TIEE

Teaching Issues and Experiments in Ecology - Volume 1, January 2004

ISSUES – DATA SET

Hubbard Brook Streamflow Response to Deforestation

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Weir for measuring stream flow © Hubbard Brook Experimental Forest {www.hubbardbrook.org}

THE ECOLOGICAL QUESTION:
What are the short- and long-term effects of a whole-watershed deforestation experiment on streamflow?

ECOLOGICAL CONTENT:
small watershed concept; watershed response to major disturbance (i.e., deforestation); forest hydrology; importance of long-term research in ecology; experimental design.

WHAT STUDENTS DO:
Students will use MS Excel file or hard copy of data to graph short- and long-term streamflow response to a whole-watershed manipulation. Students compare results to baseline data, draw conclusions about hypotheses, and consider implications of long-term research.

SKILLS:
Using a computer spreadsheet to make simple graphs; interpreting long-term data; critical thinking; hypothesis development and evaluation.

ASSESSABLE OUTCOMES:
Graphs from spreadsheet data; written interpretation of data; written analysis of hypothesis results; poster presentation of results; written discussion of short- and long-term ecological research as shown in this experiment.

SOURCE: Hubbard Brook Experimental Forest LTER archive (www.hubbardbrook.org)

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OVERVIEW OF THE ECOLOGICAL BACKGROUND

History:

The USDA Forest Service established the Hubbard Brook Experimental Forest (HBEF) in 1955 as a hydrologic research center. In the early years, scientists focused largely on assessing the impacts of forest management on water yield, water quality, and flood flow. In 1960, additional scientists become involved, and the Hubbard Brook Ecosystem Study (HBES) began. HBES scientists developed the small watershed concept, which at the time was a new approach to ecosystem science in which scientists studied and manipulated entire watersheds to learn more about elemental flux and cycling.

The Hubbard Brook flows through New Hampshire's White Mountain National Forest and drains a range of small mountains. The tributaries of Hubbard Brook form a set of discrete watersheds, separated by mountain ridges. Six of the south-facing watersheds are similar in size (~10-40 hectares), have relatively uniform characteristics (e.g., soils, vegetation, geology, atmospheric deposition), are lined with watertight bedrock and glacial till, and are representative of the surrounding northern hardwood forest that comprises much of the northeastern United States and Canada. The uniformity allows for comparisons to be made between watersheds, the watertight bedrock makes quantitative hydrologic and elemental budgets possible, and the similarity to surrounding ecosystems allows for extrapolations of results to a broader area. For these reasons as well as many logistical ones (e.g., ownership and administrative control), these watersheds are ideal for conducting long-term ecosystem experiments.

In fact, experimental manipulation of whole watersheds has long been a focus of research activities at the Hubbard Brook Experimental Forest. By establishing two reference watersheds and then comparing short- and long-term responses to manipulations of the four adjacent treatment watersheds, HBEF scientists have been able to obtain quantitative information on relevant environmental issues, test research hypotheses, and develop thorough knowledge of ecosystem patterns and processes.

The first whole-watershed experiment (1965) is the focus of this activity, and involved the deforestation of "Watershed 2" to examine hydrologic and elemental watershed output. Though they are not considered in this activity, three other watersheds have also been manipulated at the HBEF. The second manipulation, beginning in 1970, examined the effects of strip-cutting on forest processes, water yields, and elemental budgets. In the early 1980s, researchers clear-cut an entire watershed to examine how commercial logging affected watershed processes. More recently, calcium has been added to an entire watershed in an experiment examining long-term effects of acid deposition on northern hardwood forests. Scientists at the HBEF continue to monitor these watershed experiments, conduct hundreds of additional experiments and long-term monitoring efforts, and plan for future watershed manipulations on north-facing slopes.

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The Watershed 2 Experiment:

As the HBES was first getting underway, the northeastern states were experiencing a drought and many communities were suffering from water shortages. Considering the role transpiration plays in forest ecosystem water budgets, hydrologists and forest managers were curious about the effects deforestation would have on downstream water supplies.

One of their specific hypotheses was that cutting down trees would lead to increased streamflow and corresponding increases in downstream reservoirs. At the same time, cooperating ecosystem scientists were interested in studying how entire watersheds respond to major disturbances. Combining their interests, scientists designed an experiment in which an entire watershed would be deforested. The team of scientists involved would then study streamflow, element and nutrient cycling, and soil and vegetation responses.

