization, as students will assess at the end of *Activity C*. <http://pubs.usgs.gov/fs/fs07603/>
7. Baker, D.B., R.P. Richards, T.T. Loftus, and J.W. Kramer, 2004. A new flashiness index: Characteristics and applications to midwestern rivers and streams. *Journal of the American Water Resources Association* 40(2): 503-522. <http://onlinelibrary.wiley.com/doi/10.1111/j.1752-1688.2004.tb01046.x/abstract>. This paper is an optional extension to *Activity C* for advanced students. Students can calculate the Baker-Richards flashiness index for streams in the USGS network using Excel.
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## Presentation

The purpose of this assignment is to expose students to available USGS gauging station data and have them manipulate that data with guiding questions of changing streamflow and flood frequency. To introduce this subject, we have included a Powerpoint that illustrates key concepts. Instructors can pick and choose from the PowerPoint as needed for their classroom. Following is an overview of the slides.

### Part 1: What is discharge?

* [Photo of a stream] How would you describe the quantity of water in this stream? You could measure the volume, but that does not get to the whole story, because new water is coming from upstream. Discharge is the volume of water flowing past a point on the bank per unit time and describes the rate at which new water becomes available in the system. Discharge is usually given the symbol Q and is measured in cubic meters per second or cubic feet per second (cfs).

### Part 2: The importance of discharge

* [Pulse flow on the Colorado River] The lower Colorado has been dry for decades due to extractions for irrigation. Low discharge means that little water is available for consumptive uses such as irrigation. Very low discharge blocks the passage of anadromous fish.
* [Flood on the Ganges, flood on the Mississippi] Extremely high discharge means flooding!

### Part 3: Measuring discharge

* [Two ways to measure discharge] Note that it is exactly the same to measure mean velocity through a cross sectional area, which is much easier to measure than volume per time.
* [Measuring discharge with a velocity meter] This man is holding a current meter on a stick. He is measuring velocity at different locations (from which he will estimate mean velocity) and depth at different locations (from which he will estimate cross sectional area). This is labor intensive!
* [Staff gage] Something that is even easier to measure than discharge is **gage height** or **stage**. At its simplest, a “staff gage” is nothing more than a ruler attached to a permanent structure such as a bridge abutment. Gage height can be read off of the ruler. Gage height monotonically increases as discharge increases, but the exact relationship is non-linear and depends on the geometry of the stream channel. Therefore, gage height cannot be converted into discharge without first determining this relationship.
* [Rating curve] The relationship between gage height and discharge is called the **rating curve**. For every point on the rating curve, someone had to note gage height and had to get into the stream to measure discharge!
* [Gaging station] Once the rating curve is developed, we can continue to measure gage height and translate that number into discharge. Gaging stations such as this one on Mill Creek in Walla Walla are part of the USGS real-time streamflow network. This station automatically uploads stream discharge data (calculated from gage height) to the network.

### Part 4: What affects discharge

* [Hydrograph] A **hydrograph** plots discharge over time. Notice in this hydrograph that the river reached **flood stage** (the gage height at which water spills out of its banks and flooding occurs). A flood can be a dangerous event. Notice this characteristic shape of the storm hydrograph. (Also note, the y axis is in gage height but could also be in discharge, depending on the hydrograph.)
* [Rain and hydrograph] Floods are caused by rain falling or snow melting upstream. More rain intensity (rain per unit time) means higher peak discharge, all other things being equal. How will changes in climate affect discharge?
* [Infiltration and runoff] The importance of infiltration: water enters streams via many paths: direct runoff, and infiltration to groundwater. Pavement and other byproducts of urbanization shunt flow to runoff, making the rainwater enter the stream all at once, instead of gradually. This makes the peak discharge higher.
* [Newaukum Creek gaging station] This aerial imagery of the location of the Newaukum Creek station shows the generally rural setting of the creek, which flows in from the south.
* [Mercer Creek gaging station] In contrast, the Mercer Creek station is just southeast of Bellevue, Washington, part of the greater Seattle urban region. This watershed has experienced rapid urbanization since the 1970s.
* (Remaining optional slides of Neversink River data may be useful during Activities A and B.)

## Activity A: Variability in real stream data

Activity A is designed to introduce the Hydrologic Benchmark Network and its data. After this activity, students will understand how to access HBN data on the web; they will understand that streamflow is variable, and that it varies seasonally. For this stage, students will not need to download data; instead, they can view data using the built-in graphing capabilities of the USGS website. Students will begin to think about variability in discharge on different timescales (weekly vs. monthly). If your students have a good grasp of these concepts already, you may wish to skip Activity A in order to allow more time for other activities.

### Notes on questions for Activity A:

* Question 1: This is a great place to think about what variability means. We all know what variability looks like, but quantifying it may be less obvious for students.
* Question 2: Notice that temperature time series has a strong diurnal component, which implies that solar energy is responsible for most of the observed temperature changes. (The relative proportion of groundwater and surface water can also affect temperature.)
* Question 3: *This is a good question for discussion* (especially as it would be difficult to grade!).