The experiment began in December 1965, as all trees in experimental Watershed 2 were cut and left on top of the snow (to minimize disturbance). In the summers of 1966, 1967, and 1968, two herbicides were applied to the entire watershed to prevent the regrowth of any vegetation. Applying the herbicides allowed hydrologists to answer the water flow hypothesis discussed above and enabled collaborating scientists to study element cycling. Scientists believe that the herbicides were added in such low concentrations that it did not negatively affect organisms in the watershed or downstream.

In this activity, students will determine whether streamflow results support or refute the hypothesis that deforestation leads to increased streamflow. To do so, they will examine short- and long-term streamflow data from Watershed 2 and Watershed 3 (reference). Streamflow has been measured constantly in these watersheds since stream weirs were installed in the late 1950s.

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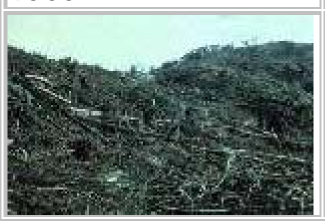
Archival Photos (note: visit the TIEE website and to see these images full size):

Figure 1. Stream weir in the Hubbard Brook Experimental Forest.	
Figure 2. Aerial view of Watershed 2 taken in the early 1970's	
Figure 3. Helicopter herbicide application to Watershed 2 in summer following deforestation. Reference Watershed 3 is in the background.	

<table>
<tr><td colspan="4">Figures 4A-D. Series of four photos taken near the top of Watershed 2. All photos were taken at the same point, looking in the same direction in:</td></tr>
<tr><td>1969</td><td>1970</td><td>1971</td><td>1972</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
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Long Term Ecological Research at the Hubbard Brook Experimental Forest:

In 1980, the National Science Foundation established the Long Term Ecological Research network (LTER) to support research on long-term ecological phenomena in the United States. Since that time, the LTER network has grown to 24 sites and over 1,100 scientists, graduate students, and research technicians. The sites represent several different biomes and are located across the United States and Antarctica. The Hubbard Brook Experimental Forest joined the network in 1987, with an ongoing objective to develop a better understanding of the response of northern hardwood forest ecosystems to large-scale disturbances such as deforestation or acidic deposition.

Although Hubbard Brook and the other sites have their own unique interests, as LTER sites they all focus in part on five core research topics. Scientists at the central office help coordinate these research activities, encourage inter-site collaborations and synthesis of results, and strive to meet the LTER central mission. This activity demonstrates the importance of long-term data collection and the subsequent significance of the LTER network. For more information, visit the LTER website at www.lternet.edu.

LTER Core Research Topics:

1. Pattern and control of primary production;
2. Spatial and temporal distribution of populations selected to represent trophic structures;
3. Pattern and control of organic matter accumulation and decomposition in surface layers and sediments;
4. Patterns of inorganic inputs and movements of nutrients through soils, groundwater and surface waters; and
5. Patterns and frequency of disturbances.

LTER Mission:

1. Understand ecological phenomena over long temporal and spatial scales;
2. Create a legacy of well-designed and document long-term experiments and observations for future generations;
3. Conduct major synthetic and theoretical efforts; and
4. Provide information for the identification and solution of ecological problems.

References:

Hornbeck, J. W., M. B. Adams, E. S. Corbett, E. S. Verry, J. A. Lynch. 1993. Long-term impacts of forest treatment on water yield: a summary for northeastern USA. *Journal of Hydrology* 150:323-344.

The Hubbard Brook Ecosystem Study Website. 2003. www.hubbardbrook.org.

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STUDENT INSTRUCTIONS

Background information:

The USDA Forest Service established the Hubbard Brook Experimental Forest (HBEF) in 1955 as a hydrologic research center. In the early years, scientists focused largely on assessing the impacts of forest management on water yield, water quality, and floods. In 1960, additional scientists become involved, and the Hubbard Brook Ecosystem Study (HBES) began. HBES scientists developed the small watershed concept, which at the time was a new approach to ecosystem science in which entire watersheds were studied and manipulated to learn more about nitrogen, phosphorus, carbon, and other elemental cycling.

Around that time, the northeastern states were experiencing a drought and many communities were suffering from water shortages. Knowing that plants (especially trees) take up large volumes of water from the soil and convert it to water vapor, the forest scientists wondered whether cutting down trees might increase water supplies. At the same time, the small watershed scientists were interested in studying how entire watersheds respond to major disturbances.

Combining their interests, scientists designed an experiment in which all the trees in an entire watershed would be cut down. The experiment had many different goals and objectives, reflecting the diverse interests of the scientists involved. In this activity, you will only focus on one of the major land management hypotheses: if trees were cut down and therefore not using as much water, would more water flow into the reservoirs?

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The Experiment:

The Hubbard Brook flows through New Hampshire's White Mountain National Forest and drains a range of small mountains. The tributaries of Hubbard Brook form a set of discrete watersheds, separated by mountain ridges. Because these watersheds share many characteristics in common (for example, similar size and vegetation), they provide an ideal setting for conducting ecosystem experiments.

In the laboratory, scientists use controls to compare with results of experiments. For example, a scientist studying the effect of salt on plants would expose some plants to salt (treatment) and compare their growth to plants growing without salt (control). Similarly, HBEF scientists devised an experimental treatment in which an entire watershed would be manipulated. When scientists manipulate the world outside of the laboratory, they are conducting a field experiment.

In the experimental watershed, researchers cut all the trees in the middle of winter and left them lying on the snow so that the soil was not disturbed. A nearby watershed was left intact, similar to a control. However, unlike laboratory studies, the ecosystem experiment did not have a true control. Although the two watersheds were similar in size and vegetation, they were not exact replicates. (It is virtually impossible to have true replicates or controls in nature because of normal variability in soil, plants, etc.) Thus, the watershed that was left intact is referred to as the "reference" rather than the control watershed.

To measure the changes in water flowing out of the watersheds, scientists installed special gauges on forest streams, called "weirs" (see Figure 1). Weirs are permanent concrete structures consisting of a large basin with a v-notch cut on the side of the downstream end. The stream flows directly into the basin where it slows down and becomes still, and then flows out over the v-notch. By constantly measuring the stream height as it passes over this v-notch, and entering this height into a known formula, researchers can accurately determine streamflow volume even when flow levels are very low.

In this activity, you will be looking at some of the original streamflow data collected from two watersheds at Hubbard Brook to determine the short-term and long-term results of a tree-cutting experiment. Watershed 2 is the treatment watershed, and Watershed 3 is the reference watershed.

All trees in Watershed 2 were cut in December 1965 and left on top of the snow. In the summers of 1966, 1967, and 1968, two herbicides were applied to the entire watershed to prevent the regrowth of any vegetation. The herbicides were applied both to answer the water flow hypothesis discussed above as well as to help collaborating scientists studying element cycling. Scientists believe that the herbicide was added in such low concentrations that it did not negatively affect organisms in the watershed or downstream.

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Using data to make graphs:

1. Examine the spreadsheet on the computer or the hard copy handed out by your teacher. This spreadsheet includes the streamflow and precipitation data collected from Watersheds 2 and 3 at the Hubbard Brook Experimental Forest over a 30-year period. Initially, you will be graphing the streamflow data in Watersheds 2 and 3 for the years before the deforestation treatment (1958-1965). Scientists refer to this as "baseline" data. You will then graph streamflow data in both watersheds for the five years following the treatment (1966-1970) and will assess the streamflow response of Watershed 2. Lastly, you will graph the remaining data (1971-1988) from both watersheds.

2. Notice the headings at the top of the columns.
   a) The first column is labeled "year." Data from 1958-1988 are presented.
   b) Streamflow data from the different watersheds (columns B and C) are presented as annual streamflow in mm per standard area per year. These values have been adjusted to account for the difference in size between the watersheds.
   c) For each watershed, mean annual precipitation values are also provided (columns D and E). As you can imagine, the amount of rain usually varies from year to year, and the amount of rain that falls on the watershed obviously influences how much water comes out in streamflow.

3) You (and your partner, if you are working in pairs) should examine the data. What is the best way to graph them? What will you use as your x-axis? Y-axis? You are interested in determining the watershed baseline and then the response following the deforestation treatment. Your teacher may lead a classroom discussion about the best way to graph these data. As you determine the best type of graph to use, consider the idea that bar graphs might not be the most useful way to represent this type of data.

4) Graph streamflow in Watershed 2 (the treatment watershed) from 1958 - 1965. These are the baseline data.

5) Do the same with Watershed 3. Decide if you want to graph the two watersheds together or on separate pages.

6) Do you see any trends in annual streamflow in the watersheds? How do the watersheds compare to each other (e.g., does one watershed always have higher streamflow values, or is there variability between years and watersheds)? What do these baseline (before cutting) data tell you about the watersheds' streamflow? When doing field experiments, scientists try to have an understanding of how the ecosystem is working before the treatment. In interpreting the results of the field experiment, it is essential to compare the watershed streamflow after the treatment (deforestation) to the streamflow before the experiment, for both watersheds.