## Activity B: Changes in discharge over time

In Activity B, students will learn about how to plot variability through time. They will also make some (fairly rudimentary) plots in Excel. In the first part of the exercise, the instructor may wish to provide the data to students rather than having everyone download the same dataset. However, later parts of this activity require that the students have access to the online datasets, so it is recommended that you have students practice accessing the data themselves.

Students begin by analyzing a particular dataset (the Neversink River in New York). The instructor may wish to walk students through this part of the analysis. After this preliminary analysis is complete, students will repeat the exercise on their own with a new watershed of their choice. After everyone has analyzed a new region, the instructor can lead a discussion to summarize the students’ findings.

### Notes on questions for Activity B, Part 1 (the Neversink River section)

* Students are first asked to plot February mean discharges over the period of record. They are asked a few questions to make sure they are closely examining the graph. They should note that the highest mean February discharge of 747.3 cfs occurred in 1981.
* Students are then asked to make a similar plot for August, and compare them. They should notice that most discharges in August are in the neighborhood of 50-100 cfs, compared to February discharges between 100 and 200 cfs. The highest discharges are also higher for February than for August.
* Finally, students plot the trendlines and are asked to assess the trends. Each chart has a slight increasing trend, but students should note that the R-squared is very small, meaning that most of the variance in the data cannot be explained by the trendline. (Unfortunately, Excel does not show the p-value for these relationships.)

Discussion questions:

1. *How many watersheds seem to have decreasing mean discharge through time? How many are increasing?*
2. *What are some possible explanations for the changes you observe?*
3. *Is February different from August? How?*

Suggested assignments:some of the datasets from different geographic areas are different, as you might expect. Ask students to develop some hypotheses to account for their observations. For each explanation, ask students to consider ways they might test the hypothesis.

## Activity C: Peak discharges and flood hazard

In this activity, students will transition from thinking about mean discharge to thinking about peak discharge, and will learn how to predict simple flood probability and recurrence interval using USGS data. In Excel, students will learn to use formulas, in addition to practicing their plotting skills from the previous exercise.

Be aware that the basic analysis takes a bit longer than the Neversink River exercise in the last activity. However, it has the same structure: first, the students are guided in a “cook-book” exercise guiding them through the analytical process of calculating flood frequency. In the second part, they apply these skills to questions about urbanization and changes in flood frequency. However, unlike Activity B, the datasets are predefined so that students will be able to answer interesting questions.

If you have advanced students, you may want to have them calculate a flashiness index for each stream using the Richards-Baker calculation, detailed in the Baker et al. (2004) paper listed above.

### Notes on questions for Activity C:

* Question 1. The maximum discharge on record was a discharge of 1,080,000 cfs (about 30,600 cubic meters per second) on August 1 of 1993. The gage height was 49.58 feet (15.11 m) during this event.
* Question 2. The mean peak discharge (calculated from 1933 through 2014) was about 527,100 cfs (about 15,000 cubic meters per second), with a standard deviation of about 172,000 cfs (about 4870 cubic meters per second). This puts the highest peak discharge at (1,080,000 - 527,100)/172,000 = about 3.2 standard deviations above the mean.
* Question 3. There is a 1% chance of a "100-year flood" each year. This gives you no information about when this flood will occur.
* Question 4. Recurrence interval incorrectly implies that current water conditions are somehow governed by events in the distant past, e.g. that a 100-year flood last year means that you have 99 years until the next one. Probability correctly shows that the probability of next year's flood is unrelated to when the previous flood occurred.
* Question 5. Students may need some help reading values off of a logarithmic graph. The 50-year flood should be at about 900,000 cfs. The 100-year flood is more difficult to establish because it is extrapolated, not interpolated. Based on the trajectory of your points, the 100-year event should be somewhere between 1,080,000 cfs (the largest event on our record, the "82-year event"), and 1,500,000 cfs. Note that plotting a trendline is NOT what you want to do here. There is no reason that flood probability should fit to a trendline.
* **Urbanization analysis**
  + Mercer Creek until 1977: 315-340 cfs for 10-year flood
  + Mercer Creek after 1977: 703-754 cfs for 10-year flood
    - Change: 107-140% increase
  + Newaukum Creek until 1977: 1320 cfs for 10-year flood
  + Newaukum Creek after 1977: 1230-1280 cfs for 10-year flood
    - Change: 3-7% decrease
* **Flood control analysis**
  + Green River until 1961: 20,300-22,000 cfs for 10-year flood
  + Green River after 1961: 11,400-11,500 cfs for 10-year flood
    - Change: 43-48% decrease
  + Note: it turns out that there are only 18 data points in the Newaukum Creek dataset if you take only data up to 1961. Thus, it is better to go with the Newaukum Creek calculations you made above.