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7) Continuing on the same graph(s), you should now include data from the next five years (1966-1970). Do you see any changes in watershed streamflow? By about how much did streamflow change? Are these changes in one or both watersheds? How do the two watersheds compare to each other in the five years following the treatment? If there is a change, what year marks the change? The original hypothesis of this experiment was that if scientists cut down trees and applied herbicide to a watershed, more water would flow out of it. Did this happen? Can you make any conclusions?

8) Now put the remaining data on the same graphs (1971-1988). What do you see now? What has happened to the streamflow in both watersheds, and how do they compare to each other? Do you see any differences between the short-term data (1966-1970) and the long-term data (1966-1988)? Does this information change your interpretation of the results? Do the reference and treatment graphs follow the same pattern? How do you explain what is happening?

9) Graph average annual precipitation in Watershed 2 and Watershed 3. Your teacher may ask you to transfer the graph to a transparency and superimpose it on the graph from step 5, and if you made separate graphs, step 6. Does the precipitation information change your interpretation of the results?

10) Using a graph, what is another way you might compare these two watersheds' annual streamflow? Consider graphing the difference between the two watersheds (i.e., Watershed 2 annual streamflow - Watershed 3 annual streamflow). What can you learn from this graph?

11) You have probably noticed that there are differences between the short-term and long-term W2 streamflow data. Why might this have happened? Your teacher may lead the class in a discussion of possible reasons.

12) Given all of the streamflow data you have seen, what can you say about the original hypothesis? Does cutting all the trees in a watershed increase streamflow? Think about short- and long-term responses.

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NOTES TO FACULTY

How to use this data set in a class:

This activity compares short- and long-term data collected after a whole-watershed experiment conducted in HBEF Watershed 2 in 1965. Because data collected in the years immediately following the experiment suggest a different response than data collected twenty years later, this activity would be a useful addition to a discussion of the importance of long-term experiments and data collection in ecological research.

In the activity, students will compare a treatment watershed (deforestation followed by herbicide application in Watershed 2) with a reference watershed (uncut reference forest in Watershed 3). Students will manipulate the data to determine whether the treatment produced the expected outcome: less water taken up by vegetation and more water leaving the watershed as streamflow. (Another way to present this would be that students are testing the hypothesis that deforestation increases streamflow.)

Though this activity primarily focuses on streamflow data, you may also find it useful to have students examine the supplemental data set containing annual rainfall amounts. These data suggest that precipitation amounts were not the cause of the changes in Watershed 2 streamflow. This additional data set may help reinforce the concept that it is necessary for scientists to measure a wide range of variables when conducting ecosystem experiments. To further extend the activity, you could ask students to consider how additional ecosystem variables (e.g., soil type, vegetation, season) might affect streamflow. Many related data are available on the HBES website (www.hubbardbrook.org).

Producing graphs

The activity procedure indicates that students will receive either printed spreadsheets or computer files containing streamflow data from Watersheds 2 and 3. We have provided the data in two MS Excel files: one for faculty, and one for students. The faculty file contains annual streamflow and precipitation data as well as a variety of graphs for faculty reference. The student version does not contain graphs. If you decide to use Excel, students will need only a basic familiarity with its graphing capabilities. Several online tutorials are listed in the "resources" section of this activity.

Students may work in small groups or as individuals, and will use either graph paper or spreadsheet software to generate a figure or figures that show streamflow changes over time in the treatment and reference watersheds. Begin the activity by having the entire class review the data set and discuss the best approach for data analysis.

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Before you continue, decide how you want your students to discuss their final results. For example, you may ask your students to work together in small groups (2-3 students) with Excel to create graphs and discuss their implications. In smaller classes, each group can then present their ideas, results, and questions to the entire class at the end of the activity; in larger classes you may only be able to have a few groups present. Finally, you may wish to wrap up the activity with an entire class discussion of the questions presented below.

In whatever arrangement you decide on, students should create two separate graphs of annual streamflow in Watershed 2 (W2) and annual streamflow in Watershed 3 (W3), or one graph containing both. One interesting way to compare the treatment and reference watersheds is to transfer the graph for W3 (reference) to a transparency, so that it can be superimposed on the graph for W2 (treatment). It is also instructive to graph the annual average precipitation for each watershed on transparencies and superimpose them on the two streamflow graphs.

Students will first graph results from the five years immediately following the deforestation, and will then examine the remaining 18 years. Through comparing the short-term and long-term data, students should gain an understanding of how short-term trends can be misleading in ecology. One option for the activity's classroom organization would be to have your students graph the baseline data individually or in small groups, and then gather as an entire class to discuss what the data indicate. Repeat this for the second data section (the five years after deforestation) and again for the third section (the final 18 years). You may find it useful to allow students to compare their final graphs to those in the Faculty Data Set.

In addition to graphing changes in the two watersheds over time, students can use the annual streamflow values to calculate the difference in streamflow (W2 - W3) between the watersheds. They will observe a pre-treatment difference between W2 and W3. Then they will observe that in the years immediately after the treatment, the difference between W2 and W3 increases dramatically. Streamflow in W2 increased an average 32 % in the three years after deforestation (herbicides were applied all three years).

With time, however, the difference between the two watersheds returns to baseline values. And then, something very interesting happens. Streamflow in W2 becomes even smaller than it was before the treatment. Thirteen to 23 years after treatment, the average streamflow in W2 is 7% less than it had been before the treatment.

What's going on? For three years after the trees were cut, herbicides were applied to prevent any vegetation from regrowing. But once the herbicide treatments stopped and the vegetation was allowed to grow back, water yields declined rapidly. The original forest had been composed of mature hardwood species such as sugar maple, American beech, and yellow birch. But when the scientists stopped applying herbicides, the regenerating forest had a different composition. Most of the trees were

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pin cherry and paper birch. Studies at Hubbard Brook have demonstrated that these two species transpire more, and thus take up more water from the soil, than the original mature forest species. Data on total vegetative biomass in W2 can be found on the Hubbard Brook website (http://www.hubbardbrook.org).

The story is not over, however, because pin cherry trees do not live very long - usually only about 30 years. Data are provided through 1988, 23 years after treatment. As pin cherry trees die off at Hubbard Brook, they should be replaced by the original hardwood species - maple, beech, and yellow birch. So the trend in water yield could change again. Data from 1989-2000+ are available on the Hubbard Brook website, so your students could explore water yields not covered in this activity. These data are variable, but suggest that Watershed 2 streamflow is beginning to return to pre-experiment levels.

Questions for discussion:

1. What misinterpretations might scientists have made if they did not collect data before the deforestation treatment? In other words, why are baseline data critical to long-term studies?

2. Explain why it is important to monitor the reference watershed (Watershed 3) as well as the treatment watershed (Watershed 2) after the treatment.

3. The original hypothesis of this experiment was that if scientists cut down trees and applied herbicide to a watershed, more water would flow out of it. Did this happen? Can you make any conclusions? What would be some potential implications of this type of watershed management?

4. What does this experiment say about the need for long-term research? If the research had stopped five years after the deforestation treatment, do you think your (and other people's) perceptions of deforestation effects on streamflow would be different than they are now? If communities are trying to increase reservoir levels, is cutting down trees in a nearby forests a good way to do it?

5. Given all of the streamflow data you have seen, what can you say about the original hypothesis? Does cutting all the trees in a watershed increase streamflow? Think about short- and long-term responses.

6. Discuss possible limitations of this experiment.

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Assessment

To assess your students' learning you need to first determine what you most want them to learn (e.g., how to use Excel differences between short- and long-term ecological research; watershed responses to deforestation). A rich discussion on assessment and evaluation appears elsewhere in TIEE in a paper on Assessment and Evaluation. Assessable tasks include written answers to one or more of the questions above; creation of figures with Excel; written analysis of hypothesis results; poster presentation of results; written discussion of short- and long-term ecological research as demonstrated in this activity.

Resources to Help Students Analyze these Data Sets

ESA, HBEF and LTER Websites:

- ESA Ecological Data Archives (www.esapubs.org/archive/)
- The Hubbard Brook Ecosystem Study (www.hubbardbrook.org)
- The Long Term Ecological Research Network (www.lternet.edu)

Sites with Excel tutorials:

- www.usd.edu/trio/tut/excel/ - basic information - how to use functions, filling down, formatting, inserting, graphs and graphing
- homepage.cs.uri.edu/tutorials/csc101/pc/excel97/excel.html - basic - from "what is excel?" to "creating charts"; copyright of University of RI Computer Science Dept.
- www.fgcu.edu/support/office2000/excel/ - Florida Gulf Coast University; basic - includes visuals.
- www.baycongroup.com/el0.htm - a lot of introductory information; BayCon Group - commercial site.

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